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Pacific Northwest
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Hanford Site Groundwater Monitoring for Fiscal Year 2002

Editors
M. J. Hartman
L. F. Morasch
W. D. Webber

March 2002

Prepared for the U.S. Department of Energy
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Abstract

This report presents the results of groundwater and vadose zone monitoring and remediation for fiscal year 2002 on the U.S. Department of Energy's Hanford Site, Washington.

Water-level monitoring was performed to evaluate groundwater flow directions, to track changes in water levels, and to relate such changes to evolving disposal practices. Water levels over most of the Hanford Site continued to decline between March 2001 and March 2002.

The most extensive contaminant plumes are tritium, iodine-129, and nitrate, which all had multiple sources and are very mobile in groundwater. The largest portions of these plumes are migrating from the central Hanford Site to the southeast, toward the Columbia River. Concentrations of tritium, nitrate, and some other contaminants continued to exceed drinking water standards in groundwater discharging to the river in fiscal year 2002. However, contaminant concentrations in river water remained low and were far below standards.

Carbon tetrachloride and associated organic constituents form a relatively large plume beneath the central part of the Hanford Site. Hexavalent chromium is present in smaller plumes beneath the reactor areas along the river and beneath the central part of the site. Strontium-90 exceeds standards beneath each of the reactor areas, and technetium-99 and uranium are present in the 200 Areas. Minor contaminant plumes with concentrations greater than standards include carbon-14, cesium-137, cis-1,2-dichloroethene, cyanide, fluoride, plutonium, and trichloroethene.

Resource Conservation and Recovery Act of 1976 groundwater monitoring continued at 24 waste management areas during fiscal year 2000:

- 15 under interim or final status detection programs and data indicate that they are not adversely affecting groundwater
- 7 under interim status groundwater quality assessment programs to assess contamination
- 2 under final status corrective-action programs

Interim groundwater remediation in the 100 Areas continued with the goal of reducing the amount of chromium (100-K, 100-D, and 100-H) and strontium-90 (100-N) reaching the Columbia River. The objective of two interim remediation systems in the 200 West Area is to prevent the spread of carbon tetrachloride and technetium-99/uranium plumes. Groundwater monitoring continued at these sites and at other sites where there is no active remediation.

Vadose zone monitoring, characterization, and remediation continued in fiscal year 2002. Sediment samples from past-practice waste sites indicated that most contaminants are concentrated at shallow depths. Sediment samples also were collected from beneath single-shell tanks to study the distribution of contaminants. Selected wells in single-shell tank farms and other waste sites in the 200 Areas were logged to identify gamma-emitting radionuclides and track their movement. Soil-gas monitoring at the 618-10 burial ground did not indicate the presence of tritium contamination from the burial ground. Remediation and associated monitoring continued at a soil-vapor extraction system in the 200 West Area, which removes gaseous carbon tetrachloride from the vadose zone.

In fiscal year 2002, two new wells were installed for RCRA monitoring to replace dry wells or to improve monitoring coverage. Twenty-three new wells were installed

for activities related to environmental restoration and three wells to monitor a proposed low-activity waste disposal site in the 200 East Area.

A set of computer models known as the System Assessment Capability simulates movement of contaminants from waste sites through the vadose zone and groundwater. In fiscal year 2002, modelers completed an initial assessment of 10 contaminants, simulating their movement over the years 1944 through 3050.

This report is available on the Internet through the Hanford Groundwater Monitoring Project's web site: http://groundwater.pnl.gov/. Inquiries regarding this report may be directed to Ms. Mary J. Hartman, Pacific Northwest National Laboratory, P.O. Box 999, Richland, Washington 99352 or by electronic mail to mary.hartman@pnl.gov.

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This report represents the efforts of dozens of individuals who contribute to the Hanford Groundwater Monitoring Project: planners, schedulers, samplers, laboratory technicians, data management staff, site scientists, editors, text processors, and staff in graphics and duplicating.

John Fruchter and Stuart Luttrell managed the Hanford Groundwater Monitoring Project and the Groundwater Monitoring Task, respectively. Dot Stewart managed the monumental tasks of sampling and analysis, quality control, and data management.

Most of the graphics for this report were generated by Mickie Chamness and Chris Newbill, who all put in many hours to meet our tight schedule. Jennifer Carr, David Lanigan, John McDonald, Joanne Rieger, and Elaine Schneider also assisted with graphics.

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Mary Hartman
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Report Contributors

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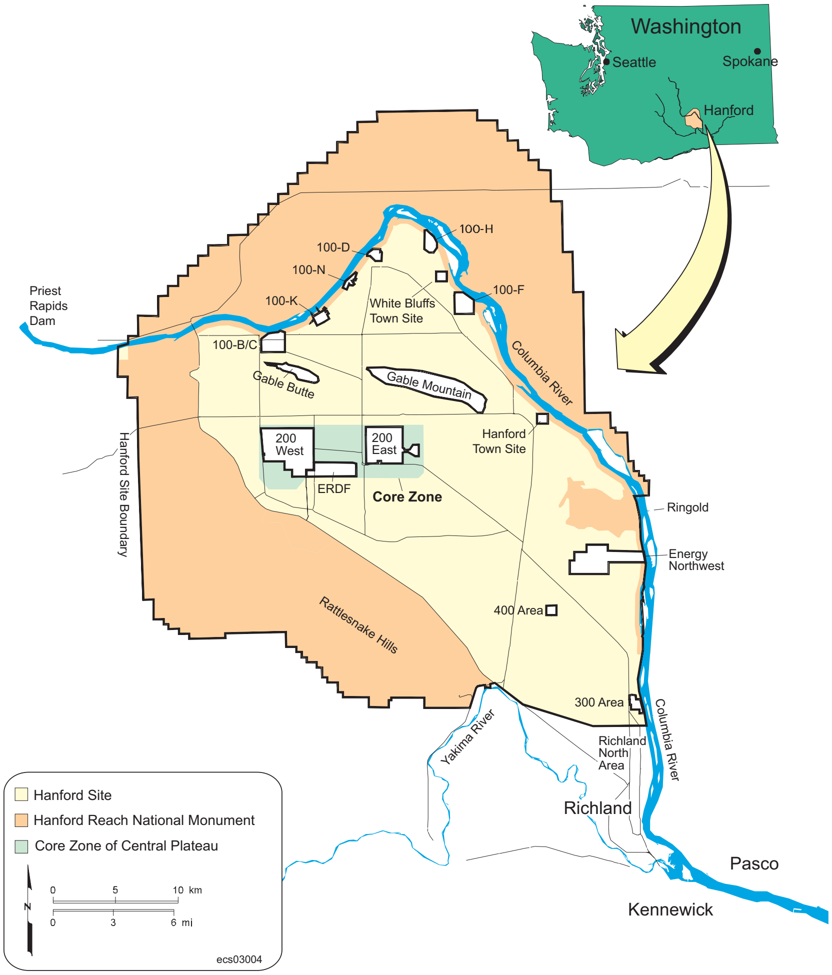
Summary

The Hanford Site, a facility in the U.S. Department of Energy (DOE) nuclear weapons complex, encompasses ~1,517 square kilometers northwest of the city of Richland along the Columbia River in southeast Washington State. The site was acquired by the federal government in 1943, and until the 1980s was dedicated primarily to the production of plutonium for national defense and the management of resulting waste.

In 1995, all unrestricted discharge of radioactive liquid waste to the ground was discontinued. Today, DOE's mission on the Hanford Site is to restore the Columbia River corridor, transition the central portion of the site toward its long-term waste management role, and prepare for the future.

DOE has monitored groundwater on the Hanford Site since the 1940s to help determine what chemical and radiological contaminants have made their way into the vadose zone and groundwater. As regulatory requirements for monitoring increased in the 1980s, there began to be some overlap between various programs. DOE established the Hanford Groundwater Monitoring Project (groundwater project) in 1996 to ensure protection of the public and the environment while improving the efficiency of monitoring activities. The groundwater project is



The Hanford Site occupies approximately 1,517 square kilometers of arid land in southeastern Washington.

Groundwater *is the water that fills the pores or cracks between grains in a layer of sediment or rock. An* ***aquifer*** *is a geologic layer that allows water to pass through easily, with all its pores saturated with water. The top of the saturated zone is called the* ***water table****. The* ***vadose zone*** *is the soil or rock between the ground surface and the water table. It usually contains some water, but also contains air.*

Groundwater monitoring *helps determine what contamination exists beneath the Hanford Site. This information will help regulators and DOE make cleanup decisions based on scientific information and technical capabilities.*

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designed to support all groundwater monitoring needs at the site, eliminate regulatory program redundancy, and establish a cost-effective hierarchy for groundwater monitoring activities. Specific objectives include

- maintain and verify compliance with all applicable groundwater regulations
- characterize and define physical and chemical trends in groundwater
- establish baselines of groundwater quality
- provide continuing, independent assessment of groundwater remediation activities
- identify and quantify new or existing groundwater problems

This report *is written to meet the requirements in the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), Resource Conservation and Recovery Act (RCRA), Atomic Energy Act of 1954, and Washington Administrative Code.*

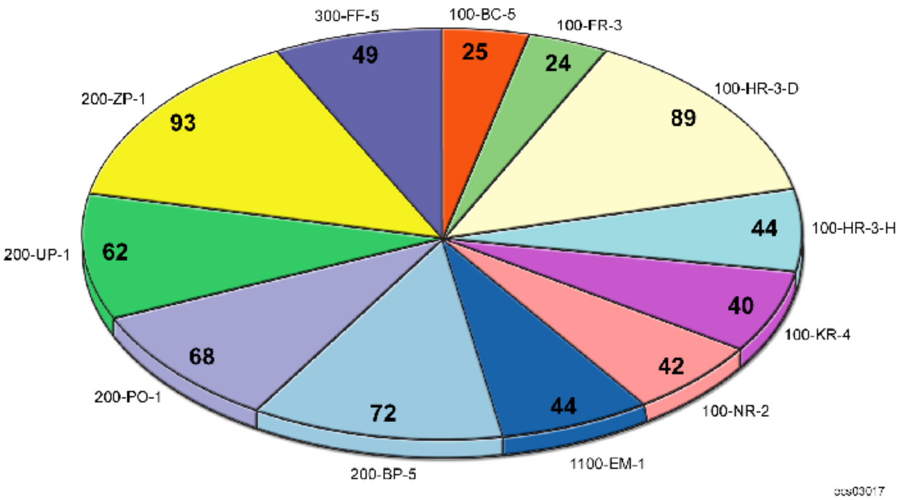
Contamination may reach the Columbia River by moving down through the vadose zone, into the groundwater, and then into the river. The analysis of groundwater samples helps determine the potential effects that contaminants in Hanford soil and groundwater could have on human health and the environment. DOE works with the regulators, such as the U.S. Environmental Protection Agency (EPA) and the Washington State Department of Ecology, to make cleanup decisions based on sound technical information and the technical capabilities available.

Groundwater Highlights for Fiscal Year 2002

DOE's major accomplishments related to groundwater monitoring in fiscal year 2002 included the following:

- Workers sampled ~650 monitoring wells to determine the distribution and movement of contaminants. Many of these wells were sampled multiple times during the year. Data from these samples were used to identify and characterize existing, potential, and emerging groundwater contamination problems.
- During the past year, 1,756 samples of Hanford groundwater were analyzed for chromium, 1,086 for nitrate, and 913 for tritium. Other frequently-analyzed constituents include carbon tetrachloride, technetium-99, and uranium, which were analyzed in ~600 samples.
- Interim remedial measures continued to limit the spread of groundwater contamination in the 100 and 200 Areas. Since their inception, remedial measures

The Hanford Groundwater Monitoring Project sampled ~650 wells during fiscal year 2002. Iodine-129, nitrate, and tritium are the most widespread contaminants.

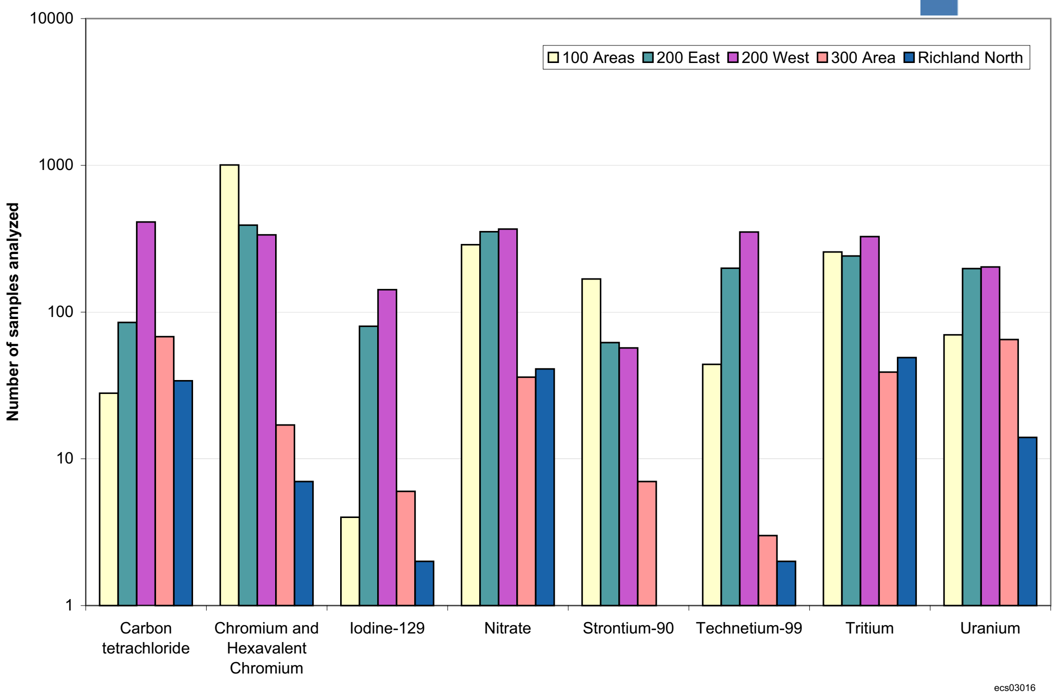


Hanford Site groundwater monitoring is organized by areas of interest, which are informally named after the groundwater operable units. This chart shows the number of wells sampled in each region in fiscal year 2002.

have treated over 6 billion liters of groundwater to remove carbon tetrachloride, chromium, nitrate, technetium-99, and uranium.

- Average trichloroethene concentrations in compliance wells in the 1100-EM-1 Operable Unit (Richland North Area) remained below the maximum contaminant level for the second year in a row. This contaminant has been attenuating naturally, more rapidly than expected.
- The groundwater project continued to monitor 24 *Resource Conservation and Recovery Act* (RCRA) sites, 5 other regulated units, and 11 *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA) groundwater operable units.
- RCRA monitoring provided no evidence of new contamination from sites in detection programs. Seven sites continued to be monitored under assessment programs, and two under final-status corrective action.
- The groundwater project evaluated the adequacy of RCRA monitoring networks. At single-shell tank Waste Management Areas A-AX and C, the direction of groundwater flow has been re-interpreted and the monitoring networks are being modified. Because the water table is dropping in the 200 Areas, many monitoring wells have gone dry in recent years. Networks contain fewer than the minimum required number of wells at 216-S-10 pond, 216-U-12 crib, the Liquid Effluent Retention Facility, and Low-Level Waste Management Areas 3 and 4.
- Monitoring provided no evidence of new leaks from fuel storage basins in the 100-K Area.
- Monitoring results at the following regulated units remained within permit limits: 400 Area Process Ponds, State-Approved Land Disposal Site, and Treated Effluent Disposal Facility. Concentrations of some constituents of concern at the Environmental Restoration Disposal Facility were elevated but reflect

Groundwater sampling wells *form a monitoring network across the Hanford Site and along the Columbia River. This network provides a picture of the status of groundwater beneath Hanford that will help protect human health and the environment.*



The groundwater project requests specific laboratory analyses based on the well's location, historical contaminant trends, and regulatory requirements. This graph shows the number of analyses for each geographic region during fiscal year 2002.

migration of contaminant plumes from sources in the 200 West Area. At the Solid Waste Landfill, specific conductance, pH, chloride, sulfate, and coliform bacteria exceeded their background threshold levels in one or more samples.

- Monitoring indicated that the tritium plume that originated in the 200 East Area did not move closer to the city of Richland or its water supply wells.
- During calendar year 2002, drillers completed 2 new RCRA monitoring wells, 3 wells to monitor a proposed low-activity waste site in the 200 East Area, 21 wells for groundwater remediation and monitoring in the 100-D Area, and 2 wells for groundwater remediation and monitoring in the 200 West Area.
- In fiscal year 2002, development of the site-wide groundwater model focused on improvements to the base-case model and development of additional alternative conceptual models.
- The System Assessment Capability is a set of computer modules simulating movement of contaminants from waste sites through the vadose zone and groundwater. In fiscal year 2002, scientists completed an initial assessment of 10 contaminants released from 890 waste sites, simulating movement of the contaminants from 1944 through 3050.

Vadose Zone Highlights for Fiscal Year 2002

The vadose zone is the area between the ground surface and the water table. Many activities focused on the vadose zone to further understand the physical and chemical properties of this area in an attempt to limit the migration of contamination. The work is designed to result in new, innovative methods for cleanup and monitoring at the Hanford Site. DOE's accomplishments in vadose zone work included the following:

- Scientist used sediment samples from boreholes at the B-BX-BY Tank Farms to study the distribution and mobility of radionuclides. Under current conditions, strontium-90 and uranium appear to be relatively immobile, but uranium could become mobile under certain chemical and physical conditions.
- Researchers studied soil gas at the 618-10 burial ground in the southeast part of the Hanford Site to determine whether there is a previously undiscovered tritium plume in the vadose zone or in groundwater. Results did not indicate a new plume.
- Geophysicists investigated the possibility of using gamma logging to identify zones of strontium-90 contamination in sediment around boreholes. Results showed a strong correlation between strontium-90 and gamma activity, and may lead to a method for quantitative measurement of strontium-90 in the subsurface.
- DOE expanded their efforts to protect tank farms from the effects of infiltrating water. Workers built berms and installed a culvert to divert ponded precipitation from tank farms in the 200 East Area before it can infiltrate. Workers tested water lines and cut and capped those that are not needed. Similar efforts were conducted for the 200 West Area tank farms in fiscal year 2001.
- Workers drilled and sampled three boreholes in locations of known or suspected contamination in the TX Tank Farm. One of the boreholes was outfitted with vadose zone monitoring equipment as it was backfilled.

A study of the correlation between strontium-90 concentrations and gamma log response was undertaken to help scientists determine a way to measure strontium-90 concentrations in the vadose zone. The results may lead to a method for quantitative measurement of strontium-90 in the subsurface.

Emerging Issues

As monitoring, remediation, and related work progress, new issues of potential concern arise. Some of the issues that DOE will address in coming years include the following:

- **Integration of Monitoring** – Long-term groundwater monitoring under CERCLA, RCRA Past-Practice, or the *Atomic Energy Act of 1954* share many of the same objectives, i.e., to track contaminant plumes and trends in groundwater. While sampling and analysis already are coordinated, further integration will create even greater efficiency. DOE and the regulators began planning for this type of integration in the 100-BC-5, 100-FR-3, 200-BP-5, 200-PO-1, 200-UP-1, and 200-ZP-1 Operable Units in fiscal year 2002. DOE will continue to work with regulators to integrate monitoring at other groundwater operable units and to develop a plan for long-term stewardship.
- **Alternatives to Pump-and-Treat Systems** – The objective of interim-action pump-and-treat systems is to limit the spread of existing contamination. In some cases, it is not an effective way to clean up the aquifer. For example, in the 100-N Area, the pump-and-treat system is removing far less strontium-90 than is removed naturally by radioactive decay. DOE is investigating alternative approaches to cleanup, including natural attenuation at some sites.
- **Adequacy of Monitoring Networks** – As wells in the 200 Areas go dry, some groundwater monitoring networks are no longer adequate to detect new contaminants or assess existing contamination. Installation of new wells at these sites compete for funding with other well needs, e.g., remedial action wells. In 2002, DOE's Cleanup, Constraints, and Challenges Team (C3T) was formed to assess and define well needs to meet all groundwater objectives in the 200 Areas. These wells will be scheduled for installation over the next 4 years according to their relative priority.

The top of an ***unconfined aquifer*** *is the water table. At Hanford, the unconfined aquifer is in a sequence of sandy, gravelly sediment, and depth to the water table ranges from less than 1 meter near the river to more than 100 meters in the center of the site.* ***Confined aquifers*** *are capped by less permeable layers that cannot transmit much water. Confined aquifers at Hanford occur beneath clay or basalt layers.*

Wells in the 200 Areas that were formerly sampled for the Groundwater Project have gone dry as the water table declined. Most of the wells are in the 200 West Area.

Fiscal Year	200 West	200 East	Other Areas	Total
1998	2	1	2	5
1999	9	0	1	10
2000	12	2	2	16
2001	7	0	1	8
2002	10	2	1	13
Total	40	5	7	52

- **Transition of RCRA Interim Status Units to Final Status** – As RCRA units are incorporated into revisions of the Hanford Facility RCRA Permit, they are subject to the requirements of final-status monitoring (WAC 173-303-645). In many cases, this transition requires application of alternative statistical evaluations and, at locations where the water table is declining beneath the bottom of the aquifer, an entirely new approach to monitoring. Such alternatives must be evaluated carefully by scientists, statisticians, and regulators.

- **Carbon Tetrachloride Distribution** – EPA's five-year review of remedial actions, published in fiscal year 2001, cited the need to define the distribution of carbon tetrachloride with depth in the aquifer. Data from wells completed deep in the unconfined aquifer indicate that in some locations, concentrations are higher at depth than they are at the water table. However, relatively few deep wells are available, hindering interpretation.
- **BC Cribs and Trenches** – These facilities are located south of the 200 East Area and were used from 1956 to 1958. Recent computer models indicate that the majority of tank waste sent to liquid discharge sites was disposed at the BC cribs and trenches. The constituents of interest include cobalt-60, cyanide, technetium-99, ferrocyanide, and chromium. Groundwater monitoring of this facility is being increased.
- **Chromium in 100-D Area** – The concentration of hexavalent chromium within a few wells in the redox treatment zone increased unexpectedly. DOE re-injected treatment solution into some of the wells in fiscal year 2002 and will evaluate the need for further action in other wells.

__Water-table elevations__ are measured across the Hanford Site with an electronic water-level tape once each year. In addition, water levels are measured each time a well is sampled during the year.

Groundwater Flow and Movement

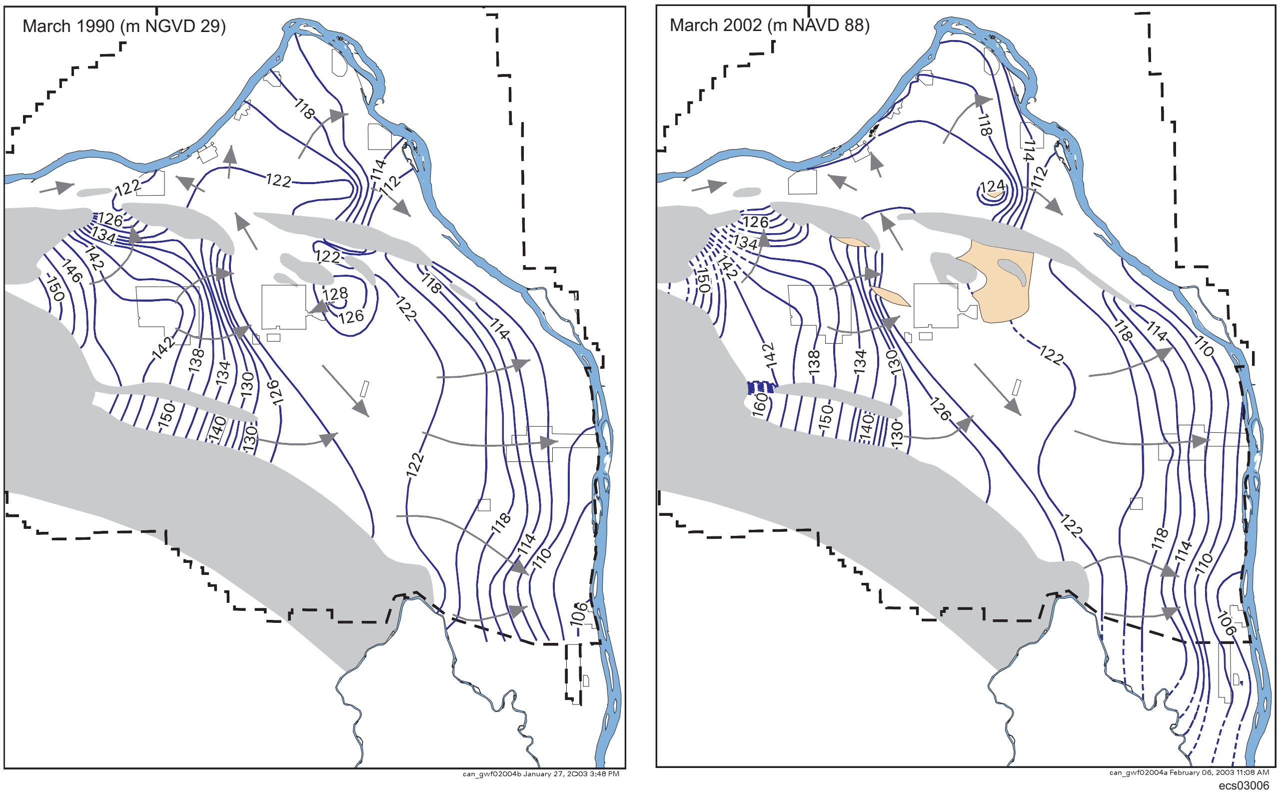
Groundwater in the unconfined aquifer generally flows from west to east across the Hanford Site to discharge areas along the Columbia River. The direction of groundwater flow is inferred from water-table elevations, barriers to flow (e.g., basalt or mud units at the water table), and the distribution of contaminants.

General directions of groundwater flow are illustrated on the following map for March 2002. Beneath the reactor areas, groundwater flows generally toward the Columbia River. Groundwater seeps appear along the riverbank when river levels are low. Farther inland, north of Gable Mountain, flow is toward the northeast and east. Groundwater flows eastward beneath the 200 Areas and then flows to the southeast or northward through the gap between Gable Butte and Gable Mountain. Groundwater converges on the 300 Area from the northwest, west, and southwest and discharges into the Columbia River to the east. Groundwater in the Richland North Area flows generally eastward to the Columbia River.

The natural pattern of groundwater flow was altered during the Hanford Site's operating years by the formation of mounds in the water table. The mounds were created by the discharge of large volumes of wastewater to the ground and were present in each reactor area and beneath the 200 Areas. Since effluent disposal has decreased significantly, these mounds are disappearing. The 1990 water-table map shows groundwater mounds beneath the 200 West and 200 East Areas, which created the potential for radial flow near the mounds and induced northward flow toward the gap between Gable Mountain and Gable Butte. The 200 East Area mound is gone and the 200 West Area mound is much less prominent in the fiscal year 2002 map. Water levels east of the 200 East Area have dropped below the top of a fine-grained confining unit, thus creating a barrier to movement in the surrounding unconfined aquifer. Beneath this confining unit, the uppermost aquifer is a permeable unit in the Ringold Formation. Groundwater flow in this confined aquifer still is influenced by the recharge mound that formerly created an unconfined aquifer above the fine-grained confining unit in the area.

A __groundwater monitoring network__ strategically located across the Hanford Site helps determine changes in the direction of groundwater flow as the site returns to pre-Hanford conditions.

Groundwater in the upper basalt-confined aquifer generally flows from west to east across the Hanford Site, up through the unconfined aquifer, and into the Columbia River. Vertical gradients between the basalt-confined aquifer and the unconfined aquifer are upward on most of the Hanford Site. Therefore, there is little potential for contaminants to migrate from the unconfined aquifer into the



These maps show the water table and inferred flow directions in June 1990 (National Geodetic Vertical Datum of 1929) and March 2002 (North American Vertical Datum of 1988). NGVD29 is approximately 1 meter lower than NAVD88. The water table declined beneath most of the Hanford Site during that period. Shaded areas in both maps show where the unconfined aquifer is absent.

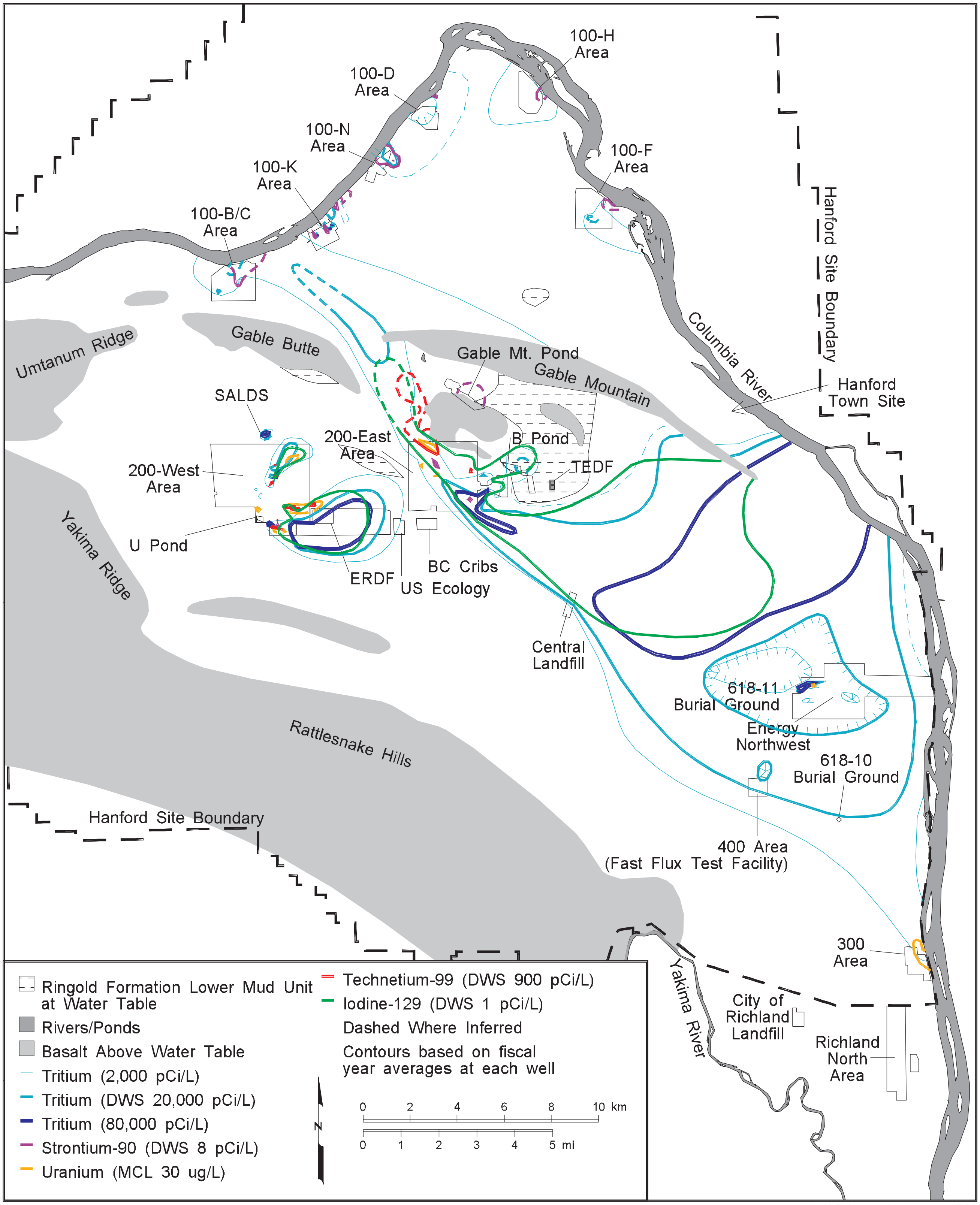
basalt-confined aquifer, where it could move offsite. Downward gradients are measured beneath the west portion of the Hanford Site and north and east of the Columbia River.

Overview of Contaminants

The goal of DOE's Groundwater Protection Program is to clean up groundwater contaminants, avoid future groundwater contamination, and prevent contaminants from reaching the Columbia River. Some contaminants, including chromium, strontium-90, tritium, and uranium, flow from specific parts of the shoreline called springs or seeps. Springs or seeps are small areas where the groundwater meets the river. Just beyond the seeps in the river, contamination is diluted far below levels of concern for human or ecological health. The Washington State Department of Ecology and the U.S. Geological Survey both gave the Columbia River the highest rating for water quality — Class A, meaning "Excellent" — from the Grand Coulee Dam to the Washington-Oregon border. A Class A rating means that the Columbia River is suitable for all types of water supplies, fish and shellfish habitat, wildlife habitat, human recreational activities, and commerce and navigation. In fact, the Hanford Reach is heavily used for recreational purposes. The Columbia River also is the city of Richland's main source of drinking water; it consistently meets all state and federal drinking water standards.

DOE monitors groundwater quality all across the Hanford Site, even far from the river, to know what contaminants are present and how they are moving. The maps on the following pages show the distribution of nine principal groundwater

Water-table maps *are used to help determine the direction of groundwater flow. Groundwater seeps between the sediment grains in the aquifer from areas where the water-table elevation is high to where it is low.*



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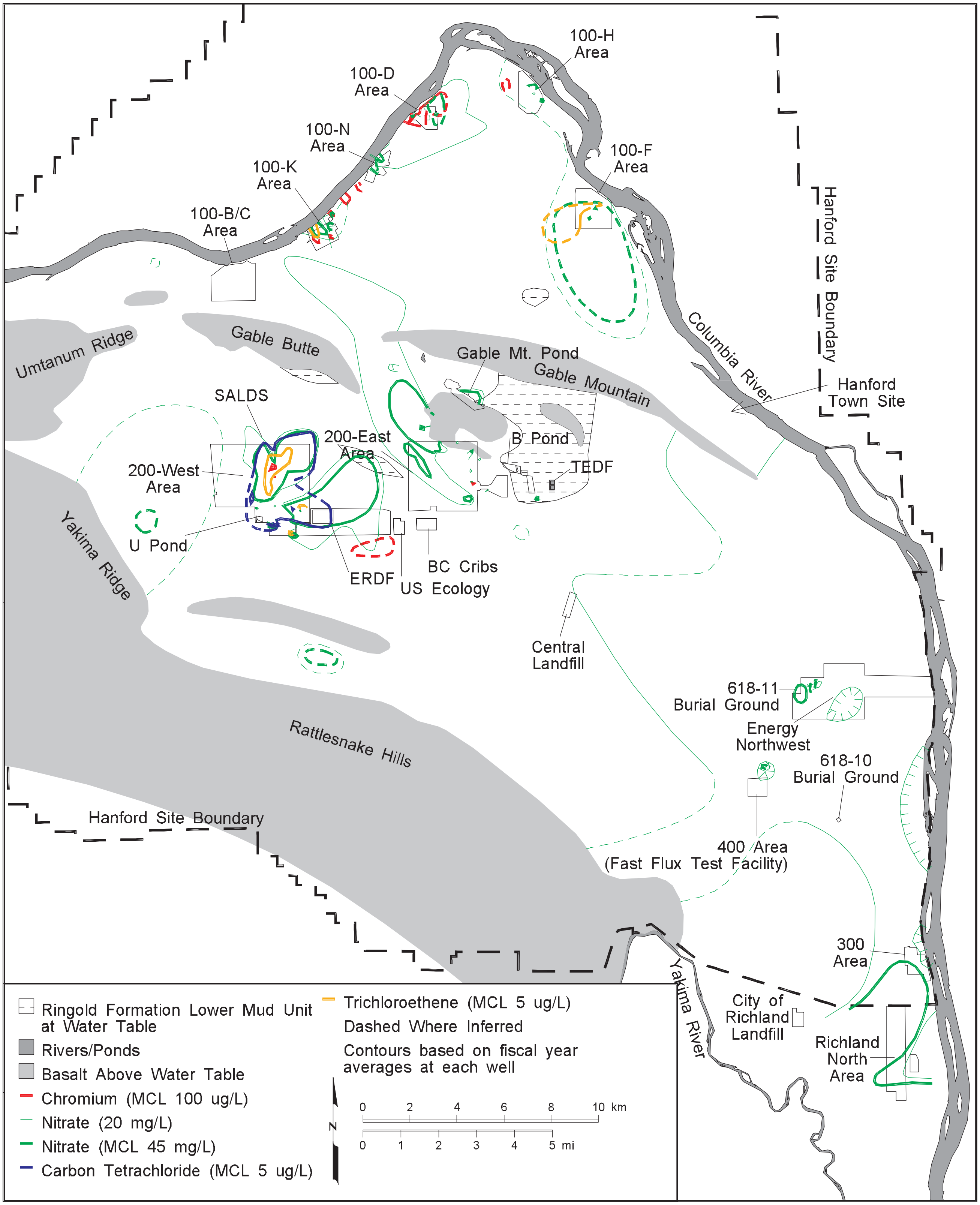
This map shows the distribution of major radionuclides in groundwater at concentrations above maximum contaminant levels or drinking water standards during fiscal year 2002.



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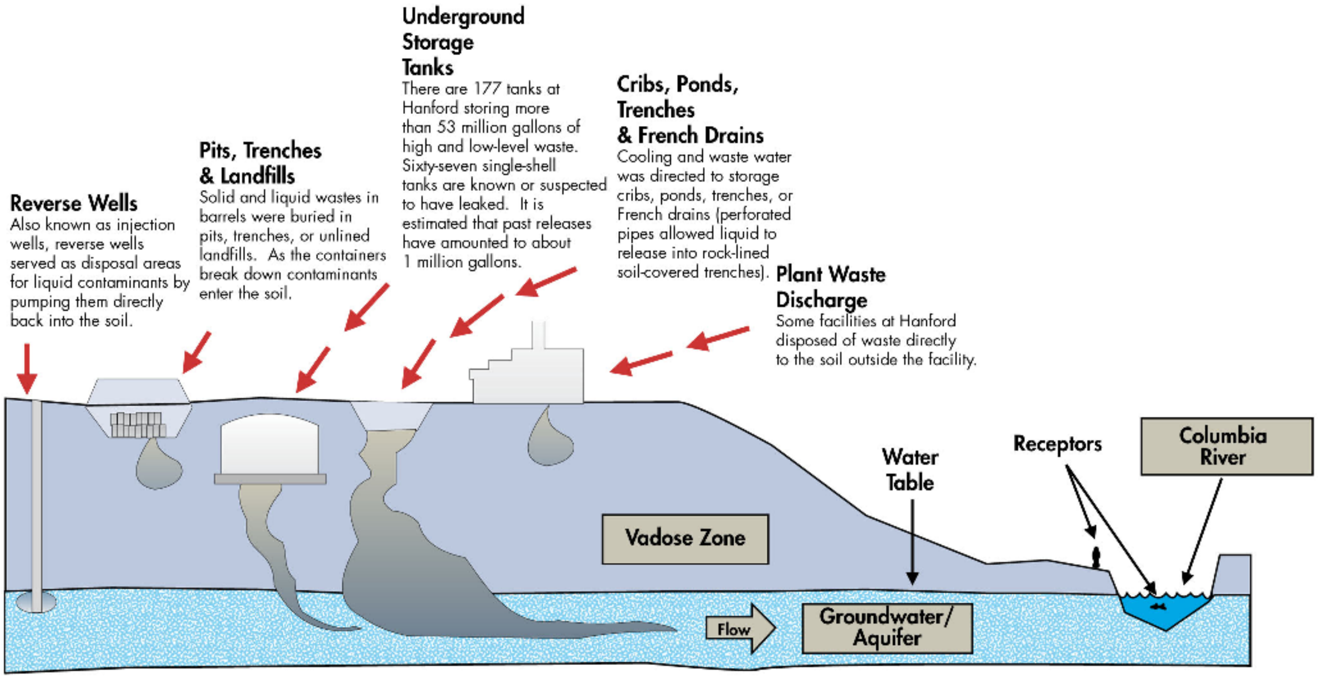
This map shows the distribution of major hazardous chemicals in groundwater at concentrations above maximum contaminant levels during fiscal year 2002.



This figure shows the sources of Hanford groundwater contamination. Groundwater is monitored to determine the nature and extent of contamination from Hanford operations.

contaminant plumes. The following paragraphs provide some basic information about contaminants on the Hanford Site, listed in order of largest to smallest plume areas. More specific information is provided in the sections on the geographic regions of the plume sources.

Tritium – Tritium was common in Hanford Site liquid waste discharged to the soil and is the most mobile and most widely distributed radionuclide onsite. It has a relatively short half-life (12.3 years). The drinking water standard, 20,000 pCi/L, is exceeded in parts of the 100, 200, and 600 Areas. The most prominent tritium plume originated from disposal cribs in the 200 East Area near the Plutonium-Uranium Extraction (PUREX) Plant and has migrated downgradient to the southeast where it meets the Columbia River.

*The **chemical and physical characteristics** of groundwater vary across areas and time. The interpretation of sampling results must, therefore, be carried out with great care.*

Iodine-129 – Iodine-129 was present in waste related to fuel processing. The presence of iodine-129 in groundwater is significant because of its relatively low (1 pCi/L) drinking water standard, its long-term releases from nuclear fuel processing facilities, and its long half-life (16 million years). Iodine-129 is very mobile in groundwater. Waste containing iodine-129 was historically disposed of in the 200 Areas, and groundwater plumes are similar in shape and extent to the tritium plumes, though concentrations above the drinking water standard have not reached the Columbia River.

Nitrate – Nitrate contamination in the unconfined aquifer reflects the extensive use of nitric acid in decontamination and chemical processing operations. Like tritium, nitrate was present in many waste streams and is mobile in groundwater. Agricultural sources of nitrate are located off the Hanford Site to the south and west. Nitrate was measured at concentrations greater than the maximum contaminant level (45 mg/L) in wells in all operational areas except 100-B/C Area.

Carbon Tetrachloride – Carbon tetrachloride was used in plutonium processing in the 200 West Area, where concentrations in groundwater exceed the 5-µg/L maximum contaminant level. The plume extends beyond the area boundary and forms the most widespread organic contaminant plume on the Hanford Site.

Area of Contaminant Plumes at Levels Above Drinking Water Standards (square kilometers)

Constituent (drinking water standard)	Fiscal Year 2000	Fiscal Year 2001	Fiscal Year 2002
Carbon tetrachloride (5 µg/L)	9.8	9.8	9.9
Chromium (100 µg/L)	2.8	2.8	2.6
Iodine-129 (1 pCi/L)	89.6	79.5(a)	79.4
Nitrate (45 mg/L)	36.3	38.4	35.7
Strontium-90 (8 pCi/L)	2.8	2.7	2.7
Technetium-99 (900 pCi/L)	2.3	2.4	2.3
Trichloroethene (5 µg/L)	4.2	4.3	3.4(a)
Tritium (20,000 pCi/L)	152	151	142
Uranium (20/30 µg/L)	2.0	1.6	1.5
Combined Plumes	210	208	196

(a) These large changes in estimates of plume area are caused by changing interpretations of the data and changes to the monitoring network. Changes in actual plume size are usually more gradual.

Trichloroethene – Trichloroethene was used on the Hanford Site in the 1960s and 1970s as a degreasing compound. The drinking water standard is 5 µg/L. The most extensive plume is in the 200 West Area. Trichloroethene also exceeded the standard in the 100-K and 100-F Areas. Concentrations in the 300 and Richland North Areas remained below the standard in fiscal year 2002.

Chromium – A major source for chromium was the sodium dichromate used as a corrosion inhibitor in cooling water for reactors in the 100 Areas. The most significant chromium plumes are located in the 100-K, 100-D, and 100-H Areas.

Strontium-90 – Strontium-90 was present in waste associated with fuel processing. It was released also by fuel element failures during reactor operations. Strontium-90 has a half-life of 28.8 years and a drinking water standard of 8 pCi/L. It moves slowly through the vadose zone and in groundwater. Strontium-90 exceeds the drinking water standard beneath each of the reactor areas, small parts of the 200 Areas, and the former Gable Mountain Pond.

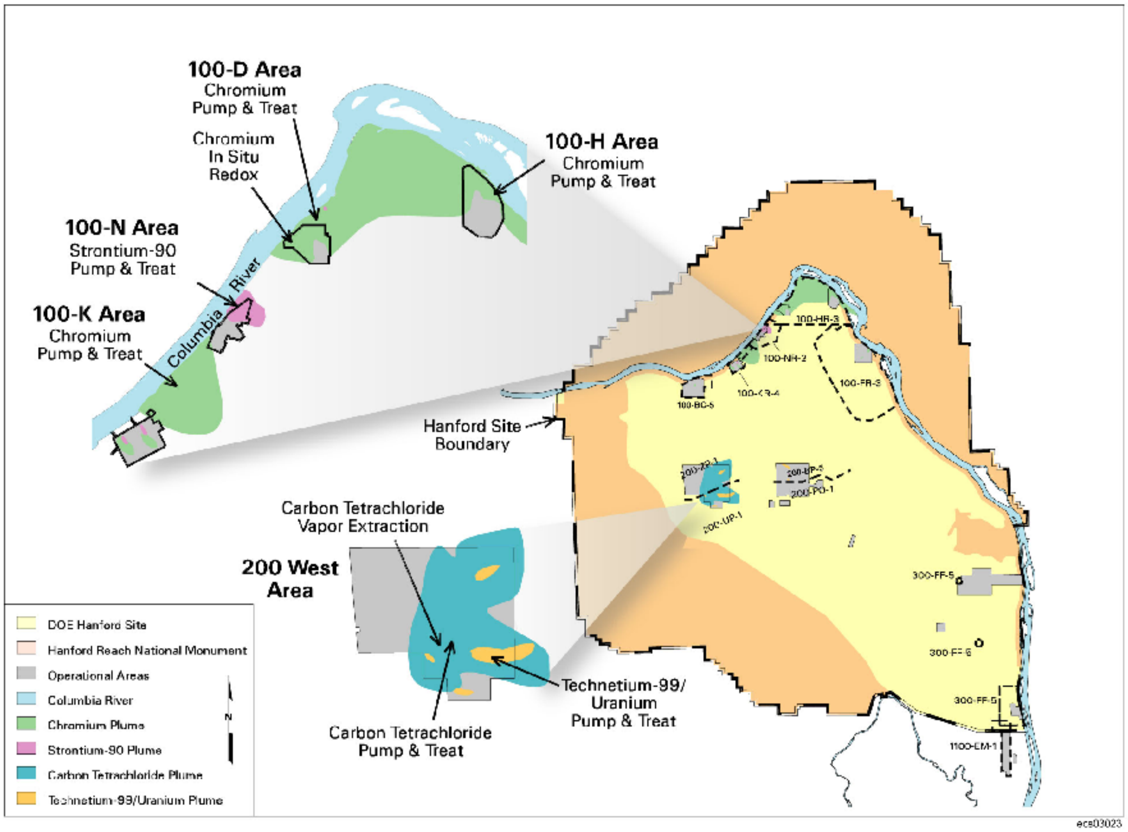
Technetium-99 – Technetium-99 was present in waste streams associated with fuel processing. It has a half-life of 210,000 years and a drinking water standard of 900 pCi/L. Technetium-99 is very mobile in groundwater and concentrations exceed the drinking water standard beneath portions of the 200 Areas.

Uranium – Uranium contamination on the Hanford Site had numerous potential sources including fuel fabrication, fuel processing, and uranium recovery from separations activities. Uranium tended to be associated with technetium-99 through the fuel processing cycle, but uranium is less mobile in groundwater on the Hanford Site. The drinking water standard is 30 µg/L. Plumes are detected in the 200 West, 200 East, and 300 Areas.

Carbon-14 – Carbon-14 exceeded the 2,000-pCi/L drinking water standard in two small plumes near waste disposal facilities adjacent to the KW and KE Reactor buildings where reactor atmosphere gas condensate was discharged to the ground in the past. The half-life is 5,730 years.

Cyanide – Cyanide was associated with waste discharged to the BY cribs near 200 East Area. In groundwater, it exceeded the 200-µg/L drinking water standard in two wells near the cribs.

Because ***contaminants*** *were disposed to the ground or were contained in leaking tanks, groundwater is a major pathway through which contaminants move across the Hanford Site.*



DOE operates five pump-and-treat systems, one in situ remediation system, and one soil-gas extraction system to limit movement of contaminants in groundwater and the vadose zone.

Cesium-137 – Cesium-137 has a half-life of 30 years and a drinking water standard of 200 pCi/L. It was present in waste associated with fuel processing and has been released in reactor areas by fuel element failures. Cesium-137 was present in waste that leaked from underground storage tanks in the past. It is present in the vadose zone near the single-shell tanks, but is detected in groundwater only near the former 216-B-5 injection well in the 200 East Area.

Plutonium – Plutonium was present in waste associated with fuel processing. It has a low mobility in groundwater and a long half-life (24,000 years for plutonium-239 and 6,500 years for plutonium-240). The only significant detection of plutonium in recent years was associated with the 216-B-5 injection well in the 200 East Area.

*When groundwater is pumped from the subsurface, it is treated to remove contaminants before being discharged. This process is often referred to as a pump-and-treat system. This common form of **groundwater remediation** is being used at Hanford to remove carbon tetrachloride, chromium, technetium-99, and uranium.*

Groundwater Remediation and Monitoring of CERCLA Operable Units

DOE monitors groundwater on the Hanford Site to comply with requirements of CERCLA at 11 groundwater operable units. DOE, EPA, and Washington State Department of Ecology determine methods for remediating contaminated groundwater via formal documents called records of decision.

One operable unit, 1100-EM-1 (Richland North Area), has a final record of decision calling for natural attenuation of volatile organic compounds. Groundwater is monitored to determine the success of this approach. In fiscal year 2002, contaminant concentrations remained below their target levels.

At six of the operable units, interim remedial actions are required until final cleanup decisions are made. DOE monitors groundwater to assess the effectiveness of the interim actions.

- **100-HR-3 (100-D and 100-H Areas) and 100-KR-4 (100-K Area)** – Chromium may pose a threat to aquatic organisms in the Columbia River. In the 100-K, 100-D, and 100-H Areas, pump-and-treat systems reduce the amount of chromium reaching the river. Also in the 100-D Area, an innovative treatment method, called in situ redox, immobilizes chromium in the aquifer. In fiscal year 2002, chromium concentrations at all these interim action sites remained above cleanup targets.
- **100-NR-2 (100-N Area)** – Strontium-90 concentrations remained much higher than the drinking water standard in wells at the river shore in fiscal year 2002. DOE operates a pump-and-treat system for strontium-90 as an interim action. The system continued to divert groundwater flow in fiscal year 2002 but is not an efficient way to clean up the aquifer.
- **200-UP-1 (200 West Area)** – An interim record of decision required operation of a pump-and-treat system to reduce technetium-99 and uranium contamination. In fiscal year 2002, some concentrations remained above target levels. Many of the wells monitoring this area have gone dry, so the size of the current plumes is uncertain.
- **200-ZP-1 (200 West Area)** – An interim record of decision requires operation of a pump-and-treat system to prevent carbon tetrachloride from spreading. In fiscal year 2002, the system continued to limit migration of the heart of the plume. DOE also is extracting and treating soil gas to remove carbon tetrachloride from the vadose zone. In fiscal year 2002, workers deepened two wells at one site and completed them as soil-gas extraction wells.

***Hanford groundwater** flows into the Columbia River, which is a major drinking water source. Therefore, DOE is focusing their remediation efforts on protecting the Columbia River.*

Groundwater Remediation

Location	Startup Date	Progress From Startup to September 2002
100-K Area 100-KR-4 Pump-and-Treat	1997	Decreases chromium to river; 175 kilograms chromium removed.
100-N Area 100-NR-2 Pump-and-Treat	1995	Diverts strontium-90 from river; 1.3 curies strontium-90 removed.
100-D Area 100-HR-3 Pump-and-Treat	1997	Decreases chromium to river; 120 kilograms chromium removed.
100-D Area 100-HR-3 In Situ Redox	1999	Decreases chromium concentration downgradient of barrier.
100-H Area 100-HR-3 Pump-and-Treat	1997	Decreases chromium to river; 34 kilograms chromium removed.
200 West Area 200-ZP-1 Pump-and-Treat	1994	Prevents high-concentration portion of carbon tetrachloride plume from spreading; 6,874 kilograms removed.
200 West Area Soil-Vapor Extraction	1992	Prevents carbon tetrachloride movement to groundwater; 77,800 kilograms removed from vadose zone.
200 West Area 200-UP-1 Pump-and-Treat	1994	Decreases migration of contaminants; 90 grams technetium-99, 158 grams uranium, 23 kilograms carbon tetrachloride, and 23,200 kilograms nitrate removed.
300-FF-5 Natural Attenuation	Not applicable	Trichloroethene concentrations below target level; uranium concentrations above target level.
1100-EM-1 Natural Attenuation	Not applicable	Trichloroethene concentrations below 5-µg/L in 2001 and 2002.

- **300-FF-5 (300 Area and satellite areas to the north)** – An interim record of decision calls for monitoring the cis-1,2-dichloroethene, trichloroethene, and uranium plumes. In fiscal year 2002, concentrations of the organic contaminants were low, but uranium remained elevated.

__Monitoring well networks__ are designed specifically for individual areas based on the type of data needed, the hydrogeologic conditions, geologic conditions, groundwater flow directions, and the expected contaminants.

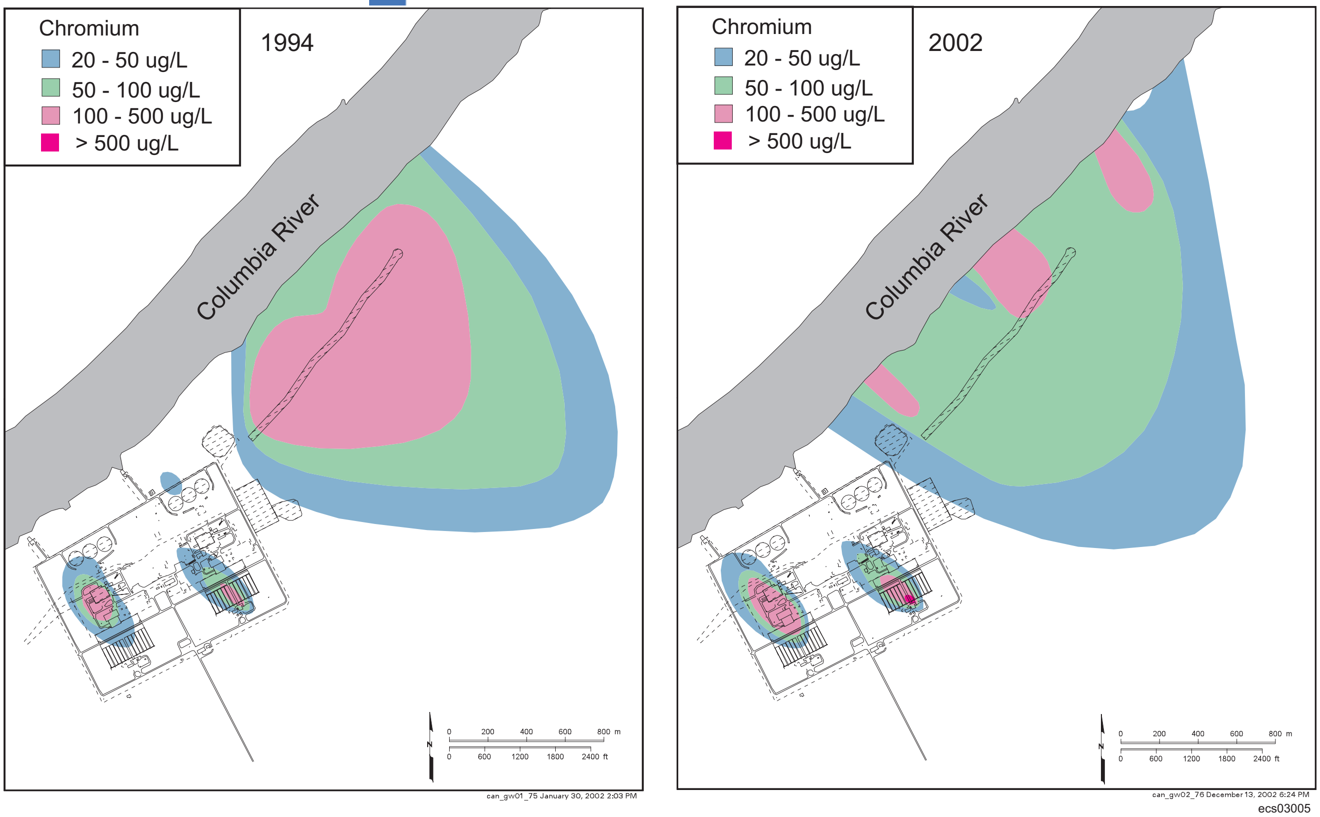
At four operable units, there is no imminent threat to human health or the environment; therefore, no interim remedial actions are required. These operable units include 100-BC-5 (100-B/C Area), 100-FR-3 (100-F Area), 200-BP-5, and 200-PO-1 (200 East Area). Waste sites and plumes will continue to be monitored until there are final records of decision.

100 Areas Groundwater Contamination

During 1944 to 1988, fabricated fuel cylinders were shipped by rail from the 300 Area to the reactors in the 100 Areas for irradiation, the second step in the plutonium production process. The nine plutonium production reactors are ~30 miles from Richland in the northern portion of the Hanford Site along the south bank of the Columbia River. The reactor areas had to be close to the river because large quantities of water were required for cooling.

Today, the most prominent contaminants in 100 Areas groundwater are tritium, strontium-90, hexavalent chromium, and nitrate. These contaminants originated from disposal cribs, trenches, and leaking retention basins. Because these sites are so close to the Columbia River, all of these contaminants have been detected in springs that discharge to the river.

100-B/C Area – Most of the groundwater contamination in the 100-B/C Area is found in the north portion of the area, beneath waste trenches and retention



A pump-and-treat system in the 100-K Area reduces the amount of chromium entering the Columbia River. The shape of the plume has remained fairly stable since 1994 but concentrations decreased in some areas.

basins. Tritium and strontium-90 exceeded drinking water standards in several wells. Nitrate and chromium were somewhat elevated, but were below drinking water standards in fiscal year 2002. Surface waste sites have been excavated and backfilled. There is no active groundwater remediation in the 100-B/C Area.

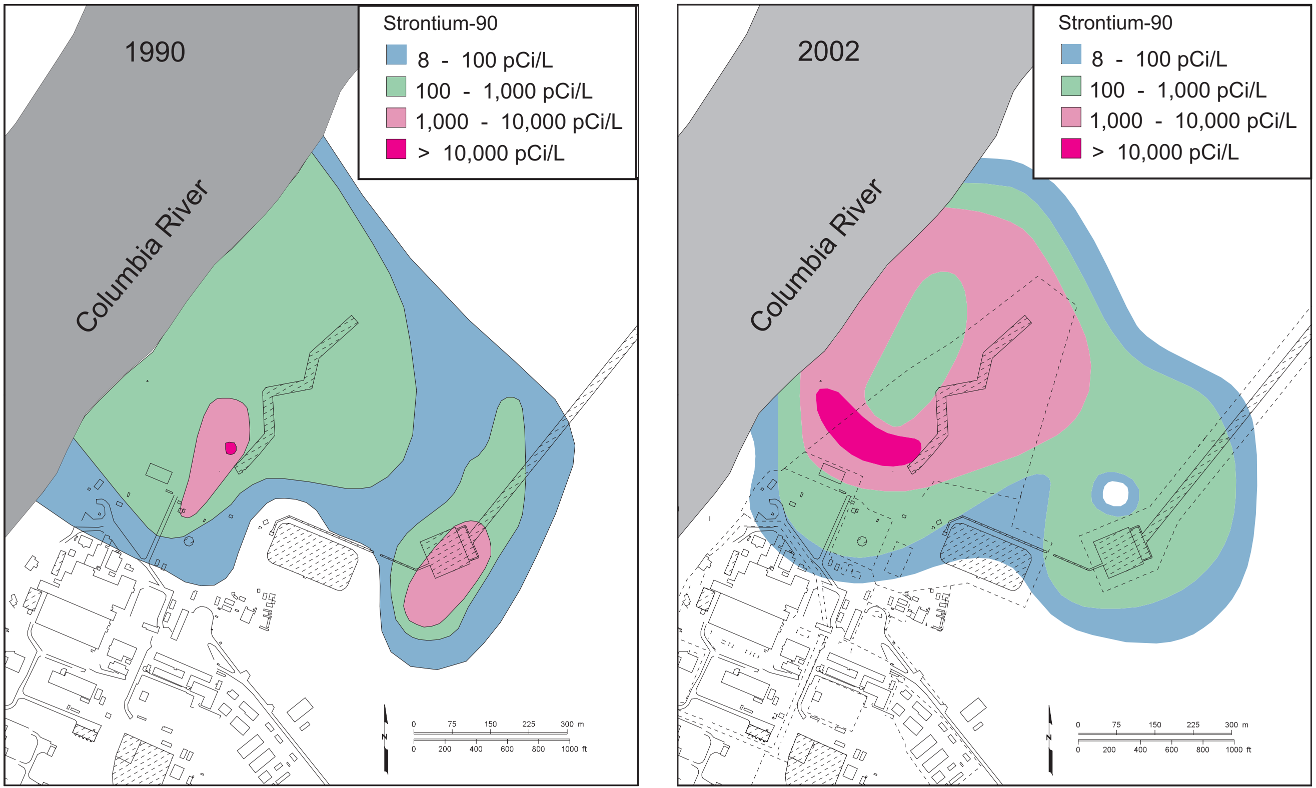
100-K Area – The primary constituents of interest in 100-K Area groundwater are hexavalent chromium and tritium. Other groundwater contaminants include carbon-14, nitrate, and trichloroethene. The major chromium plume is beneath the 116-K-2 trench, located east of 100-K Area near the Columbia River. This plume is the target of a pump-and-treat system that reduces contaminated flow into the river.

High concentrations of tritium in very small plumes originated from past leaks in fuel storage basins and waste disposal sites near the KE Reactor building. The average concentration in fiscal year 2002 was 460,000 pCi/L, but no new leaks were detected. Contractors continued to remove the spent fuel from the KE fuel storage basins in 2002.

In recent years, tritium contamination was detected in a monitoring well near the 118-K-1 burial ground. Results of a study published in 2002 suggest that the tritium is from a previously unidentified plume that may be related to former disposal of tritium-producing irradiated metallic waste in the burial ground.

100-N Area – The primary groundwater contaminant in this area is strontium-90. The plume originated at two liquid waste disposal cribs. The extent of the plume changed very little in over 12 years; however, concentrations increased during the 1990s because of changing water levels and the end of effluent discharge. A pump-and-treat system in the 100-N Area operates to reduce the movement of strontium-90 toward the Columbia River. Since strontium-90 binds to sediment grains, pump-and-treat is not an effective way to clean up the aquifer. Tritium also

What are pump-and-treat systems? *Several contaminant plumes in the 100 Areas are of special concern because they are so close to the Columbia River. DOE is pumping contaminated groundwater out of strontium-90 and chromium plumes, treating it to remove the contaminants, and injecting the clean water back into the aquifer. The primary purpose of these pump-and-treat systems is to reduce the amount of contamination entering the river until a final cleanup solution is in place.*



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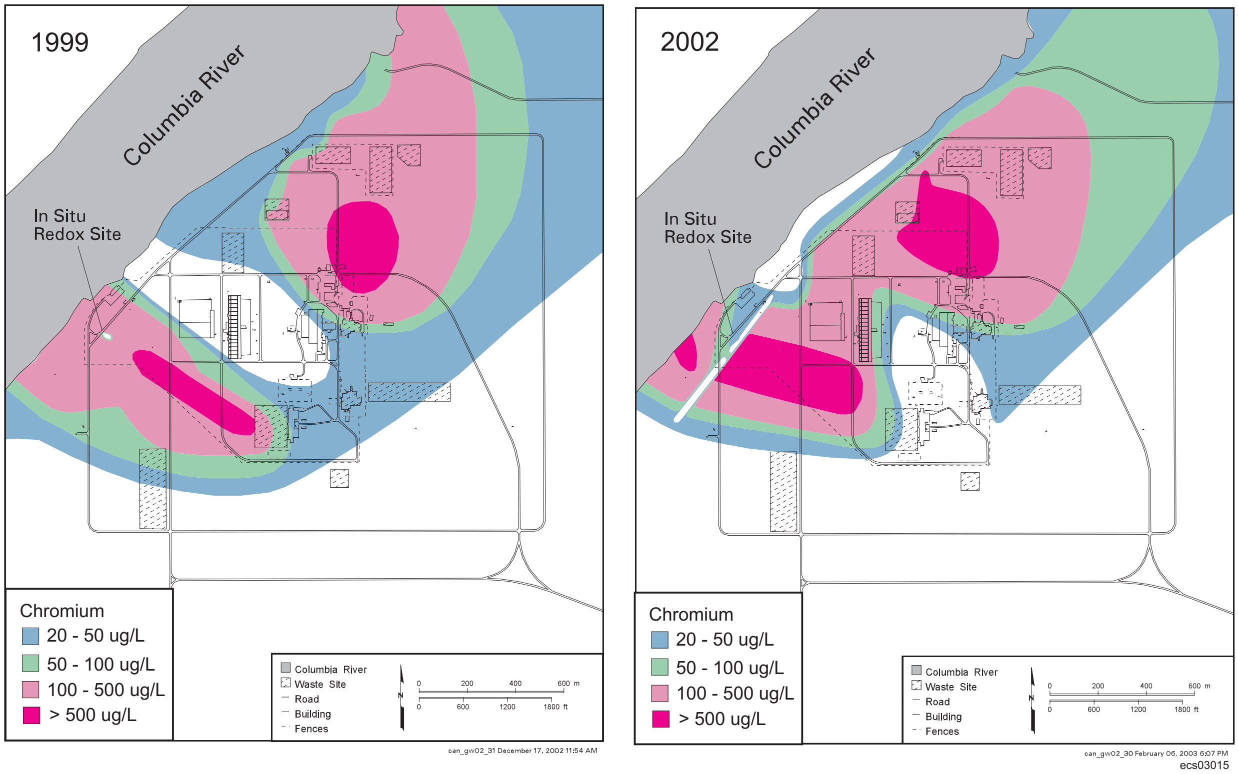
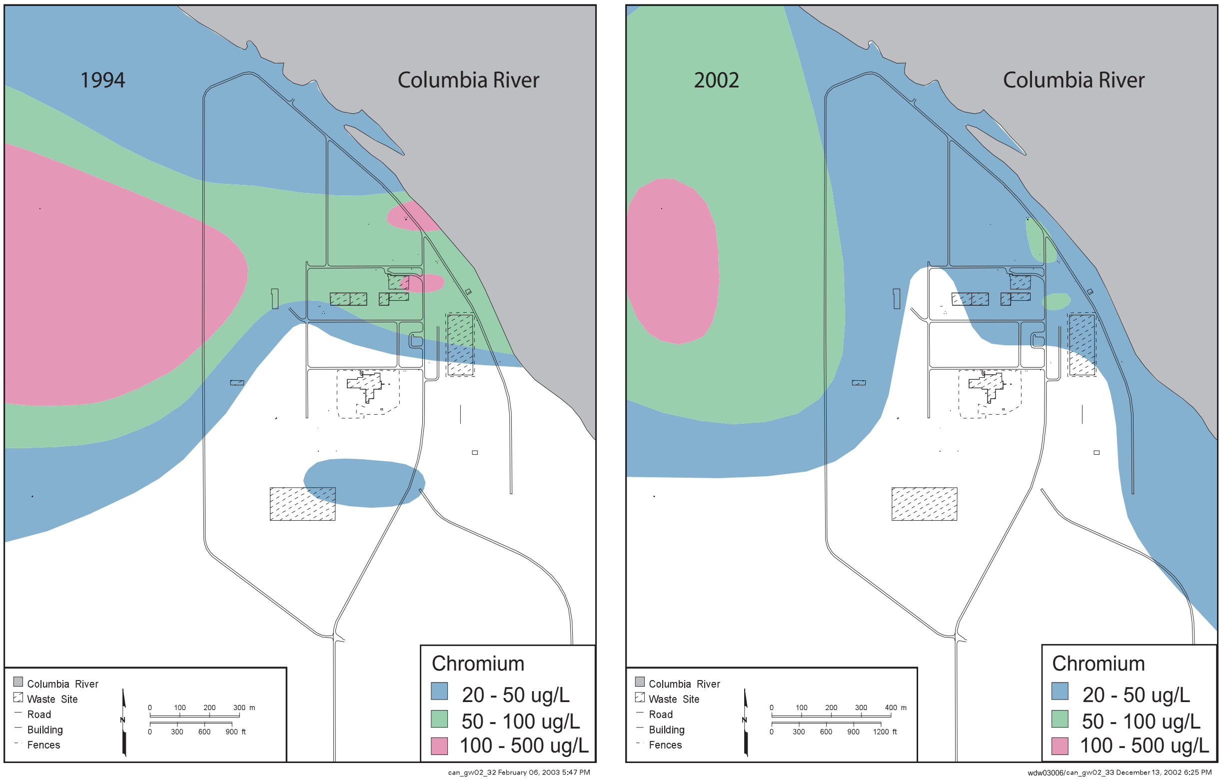
Concentrations of strontium-90 in the 100-N Area increased after 1990, but the overall shape of the plume remained about the same in 2002.



The shape of the chromium plume in the 100-D Area has changed since 1999. Plumes from two chromium sources have moved into the central 100-D Area and merged. The north plume is the target of a pump-and-treat system and the southwest plume is being treated within the aquifer.



A pump-and-treat system in the 100 H-Area reduces the amount of chromium entering the Columbia River. Between 1994 and 2002, concentrations decreased through most of the plume. Much of the decrease appears to be due to natural processes.

was present in waste discharged to the 100-N cribs. Tritium concentrations in groundwater are declining, and the plume is shrinking. Nitrate, sulfate, and petroleum hydrocarbons also are present in 100-N Area groundwater. The 116-N-1 crib was excavated in fiscal year 2002 to remove contaminated sediment near the surface.

100-D Area – Hexavalent chromium is the primary contaminant of concern in the 100-D Area. The source of this contaminant was sodium dichromate added to cooling water to inhibit corrosion. The water was discharged to cribs and ditches, and some spillage of sodium dichromate also occurred. Hexavalent chromium is highly mobile in groundwater. Chromium is distributed in two plumes that are merging. The north plume is the target of a pump-and-treat system for the 100-HR-3 Operable Unit, which also includes the 100-H Area. The southwest chromium plume is being remediated with an in situ system that immobilizes chromium in the aquifer. This plume had the highest chromium concentrations on the Hanford Site in fiscal year 2002, with an average concentration over 3,000 µg/L.

Groundwater from the Hanford Site can reach the Columbia River in days, months, or years depending on the geology and how far it has to travel. During this time, many of the contaminants are decreased by natural decay.

100-H Area – Hexavalent chromium is present in 100-H Area groundwater, but the plume is smaller and concentrations are lower than in the 100-D Area. The plume is intercepted by pumping wells, treated, and the treated water is injected into an upgradient location. Chromium concentrations have decreased in recent years. Nitrate also is elevated, but concentrations have declined from their peaks. Strontium-90 exceeds the drinking water standard beneath former retention basins. Technetium-99 and uranium are elevated in a small area but were below their drinking water standards in fiscal year 2002.

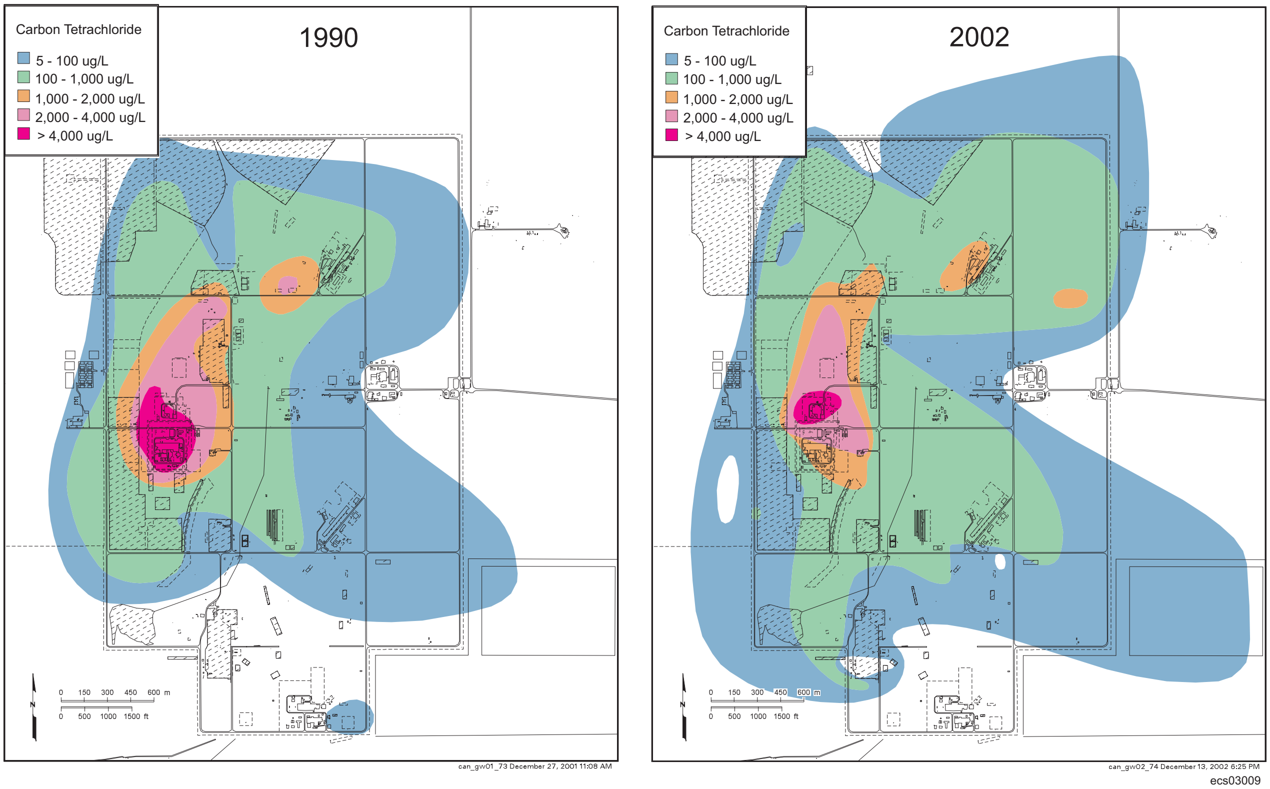
100-F Area – Nitrate exceeds the drinking water standard beneath much of the 100-F Area and the downgradient region. Strontium-90 exceeds the drinking water standard in a small plume beneath former waste sites in the eastern 100-F Area, near the Columbia River. There also is a small plume of trichloroethene at concentrations above the maximum contaminant level. Excavation of former waste sites continued in fiscal year 2002. There is no active groundwater remediation in the 100-F Area.

200 Areas Groundwater Contamination

After fuel rods were irradiated in the 100 Areas, they were shipped to the 200 Areas. There, between 1944 and 1987, separations (finishing) plants processed the fuel to extract and purify plutonium. The plutonium extraction first took place at the T and B plants and later at the Reduction-Oxidation (REDOX) and PUREX Plants. The Plutonium Finishing Plant was used for plutonium purification. U Plant was used to extract uranium from process waste and T Plant was converted to an equipment decontamination facility. Currently, the 200 Areas are used for waste management and disposal.

The 200 Areas are located 20 miles from Richland on a plateau in the center of the Hanford Site, ~5 miles south of the Columbia River. During the finishing process, contaminants such as carbon tetrachloride, chromium, fluoride, iodine-129, nitrate, technetium-99, trichloroethene, tritium, and uranium were disposed to the ground in the 200 Areas. This contamination has moved into the vadose zone and is responsible for groundwater contamination currently detected at these sites.

Radioactive and hazardous chemical waste generated from plutonium production and separation activities historically was stored in single-shell tanks in the 200 Areas. These underground tanks were constructed of reinforced concrete and steel in the 1940s. Although most of the free liquid has been removed, some of these tanks leaked in the past and appear to have contributed to groundwater contamination. The tanks still contain ~87 million liters of highly caustic saltcake



The carbon tetrachloride plume beneath the 200 West Area spread between 1990 and 2002. Since 1996, a pump-and-treat system is helping prevent further spreading of the heart of the plume, shown here in pink and red.

and 45 million liters of chemical sludge. The tanks are grouped into farms that are regulated under RCRA and monitored to detect new leaks or to define the extent of contamination.

200 West Area – The aquifer beneath the 200 West Area has a lower permeability than beneath the 200 East or 100 Areas, which slows contaminant movement.

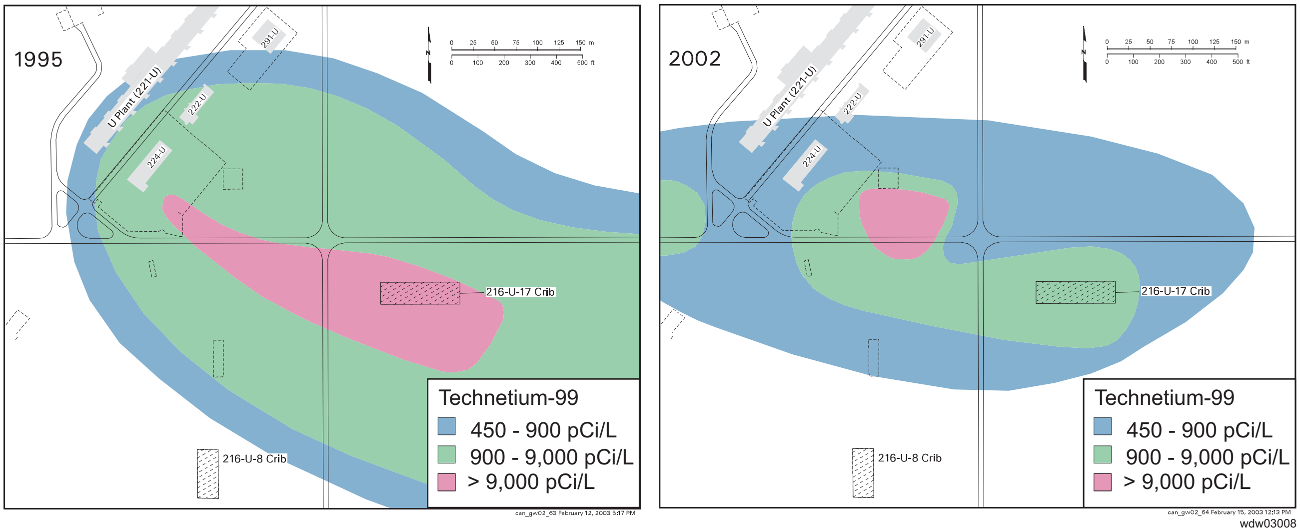
The largest plume of chlorinated hydrocarbons on the Hanford Site is beneath the 200 West Area and includes carbon tetrachloride, chloroform, and trichloroethene. The contamination is principally from waste disposal operations associated with the Plutonium Finishing Plant, where organic chemicals were used in plutonium processing. A groundwater pump-and-treat system is operating in this area to prevent the spread of the central, high-concentration portion of the carbon tetrachloride plume.

__Pump-and-treat systems__ in the 200 West Area are interim actions for groundwater remediation until a final remedy can be identified.

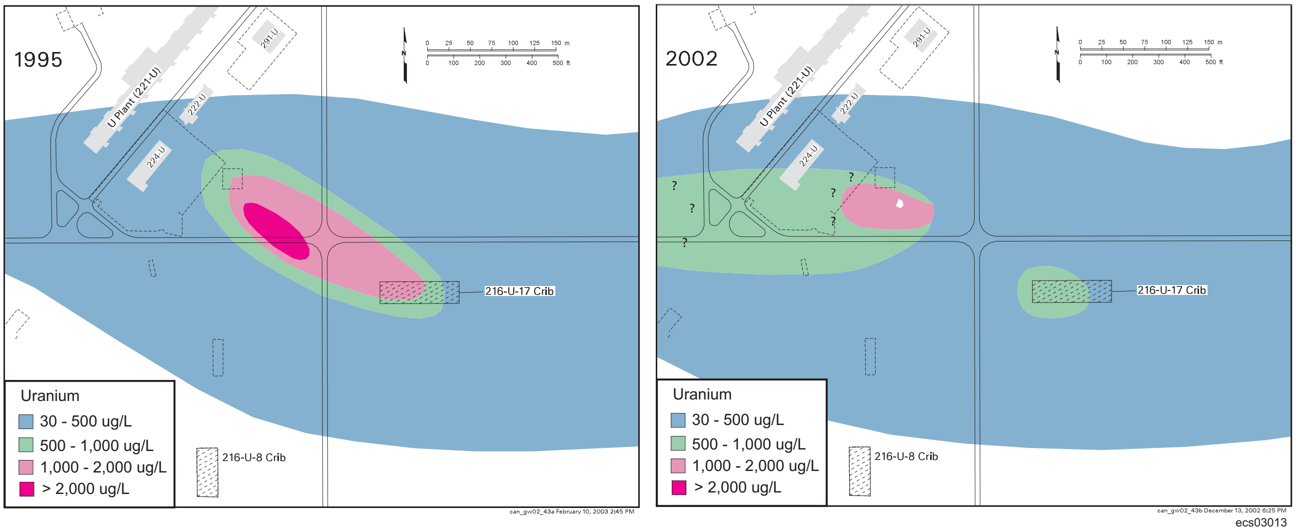
In some areas, concentrations of carbon tetrachloride decrease with depth, but at some locations carbon tetrachloride is present at higher concentrations deeper in the Hanford/Ringold sediment than at the water table. Therefore, the extent of the plume at the water table may not reflect the extent in deeper parts of the aquifer system.

The 200 West Area also contains plumes of technetium-99 and uranium from sources near T Plant and U Plant and single-shell tank farms. A groundwater pump-and-treat system is operating near U Plant to contain the technetium-uranium plume there. Contaminant concentrations have declined, and the plumes have shrunk, apparently as a result of remediation and dispersion.

The highest tritium concentrations in the 200 West Area are detected beneath waste facilities associated with T Plant. The maximum concentration detected in fiscal year 2002 was 1.7 million pCi/L, the same as in fiscal year 2001. A larger



A pump-and-treat system at the 200-UP-1 Operable Unit (200 West Area) has decreased the size of the technetium-99 plume. The system began to operate in fall 1995. However, many monitoring wells in the plume have gone dry, making interpretation of plume size less certain.

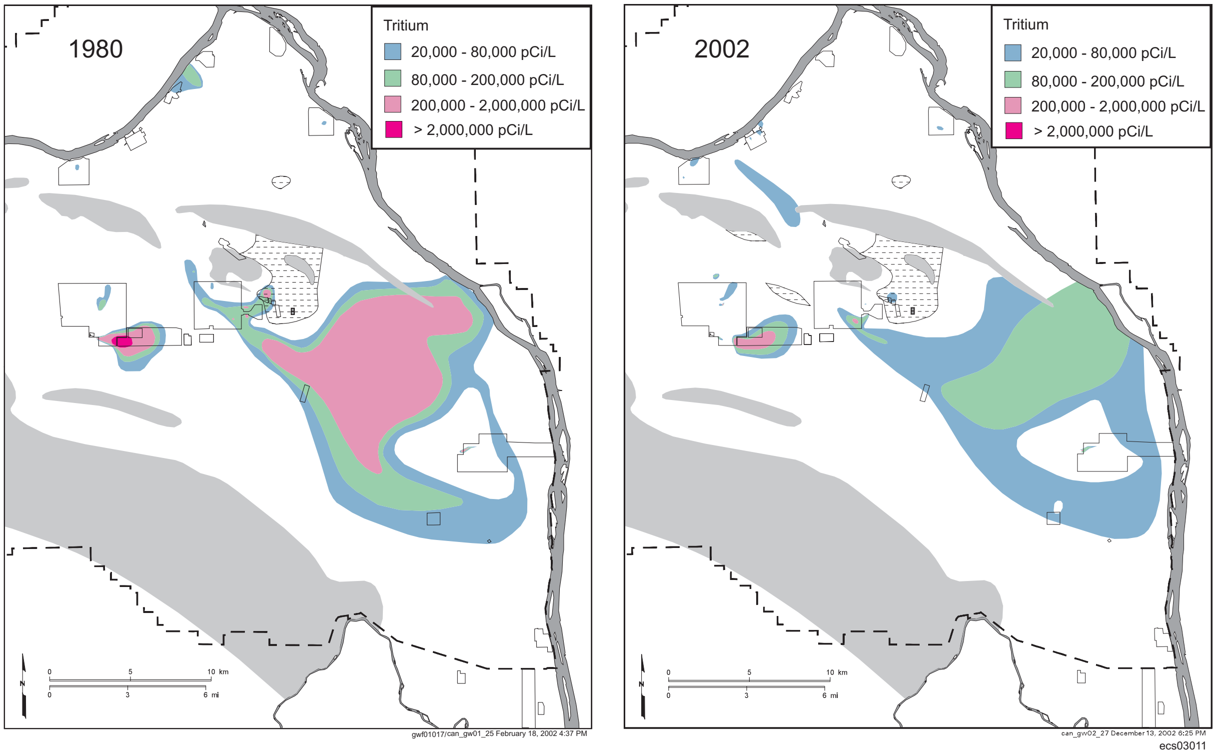


Uranium contamination in the 200-UP-1 Operable Unit (200 West Area) is not responding to the pump-and-treat system as quickly as the technetium-99. Unlike technetium, uranium interacts with sediment grains, slowing its movement and response to remediation.

plume (with lower concentrations) originated at sites associated with the REDOX Plant in the southeast part of the 200 West Area. It is slowly moving eastward with groundwater flow. Smaller tritium plumes are detected beneath a former waste site in the southwest part and near an active disposal site north of 200 West Area.

Iodine-129 plumes coincide generally with the tritium plumes associated with the T Plant and REDOX Plant. The maximum concentration in fiscal year 2002 in this region was 32 pCi/L.

The 200 West Area has two main nitrate plumes: one from the vicinity of U Plant extending into the 600 Area and another near T Plant. Lower concentrations of contamination are found near the Plutonium Finishing and REDOX Plants.



Tritium plumes in 1980 and 2002 at the 200 East Area are shown in the above maps. Concentrations in the heart of the plume have decreased over the years; in approximately 1995, the south margin appears to have ceased its southward migration.

Chromium and fluoride exceeded maximum contaminant levels in several wells near T, TX, and TY Tank Farms. The plumes are not widespread.

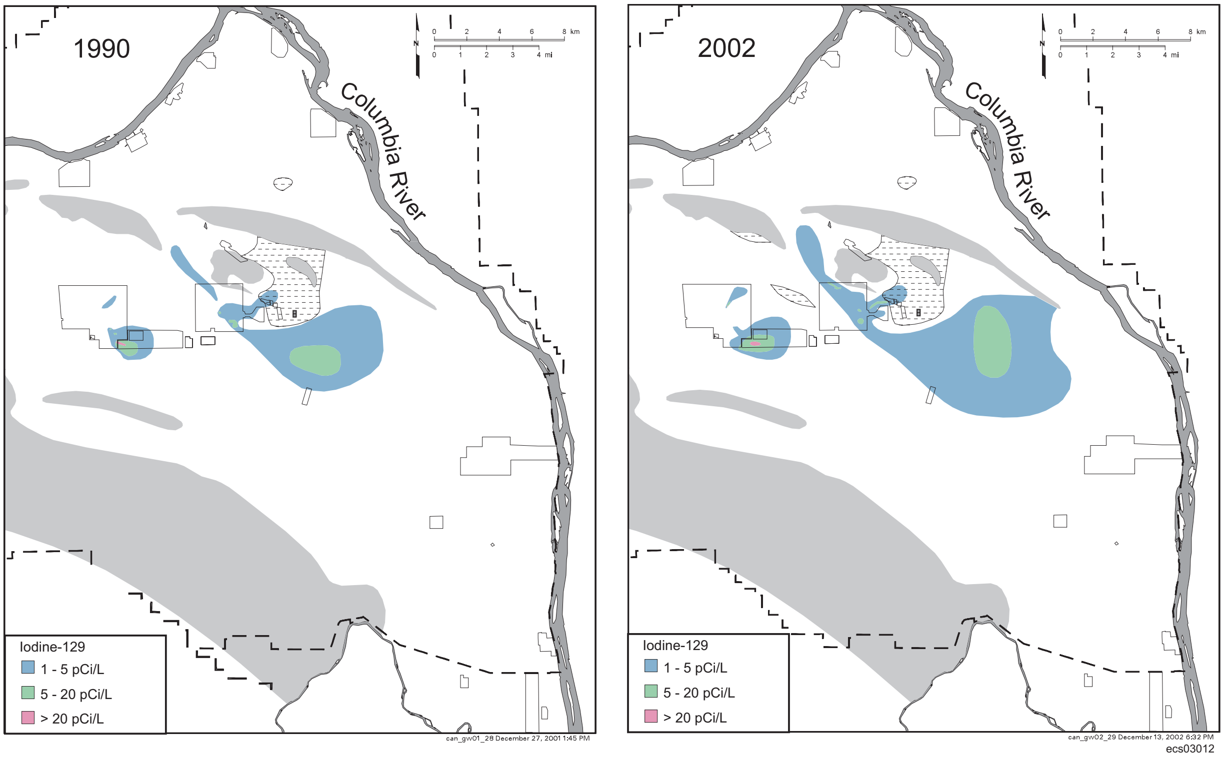
Strontium-90 has been detected in very small areas near facilities that received waste from the REDOX Plant. In fiscal year 2002, only one well had concentrations exceeding the drinking water standard.

200 East Area – Disposal of liquid waste in the 200 East Area has contaminated groundwater with tritium, iodine-129, nitrate, and several other contaminants. The most widespread and mobile contaminants have flowed through the permeable aquifer to the Columbia River.

The largest tritium plume originated at waste sites near the PUREX Plant in the southeast 200 East Area. Concentrations in one well near the former waste sites were up to 4.2 million pCi/L in fiscal year 2002, which is slightly lower than the highest concentration the previous year.

__Tritium__ is very mobile in groundwater and has migrated from sources in the 200 Areas toward the southeast and the Columbia River.

The movement of the PUREX tritium plume can be traced with historical groundwater data. By 1980, tritium concentrations above 20,000 pCi/L had reached the Columbia River at the Hanford town site. In the south portion of the Hanford Site, the 20,000-pCi/L portion of the plume had apparently flowed around less transmissive sediment beneath the Energy Northwest location. The core of the plume (concentrations >200,000 pCi/L) had broken off from the source in the southeast 200 East Area. These high concentrations decreased in the past 20 years and are not seen on the map for fiscal year 2002. The south margin of the plume ceased its southward migration in ~1995. Concentrations in the southeast part of the plume are expected to keep declining because of dispersion and radioactive decay. Concentrations also have declined in the past 10 years in the northwest 200 East Area, but a plume with its origins in that region has migrated north.



The iodine-129 plume in the 200 East Area (shown on the above maps) moves similarly to the tritium plume, but it has not moved as far. The plumes have spread between 1990 and 2002.

The iodine-129 plume originating in the 200 East Area is similar to the tritium plume, but concentrations greater than the drinking water standard have not reached the Columbia River. The iodine-129 plume from 200 East Area probably migrated at about the same rate as the tritium plume, but iodine-129 data were not commonly collected until the 1980s. By 1990, the portion of the plume exceeding the 1-pCi/L drinking water standard had traveled more than halfway to the Columbia River. It moved an additional ~4 kilometers between 1990 and 2002. The plume will continue moving toward the river, but concentrations are expected to decline because of dispersion.

Waste sites near the PUREX Plant in the 200 East Area contributed to extensive nitrate plumes that extend to the southeast, but only proportionally small areas contain nitrate at levels above the maximum contaminant level. This plume extends to wells near the Columbia River at the Hanford town site, where nitrate concentrations are below the maximum contaminant level and are gradually declining. Another nitrate plume originated from sites in the northwest 200 East Area and spread northward between Gable Butte and Gable Mountain.

Iodine-129 *flows with tritium toward the Columbia River.*

Elevated technetium-99 levels are associated with the BY cribs in the northwest 200 East Area. Past leaks from the B-BX-BY single-shell tank farms also appear to be a source of technetium-99 in this area. This plume has migrated toward the north. A less extensive plume of uranium is also present in this vicinity.

The former 216-B-5 injection well in the northwest 200 East Area contaminated groundwater with radionuclides including cesium-137, plutonium, and strontium-90. The residual contamination is very localized.

Other groundwater contaminants in the 200 East Area include cobalt-60 and cyanide near the BY cribs in the northwest part, and strontium-90 beneath the former Gable Mountain Pond.

400 Area Groundwater Contamination

The 400 Area is the location of the Fast Flux Test Facility, the largest test reactor on the Hanford Site. DOE has decided to deactivate the facility. The reactor was designed to test fuels and materials for advanced nuclear power plants as well as for the irradiation testing of fuels, core components, and target assemblies for liquid metal fast breeder reactors. Nitrate is the only groundwater contaminant attributable to 400 Area operations. The contamination is believed to have come from a sanitary sewage lagoon that is no longer in use. Nitrite also is detected in groundwater, but concentrations are below the maximum contaminant level.

300 Area Groundwater Contamination

During years of production, the 300 Area was where uranium fuel was manufactured before it was sent for irradiation in the reactors in the 100 Areas. The 300 Area was also the location of several test reactors during the Manhattan Project and Cold War periods. During the production process, contaminants such as uranium and trichloroethene were discharged to the ground. These elements, along with breakdown products of trichloroethene, are detected in groundwater, but concentrations are decreasing.

In some areas, DOE and the regulators agree that natural processes will clean up groundwater contamination. For example, dispersion (spreading) and radioactive decay decrease concentrations, while bacteria destroy other types of contaminants. Groundwater is monitored throughout the process to determine if concentrations are falling, as expected. This approach is known as ***monitored natural attenuation*** *and is being applied in the 300 and Richland North Areas.*

An area of elevated uranium concentrations is detected in the 300 Area, downgradient of the 316-5 process trenches and ponds. Uranium contamination is moving from the vicinity of the process trenches toward the southeast, entering the Columbia River. The most heavily contaminated sediment has been removed.

A plume of trichloroethene in the 300 Area is attenuating naturally, and concentrations remained below the 5-µg/L maximum contaminant level in fiscal year 2002. Bacteria naturally present in the subsurface break down the trichloroethene in this area. This degradation produces cis-1,2-dichloroethene as a byproduct, and this contaminant exceeded the maximum contaminant level in a well that monitors the bottom of the unconfined aquifer in fiscal year 2002.

Tritium from the 200 East Area has migrated into the 300 Area at levels below the drinking water standard. The plume has ceased spreading southward.

Groundwater monitoring relies on samples from wells across the Hanford Site. This photo shows the sampling vehicle and purgewater collection truck used to sample a well along the Columbia River.

Technicians collect groundwater samples and prepare them for transport to an analytical laboratory, as shown above. The types of bottles used are determined by the type of contaminant that is being investigated.

Strontium-90 concentrations are elevated in one well in the 300 Area but remained below the drinking water standard in fiscal year 2002.

The 300-FF-5 Operable Unit includes two "satellite areas" north of the 300 Area proper. These include the 618-11 burial ground, located near Energy Northwest, where the highest tritium concentrations currently in Hanford Site groundwater have been detected. Concentrations in the most-contaminated well reached 4 million pCi/L in fiscal year 2002, down from 8 million pCi/L the previous year. Monitoring of nearby wells and soil-gas testing indicate that the contamination is not widespread. The other satellite area includes the 618-10 burial ground and 316-4 cribs. Groundwater near these facilities is contaminated with uranium and hydrocarbons.

*Layers of dense, impermeable **basalt rock** prevent Hanford's groundwater contaminants from entering deep confined aquifers beneath most of the site. However, in some places the top impermeable layer of basalt is absent.*

Richland North Area Groundwater Contamination

The Richland North Area, located just south of the Hanford Site, contained site support services, such as general stores, shipping, receiving, transportation, maintenance, and general warehouse facilities. In 1998, DOE transferred ownership of portions of the Hanford Site located in the Richland North Area to the Port of Benton.

Groundwater beneath a portion of the Richland North Area is designated the 1100-EM-1 Operable Unit, which contains DOE's inactive Horn Rapids Landfill. A small, narrow plume of trichloroethene, which underlies the landfill and Framatome ANP Richland, Inc. (formerly Siemens Power Corporation), is attenuating naturally. Levels declined below the maximum contaminant level of 5 µg/L in fiscal year 2001 and remained below that level in fiscal year 2002. Contaminants also flow into the Richland North Area from offsite sources (i.e., nitrate from agriculture practices, fluoride, ammonia, and gross alpha from Framatome ANP Richland, Inc.).

*The **Resource Conservation and Recovery Act of 1976** (RCRA) regulates facilities used to treat, store, or dispose of hazardous waste. At Hanford, the law applies to sites that contained hazardous or mixed (hazardous and radioactive) waste. RCRA stipulates requirements for monitoring the groundwater beneath these sites.*

The city of Richland monitors groundwater downgradient of its sanitary landfill, located west of the Richland North Area. Chlorinated hydrocarbons were detected at concentrations above their maximum contaminant levels in fiscal year 2002. Levels were undetected in the nearest well on the Hanford Site.

The city of Richland maintains a well field in the Richland North Area. Wells are monitored frequently to detect any changes in Hanford contaminants near these wells. The tritium plume from the 200 East Area has not been detected in these wells. Low levels of tritium, similar to Columbia River water, continue to be detected.

Upper Basalt-Confined Aquifer

*The **Comprehensive Environmental Response, Compensation, and Liability Act of 1980** (CERCLA) regulates cleanup of waste sites that were active before RCRA took effect. It covers sites where radioactive or hazardous waste were disposed or leaked, and also requires groundwater monitoring where appropriate.*

Although most of Hanford's groundwater contamination is in the unconfined aquifer, DOE monitors wells in the deeper, basalt-confined aquifer because of the potential for downward migration of contamination from the unconfined aquifer and the potential migration of contamination offsite through the confined aquifer. Wells are sampled every three years and most were not sampled in fiscal year 2002 (next scheduled in fiscal year 2003).

Groundwater Monitoring of RCRA Treatment, Storage, and Disposal Units

DOE monitors groundwater on the Hanford Site to meet the requirements of the RCRA at 24 waste management areas. Fifteen are monitored under indicator evaluation (or detection) programs and do not appear to affect groundwater with hazardous constituents. The others are monitored under assessment or corrective-action programs. The following list gives specific highlights:

- **116-H-6 evaporation basins (100-H Area)** – RCRA monitoring continued during operation of the 100-HR-3 chromium pump-and-treat system. Leakage from the basins in the past contaminated the groundwater with chromium, nitrate, technetium-99, and uranium. The CERCLA program directs corrective action.
- **116-N-1 liquid waste disposal facility (100-N Area)** — The indicator parameter pH fell below its critical range in one downgradient well. This did not indicate contamination from the facility, but was related to chemical effects from a petroleum-contamination site near the well.
- **216-B-3 pond (200 East Area)** – DOE initiated a two-year demonstration of an alternative statistical method for indicator evaluation monitoring at this site in fiscal year 2002.
- **216-S-10 pond and ditch (200 West Area)** – This site continues to be monitored by just one downgradient and one upgradient well. The other wells in the network have gone dry.
- **216-U-12 crib (200 West Area)** – Assessment monitoring continued to indicate that the crib has contributed to a nitrate plume. The monitoring network contains just two useable downgradient wells and no upgradient wells.
- **316-5 process trenches (300 Area)** – The monitoring network was revised in fiscal year 2002 as described in a new, corrective-action monitoring plan. This plan implements a two-year demonstration of an alternative statistical method. The trenches and other nearby sources contaminated groundwater with cis-1,2-dichloroethene, trichloroethene, and uranium. Corrective action

During fiscal year 2002, 28 new wells were installed on the Hanford Site.

involves natural attenuation of the contaminants. Concentrations of trichloroethene declined below the 5-µg/L maximum contaminant level.

- **Liquid Effluent Retention Facility (200 East Area)** – This site is monitored under an indicator evaluation program. However, it is monitored by just one useable downgradient well. Washington State Department of Ecology instructed DOE to cease statistical evaluations.
- **Single-Shell Tank Waste Management Areas A-AX and C (200 East Area)** – Indicator evaluation monitoring continued. Directions of groundwater flow were re-interpreted and monitoring networks are being modified.
- **Single-Shell Tank Waste Management Area B-BX-BY (200 East Area)** – These tank farms may have contributed to groundwater contamination in the northern 200 East Area. However, the assessment monitoring has not clearly identified a source within the tank farms. This waste management area is located near other major sources of contamination (e.g., the BY Cribs and 216-B-8 crib) that produced the bulk of the contamination.
- **Single-Shell Tank Waste Management Area S-SX (200 West Area)** – Groundwater studies indicate that sources within the tank farms have contaminated groundwater with chromium. Assessment monitoring continued in fiscal year 2002.
- **Single-Shell Tank Waste Management Area T (200 West Area)** – Results of assessment monitoring indicate that chromium is elevated in groundwater but appears to have a source outside the waste management area. Contaminant concentrations vary with depth.

Liquid waste from past disposal sites, spills, or leaks entered the vadose zone. Not all of this water flowed through to groundwater, so some contaminated sediment or water remains in the ***vadose zone****. This contamination may continue to move downward and into groundwater over time, especially if rain or other sources of water percolate through the contaminated zone.*

- **Single-Shell Tank Waste Management Area TX-TY (200 West Area)** – Assessment monitoring continued in fiscal year 2002. Chromium concentrations are elevated and increasing. There are no known upgradient sources of chromium, implicating the tank farm as the source of chromium contamination.
- **Single-Shell Tank Waste Management Area U (200 West Area)** – Assessment monitoring continued in fiscal year 2002. Chromium concentrations are elevated in the southeast corner of the waste management area and are decreasing.

*The results of **vadose zone characterization** studies improve understanding of the distribution and movement of contamination between the ground surface and the water table.*

Well Installation

During calendar year 2002, drillers completed 2 new RCRA monitoring wells, 21 wells for operable unit remediation and monitoring in 100-D Area, 4 wells to monitor a proposed low-activity waste site in the 200 East Area, and 2 wells for operable unit monitoring in the 200 West Area. Well maintenance was carried out at 456 wells during fiscal year 2002. These activities included well or pump repair, cleaning, and general maintenance.

Modeling

Computer simulations of groundwater flow and contaminant movement are used to predict future conditions and to assess the effects of remediation systems. Pacific Northwest National Laboratory has responsibility for a site-wide, consolidated groundwater flow and transport model.

In fiscal year 2002, development of the site-wide groundwater model focused on improvements to the base-case model and development of additional alternative conceptual models. The alternative models address uncertainty in the extent and

__Computer models__ of groundwater help predict future groundwater conditions and the movement of contaminants in groundwater. This information is important in planning waste management and cleanup activities at the Hanford Site.

A steel sheet wall is installed at the mock tank study site to simulate an adjacent steel tank. Scientists studied technologies that could be used to detect leaks outside of a single-shell tank during waste retrieval operations.

distribution of major mud units in the unconfined aquifer and uncertainty in the distribution of hydraulic conductivity in the Hanford formation. These factors affect how groundwater flows through the aquifer.

Pacific Northwest National Laboratory applied the site-wide groundwater model to determine the flow path and travel time for potential contaminant releases at each of the tank farms to the Columbia River. These simulations predicted that the majority of contaminant plumes will move to the north through the gap between Gable Mountain and Gable Butte toward the Columbia River. These results differ from previous assessments using the prior model, which predicted that most of the contaminants would move to the east, and that the northern route through the gap would cease to exist because the water table would drop below the top of the basalt. Modelers continue to investigate this region of uncertainty.

As part of the Groundwater Protection Program, Pacific Northwest National Laboratory continued developing the System Assessment Capability as a tool to predict cumulative site-wide effects from all significant Hanford Site contaminants. This tool integrates several linked models, beginning with the waste inventory and simulates release and movement through the vadose zone, groundwater, and Columbia River. In fiscal year 2002, modelers completed an initial assessment of 10 contaminants released from 890 waste sites, simulating movement of the contaminants from 1944 through 3050.

Two electrical geophysical methods were tested at the 105-A Mock Tank Facility during 2002. These tests are helping scientists develop methods to detect leaks beneath buried waste tanks on the Hanford Site.

Vadose Zone

Subsurface source characterization, vadose zone monitoring, soil-vapor monitoring, and sediment sampling were conducted in fiscal year 2002.

DOE contractors studied the vadose zone at several sites in the 200 Areas to support remediation, and at one site in the 100-F Area to assess the effectiveness of surface remediation. The studies involved geophysical monitoring and analysis of soil samples and soil gas:

- Sampling in a test pit in the 100-F Area showed that contaminant levels generally decrease with depth, as previously observed in other 100 Areas.
- Samples from a borehole drilled through the 216-T-26 crib in the 200 West Area showed the presence of contamination from the surface to a depth of 18 meters. The primary contaminants were cesium-137, europium-154, cobalt-60, carbon tetrachloride, and chloroform. Contaminant distribution was strongly affected by stratigraphy, with greater concentrations near the contact between different sedimentary units.
- To help characterize the distribution of carbon tetrachloride, researchers studied samples from a new groundwater monitoring well near the Plutonium Finishing Plant and from two deepened wells near the 216-Z-9 trench. Results indicated that the vadose zone is not likely to be a source of contamination in these locations.
- Sediment samples from boreholes at the 216-B-38 trench and 216-B-7A crib in the north 200 East Area indicate that cesium-137, plutonium, and uranium appear to be concentrated in a silty, sandy gravel unit of the Hanford formation.
- Workers excavated test pits in the 216-A-29 ditch and 216-B-63 trench in the 200 East Area in fiscal year 2002 to support future decisions about cleanup. The samples contained contaminants including cesium-137, strontium-90, and plutonium-239/240 at levels above Hanford Site background.

*Air in the vadose zone can become contaminated with gaseous contaminants from landfills or other waste sites. At Hanford, **soil gas** is monitored in the 200 West Area to measure gaseous carbon tetrachloride and to assess how well vadose zone cleanup is working.*

Workers drilled and sampled three boreholes in locations of known or suspected contamination in the TX Tank Farm. Sediment samples were collected and analyzed for chemical, radiological, and geochemical properties. Results will be available in fiscal year 2003. One of the boreholes was outfitted with vadose zone monitoring equipment as it was backfilled.

At Waste Management Area B-BX-BY, results of geochemical characterization of core samples collected in fiscal year 2001 became available in 2002. Results suggest that strontium-90 is fairly stable and immobile in the vadose zone. Uranium is present as a precipitate that currently is effectively immobile, but could dissolve from the sediment under certain chemical and physical conditions.

DOE monitors carbon tetrachloride in soil vapor near vadose zone remediation systems in the 200 West Area. Results indicate that the temporary suspension of vapor extraction during part of fiscal year 2002 caused minimal vertical transport of carbon tetrachloride through the soil to the atmosphere.

Researchers studied soil gas at the 618-10 burial ground (southeast Hanford Site) to determine whether there is a tritium plume similar to the one previously discovered at the 618-11 burial ground. Results indicated no significant tritium or volatile organic constituents from the 618-10 site. Results of the investigation also were used to guide locations for groundwater monitoring wells.

Geophysicists investigated the possibility of using gamma logging to identify zones of strontium-90 contamination in sediment around boreholes. Results showed a strong correlation between strontium-90 and gamma activity, and may lead to a method for quantitative measurement of strontium-90 in the subsurface.

Researchers evaluated performance parameters for two geophysical methods to detect leaks beneath buried tanks. Preliminary results from a test tank site indicate that the tested monitoring methods may be useful for detecting leaks from real tanks and estimating their volume.

PSN00003

Scientists studied soil gas at the 618-10 burial ground to determine whether there is a tritium plume similar to the one previously discovered at the 618-11 burial ground. Results indicated no significant tritium from the 618-10 site. Results such as these can serve as a guide for locating new groundwater monitoring wells.

In fiscal year 2002, DOE continued to take measures to protect tank farms from infiltration of water from precipitation or pipe leaks. Workers constructed berms and installed a culvert to carry water away from tank farms in the 200 East Area. DOE also tested water lines for leaks, and cut or capped unneeded water lines.

Contents

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1.0 Introduction

M. J. Hartman

The U.S. Department of Energy (DOE) monitors groundwater at the Hanford Site to fulfill a variety of state and federal regulations, including the *Atomic Energy Act of 1954*, the *Resource Conservation and Recovery Act* (RCRA), the *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA), and Washington Administrative Code. DOE manages these activities through the Hanford Groundwater Monitoring Project, which is conducted by Pacific Northwest National Laboratory.

1.1 Purpose and Scope

This report describes groundwater conditions on the Hanford Site and fulfills regulatory reporting requirements. It also summarizes groundwater remediation, vadose zone studies, and groundwater modeling.

Hanford Site Groundwater Monitoring for Fiscal Year 2002 (Figure 1.1-1) presents results of groundwater monitoring, vadose zone monitoring and characterization, and groundwater modeling. This report also summarizes groundwater remediation and well installation activities for the fiscal year. Monitoring results primarily rely on data from samples collected between October 1, 2001, and September 30, 2002. Data received after November 14, 2002, may not have been considered in the interpretations.

This report is designed to meet the following objectives:

- provide a comprehensive report of groundwater conditions on the Hanford Site and adjacent areas

Groundwater monitoring helps the U.S. Department of Energy develop solutions to Hanford Site cleanup issues. The protection of the Columbia River corridor is of primary importance. Pictured above is part of the Hanford Reach.

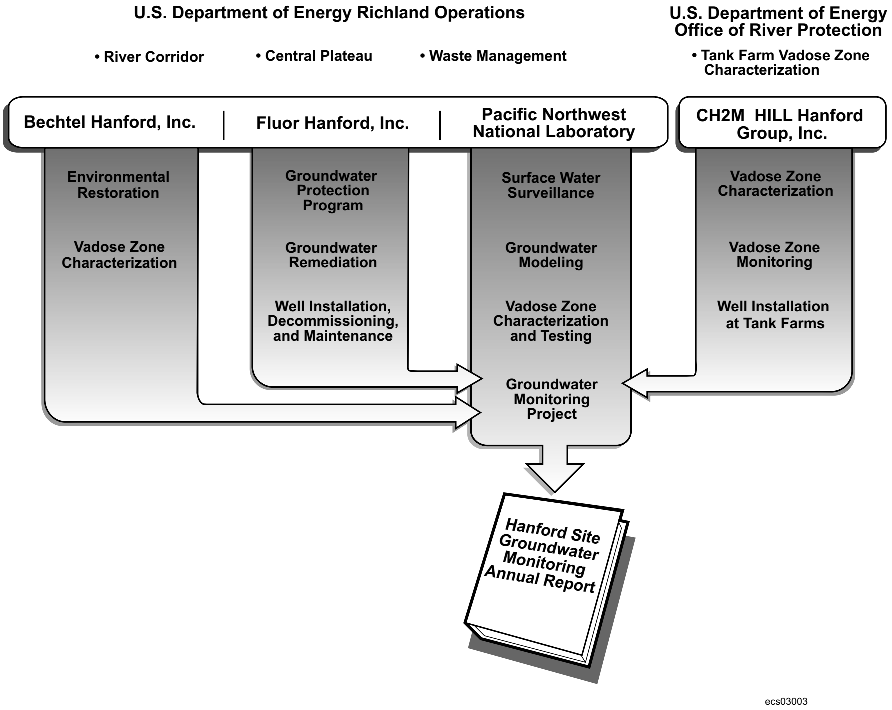

Figure 1.1-1. The Hanford Groundwater Monitoring Project Produces the Annual Groundwater Report for the U.S. Department of Energy with Input from Many Contributors

- fulfill the reporting requirements of RCRA, CERCLA (for operable units with no active groundwater remediation), DOE orders, and Washington Administrative Code
- summarize the results of groundwater monitoring conducted to assess the effects of remediation or interim measures conducted under CERCLA
- describe the results of vadose zone monitoring and characterization
- summarize groundwater modeling activities
- summarize the installation, maintenance, and decommissioning of Hanford Site monitoring wells

Groundwater remediation and associated monitoring of pumping wells was the responsibility of Bechtel Hanford, Inc. until the end of June 2002. After that time, the work moved to Fluor Hanford, Inc. Bechtel Hanford, Inc. continues to remediate surface facilities and near-surface contamination in the vadose zone. Vadose zone monitoring and characterization are conducted by Bechtel Hanford, Inc.; CH2M HILL Hanford Group, Inc.; Fluor Hanford, Inc.; and Pacific Northwest National Laboratory.

Supporting information for RCRA, CERCLA, and other waste units regulated under federal and state requirements are presented in Appendix A. Table 1.1-1 summarizes highlights or changes for those units and indicates where to find additional information. Appendix B describes results of the quality control program. Appendix C contains a list of wells currently used to monitor groundwater on the Hanford Site, a list of dry wells, and a summary of laboratory analyses run on samples in fiscal year 2002.

Background information, including descriptions of regulatory requirements, waste sites, analytical methods, regional geology, and statistics is included in a separately-published companion volume, *Hanford Site Groundwater: Setting, Sources and Methods* (PNNL-13080), and in the most recent update, which was provided in PNNL-13788, Appendix C. Those changes have been incorporated into the electronic version of this groundwater monitoring report.

As in previous reports, the compact disk and Internet website contain groundwater data for the fiscal year and historical data for selected constituents.

1.2 Related Reports

Other reports and databases relating to Hanford Site groundwater in fiscal year 2002 include the following:

- *Hanford Site Environmental Report for Calendar Year 2001* (PNNL-13910) — This annual report summarizes environmental data, describes environmental management performance, and reports the status of compliance with environmental regulations. Topics include effluent monitoring, surface water and sediment surveillance, soil and vegetation sampling, vadose and groundwater monitoring, radiological surveys, air surveillance, and fish and wildlife surveillance.
- Hanford Environmental Information System (HEIS) — This is the main environmental database for the Hanford Site that stores groundwater chemistry data, as well as other environmental data (e.g., soil chemistry, survey data).
- Quarterly data transmittals — DOE transmits letters quarterly to the Washington State Department of Ecology after groundwater data collected for the RCRA program have been verified and evaluated. These letters describe changes or highlights of the quarter with reference to HEIS for the analytical results.
- *Fiscal Year 2001 Annual Summary Report for the 200-UP-1 and 200-ZP-1 Pump-and-Treat Operations* (DOE/RL-2001-53) — This report describes results of remediation and monitoring in two groundwater operable units in the 200 West Area.
- *Calendar Year 2001 Annual Summary Report for the 100-HR-3, 100-KR-4, and 100-NR-2 Operable Units and Pump-and-Treat Operations* (DOE/RL-2002-05) — This report describes results of remediation and monitoring in groundwater operable units in the 100-K, 100-N, 100-D, and 100-H Areas.
- *Fiscal Year 2001 Annual Summary Report for the In-Situ REDOX Manipulation Operations* (DOE/RL-2002-01) — This report describes activities related to the remediation system in the southwest 100-D Area.

Abbreviations and Acronyms

CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
DOE/RL	U.S. Department of Energy, Richland Operations Office
CERCLA	*Comprehensive Environmental Response, Compensation, and Liability Act*
DCG	derived concentration guide
DWS	drinking water standard
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
HEIS	Hanford Environmental Information System
MCL	maximum contaminant level
NAVD88	North American Vertical Datum of 1988
PUREX	Plutonium-Uranium Extraction (Plant)
RCRA	*Resource Conservation and Recovery Act*
ROD	Record of Decision
Tri-Party Agreement	Hanford Federal Facility Agreement and Consent Order
WAC	Washington Administrative Code

1.3 Groundwater Protection Program

The goal of the Groundwater Protection Program at the Hanford Site is to clean up groundwater contaminants, avoid future groundwater contamination, and prevent groundwater contaminants from migrating to the Columbia River. Fluor Hanford, Inc. manages the Groundwater Protection Program, formerly known as the Groundwater/Vadose Zone Integration Project, for DOE. The Hanford Groundwater Monitoring Project is under the umbrella of the Groundwater Protection Program.

To accelerate groundwater cleanup, the Groundwater Protection Program requires a strategy to contain and reduce contaminants in the Central Plateau. The Central Plateau includes the 200 East and 200 West Areas. Numerous facilities formerly used for producing nuclear materials, as well as Hanford's 177 underground tanks for storing high-level radioactive waste, are located in the 200 Areas.

Radionuclides and Their Half-Lives

Symbol	Radionuclide	Half-Lives
^{3}H	tritium	12.35 yr
^{14}C	carbon-14	5,730 yr
^{60}Co	cobalt-60	5.3 yr
^{90}Sr	strontium-90	28.8 yr
^{99}Tc	technetium-99	210,000 yr
^{106}Ru	ruthenium-106	358.2 d
^{129}I	iodine-129	6 million yr
^{137}Cs	cesium-137	30 yr
^{234}U	uranium-234	240,000 yr
^{239}Pu	plutonium-239	24,000 yr
^{240}Pu	plutonium-240	6,500 yr

DOE plans to eventually transition the Central Plateau to a safe and stable waste storage area. To achieve this goal, DOE must limit potential exposure to humans or the ecosystem from direct contact with contamination via the soil and groundwater.

The Groundwater Protection Program has five focus areas:

- isolating waste sites
- preventing water from moving contaminants through the soil
- shrinking the contaminated area
- resolving pump-and-treat operation issues
- integrating Hanford groundwater monitoring needs

The Groundwater Protection Program also is working to develop and apply technology that solves some of Hanford's toughest groundwater problems. In addition, the program performs site-wide assessments aimed at understanding contaminant behavior and associated risks. The program also manages Hanford's key environmental data systems.

Throughout its work, the Groundwater Protection Program will continually seek the active involvement of regulators, tribal governments, the state of Oregon, stakeholders, and the public.

1.4 Helpful Information

The companion volume to this report (PNNL-13080) describes techniques used to interpret the data and conventions for plotting. Contaminant plume maps in this report show data from fiscal years 2000 and 2001 if there were no new data for a well in fiscal year 2002. Wells that monitor plumes that change slowly are sampled every 3 years, so this convention allows us to see the most recent data. Trend plots in this report use open symbols to show levels of contaminants that were so low the laboratory could not detect them. These results are typically reported as a value that represents the detection limit of the analytical method or instrument and are flagged "undetected" in the database. Analytical results that appear to be erroneous remain on the plots if they do not distort the scale or obscure the data trends. If the outlying data distort the figure, they are not plotted. All of the data from fiscal year 2002 are included in the data files that accompany this report and in the HEIS database.

Units of Measure

µg/L	micrograms per liter
µS/cm	microsiemens per centimeter
mg/L	milligrams per liter
mm/yr	millimeters per year
pCi/g	picocuries per gram
pCi/L	picocuries per liter
pCi/mg	picocuries per milligram
ppb	parts per billion
ppm	parts per million
ppmv	parts per million volume

Nitrate and nitrite are expressed as the NO_3 and NO_2 ions. Figures showing chromium results include total chromium in filtered samples and hexavalent chromium in filtered or unfiltered samples. Dissolved chromium in Hanford Site groundwater is virtually all hexavalent, so filtered total chromium represents hexavalent chromium.

This report compares contaminant concentrations in groundwater with state or federally enforceable "maximum contaminant levels" and other limits for drinking water. Although Hanford Site groundwater is not generally used for drinking, these levels provide a useful indicator to provide perspective on contaminant concentrations. See Table 5.1 in PNNL-13080 for a complete list of updated standards.

Conversion Table

The primary units of measurement in this report are metric. To convert metric units to English units, use the information provided in this table.

Multiply	By	To Obtain
centimeters	0.394	inches
meters	3.28	feet
kilometers	0.621	miles
kilograms	2.205	pounds
liters	0.2642	gallons
square meters	10.76	square feet
hectares	2.47	acres
square kilometers	0.386	square miles
cubic meters	1.308	cubic yards
curie	3.7×10^{10}	becquerel
picocurie	0.03704	becquerel
rem	0.01	sievert
°C	(°C x 9/5) + 32	°F

Table 1.1-1. Regulated Units and Groundwater Operable Units on the Hanford Site

Site or Operable Unit	Type of Monitoring Program	Text	Influence on Groundwater[a]	Compliance Issues	FY 2002 Highlights
RCRA Units (well location maps, well/constituent tables, statistics tables, and flow rates in Appendix A)					
116-N-1 (1301-N) facility	Indicator evaluation	2.4.10	None	A.1.1	No CIP exceedance;[b] new monitoring plan
116-N-3 (1325-N) facility	Indicator evaluation	2.4.10	None	A.1.3	No CIP exceedance;[b] new monitoring plan
120-N-1, 120-N-2 (1324-N/NA) facilities	Indicator evaluation	2.4.11	None	A.1.2	No CIP exceedance;[b] new monitoring plan
116-H-6 (183-H) basins	Corrective action	2.6.8	2.6.2, 2.6.6	A.1.4	Monitoring during IRA. Chromium, nitrate, technetium-99, uranium.
216-A-29 ditch	Indicator evaluation	2.9.2.9	None	A.1.5	No CIP exceedance[b]
216-B-3 pond	Indicator evaluation	2.9.2.10	None	A.1.6	Revised monitoring plan; demonstration of alternative statistical method
216-B-63 trench	Indicator evaluation	2.9.1.11	None	A.1.7	No CIP exceedance;[b] new monitoring plan
216-S-10 pond and ditch	Indicator evaluation	2.8.4.9	None	A.1.8	No CIP exceedance;[b] one upgradient and one downgradient well remain; new monitoring plan
216-U-12 crib	Assessment	2.8.3.8	2.8.3	A.1.9	Continued assessment; two downgradient wells remain
316-5 process trenches	Corrective action	2.12.6	2.12.2, 2.12.4	A.1.10	Monitoring during natural attenuation IRA. New monitoring plan; demonstration of alternative statistical method.
LERF	Indicator evaluation	2.9.1.14	None	A.1.11	Insufficient wells; no statistical comparisons
LLWMA 1	Indicator evaluation	2.9.1.13	None	A.1.12	No CIP exceedance[b]
LLWMA 2	Indicator evaluation	2.9.1.13	None	A.1.13	No CIP exceedance; dry well
LLWMA 3	Indicator evaluation	2.8.2.13	None	A.1.14	No CIP exceedance;[b] dry wells
LLWMA 4	Indicator evaluation	2.8.1.6	None	A.1.15	No CIP exceedance;[b] two downgradient wells remain
NRDWL	Indicator evaluation	2.11.1.2	None	A.1.16	No CIP exceedance
PUREX cribs	Assessment	2.9.2.7	2.9.2.4	A.1.17	Continued assessment; nitrate. Dry well.
SST WMA A-AX	Indicator evaluation	2.9.2.8	None	A.1.18	No CIP exceedance;[b] revised monitoring plan
SST WMA B-BX-BY	Assessment	2.9.1.11	2.9.1	A.1.19	Continued assessment; nitrate, nitrite
SST WMA C	Indicator evaluation	2.9.1.15	None	A.1.20	New interpretation of flow; temporarily ceased CIP comparisons. Revised monitoring plan.
SST WMA S-SX	Assessment	2.8.4.9	2.8.4	A.1.21	Continued assessment; chromium, nitrate; revised monitoring plan. New assessment report.

Table 1.1-1. (contd)

Site or Operable Unit	Type of Monitoring Program	Text	Influence on Groundwater[a]	Compliance Issues	FY 2002 Highlights
SST WMA T	Assessment	2.8.2.11	2.8.2	A.1.22	Continued assessment; chromium, nitrate; revised monitoring plan. New assessment report.
SST WMA TX-TY	Assessment	2.8.2.12	2.8.2	A.1.23	Continued assessment; chromium, nitrate; revised monitoring plan. New assessment report.
SST WMA U	Assessment	2.8.3.9	2.8.3	A.1.24	Continued assessment; nitrate
Other Regulated Units (well location maps, well/constituent tables in Appendix A)					
100-K fuel storage basins	*Atomic Energy Act of 1954*	2.3.9	2.3.9	A.2.1	No leaks detected; new monitoring plan
200 Areas TEDF	WAC 173-216	2.9.2.11	None	A.2.2	No influence in upper aquifer
4608 B/C process ponds	WAC 173-216	2.10.4	None	A.2.3	No permit limits exceeded
ERDF	CERCLA	A.2.4	None	A.2.4	No permit limits exceeded in calendar year 2001
SALDS	WAC 173-216	2.8.2.14	2.8.2.14	A.2.6	No permit limits exceeded; tritium plume possibly reached 200 West boundary
SWL	WAC 173-304	2.11.1.3	2.11.1.3	A.2.5	6 constituents exceeded background or standards; low levels of organics
CERCLA Groundwater Operable Units					
100-BC-5	Long-term monitoring	2.2	2.2	A.3.1	Began to integrate CERCLA and *Atomic Energy Act of 1954* monitoring
100-FR-3	Long-term monitoring	2.7	2.7	A.3.2	Began to integrate CERCLA and *Atomic Energy Act of 1954* monitoring
100-HR-3 (D pump and treat)	IRA; interim ROD	2.5.6.1	2.5.2.1	A.3.3	Chromium > cleanup target; new extraction well
100-HR-3 (D redox site)	IRA; interim ROD	2.5.6.2	2.5.2.2	A.3.3	Chromium > cleanup target; new injections
100-HR-3 (H pump and treat)	IRA; interim ROD	2.6.7	2.6.2	A.3.3	Chromium > cleanup target
100-KR-4	IRA; interim ROD	2.3.9	2.3.2	A.3.4	Chromium > cleanup target
100-NR-2	IRA; interim ROD	2.4.9	2.4.2	A.3.5	No decrease in plume size
1100-EM-1	Natural attenuation; final ROD	2.13	2.13	A.3.11	TCE <5 in all wells
200-BP-5	Long-term monitoring	2.9.1	2.9.1	A.3.6	Data quality objectives report; began to integrate CERCLA and *Atomic Energy Act of 1954* monitoring

Table 1.1-1. (contd)

Site or Operable Unit	Type of Monitoring Program	Text	Influence on Groundwater[a]	Compliance Issues	FY 2002 Highlights
200-PO-1	Long-term monitoring	2.9.2	2.9.2	A.3.7	Data quality objectives report; began to integrate CERCLA and *Atomic Energy Act of 1954* monitoring
200-UP-1	Interim action ROD	2.8.3.7	2.8.3	A.3.8	Technetium-99 and uranium > cleanup goals
200-ZP-1	Interim action ROD	2.8.1.5	2.8.1	A.3.9	Heart of plume contained
300-FF-5 300 Area	Natural attenuation; interim ROD	2.12.7	2.12.2, 2.12.4	A.3.10	TCE levels decreasing
300-FF-5 north	Operations and Maintenance plan	2.12.7	2.12.7	A.3.10	618-10 soil-gas survey

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(a) Influence of the facility or site for constituents of interest (e.g., RCRA-regulated constituents, CERCLA constituents of concern).
(b) Analysis of CIP provided no evidence of groundwater contamination with hazardous constituents from the unit.

CERCLA = *Comprehensive Environmental Response, Compensation, and Liability Act.*
CIP = Contamination indicator parameters.
ERDF = Environmental Restoration Disposal Facility.
FY = Fiscal year.
IRA = Interim remedial action.
LERF = Liquid Effluent Retention Facility.
LLWMA = Low-Level Waste Management Area.
NRDWL = Nonradioactive Dangerous Waste Landfill.
PUREX = Plutonium-Uranium Extraction Plant.
RCRA = *Resource Conservation and Recovery Act.*
ROD = Record of decision.
SALDS = State-Approved Land Disposal Site.
SST = Single-shell tank.
SWL = Solid Waste Landfill.
TCE = Trichloroethene.
TEDF = Treated Effluent Disposal Facility.

2.0 Groundwater

Groundwater contamination at the Hanford Site is associated with a number of sources within its active and inactive operational areas. Liquid waste, discharged to the ground since the 1940s, percolated through the soil and in many locations reached the water table. Very little liquid waste is currently disposed to the soil, and cleanup of existing groundwater contamination by pump-and-treat systems, for example, is occurring at some sites.

This section describes groundwater flow and groundwater contamination in each of the major areas on the Hanford Site. Factors that affect the distribution, migration, and concentrations of groundwater contaminants include

- **Source History** – Groundwater contaminants at the Hanford Site originated from hundreds of disposal sites. These sites were used at different periods of time so the plumes were formed and are dissipating in different ways. In addition, plumes originating from many sources are affected by the discharge of uncontaminated or less contaminated water to nearby facilities.
- **Stratigraphy** – (a) The vadose zone and uppermost aquifer beneath the Hanford Site are made up of layers of different types of sediment. Groundwater tends to flow through sediment with higher permeability rather than less permeable units. (b) In some areas, the shallowest aquifer is connected to deeper aquifers, which could allow contaminants to move into deeper aquifers.
- **Declining Water Table** – This decline may affect contaminant concentrations, which may vary with depth.
- **Well Depth** – The depth of the well, the length of the screen, and the depth of the pump intake can affect contaminant concentrations in samples if concentrations vary with depth.
- **River Stage** – (a) The stage affects distribution and trends of contaminants at sites near the Columbia River by changing direction of flow in the aquifer. (b) High water may remobilize contaminants from the vadose zone or may dilute contaminants when river water flows into the aquifer.
- **Groundwater Remediation** – (a) Extraction and injection wells affect the direction of groundwater flow locally. This affects contaminant distribution and the ability to monitor other sites (e.g., *Resource Conservation and Recovery Act* [RCRA] units). (b) Treated water is injected back into the aquifer, but may contain residual contaminants or may dilute local groundwater.

This section discusses these factors, as applicable, for individual areas or waste sites in geographic order (north to south, west to east). The results of the monitoring program are discussed, as much as possible, in relation to source areas. In some cases, several potential sources such as cribs, trenches, or other disposal facilities may contribute to a particular groundwater plume, and their individual contributions cannot be readily distinguished. Therefore, they are discussed together. Monitoring of specific storage and disposal facilities, such as RCRA units, is reported within the sections on the geographical areas. The status of groundwater remediation under RCRA or the *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA) is discussed in the relevant sections.

Waste sites, hydrogeology, and methods of sampling and analysis are described in *Hanford Site Groundwater: Settings, Sources and Methods* (PNNL-13080). That document also explains how water-level and groundwater chemistry data were interpreted and mapped.

2.1 Overview of Hanford Site Groundwater

M. J. Hartman and J. P. McDonald

This section provides a broad picture of groundwater flow and contaminant distribution beneath the Hanford Site. Details for specific locations are included in Sections 2.2 through 2.14. Supporting information for *Resource Conservation and Recovery Act* (RCRA), *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA), and other regulated units is compiled in Appendix A. Appendix C contains a list of wells currently used to monitor groundwater at Hanford.

The Hanford Groundwater Monitoring Project sampled ~650 wells during fiscal year 2002. Iodine-129, nitrate, and tritium are the most widespread contaminants.

The uppermost aquifer beneath most of the Hanford Site is unconfined and is composed of unconsolidated to semiconsolidated sediment of the Hanford and Ringold formations, which were deposited on the basalt bedrock. In some areas, deeper parts of the aquifer are confined locally by layers of silt and clay. Confined aquifers occur within the underlying basalt and associated sedimentary interbeds.

2.1.1 Groundwater Flow

During March 2002, the Hanford Groundwater Monitoring Project (groundwater project) collected 880 water-level measurements across the Hanford Site. This section describes the results of a regional-scale analysis of these data for the unconfined aquifer, including a description of the water table for March 2002 and changes during the previous year.

Contour maps of water-level elevations indicate the general direction of groundwater movement. Water-level gradients, in conjunction with the hydraulic properties of the aquifer, are used to estimate the rate of groundwater flow.

DCP_0472

Groundwater monitoring relies on samples from wells across the Hanford Site. This photo shows the sampling vehicle and purgewater collection truck used to sample a groundwater well along the Columbia River.

Water-level data and water-level maps are used to support the calibration of groundwater flow models and to interpret groundwater sampling results. The unconfined aquifer is the primary focus of this section because it is the most likely groundwater pathway for migration of contaminants off the Hanford Site. However, measurements also are taken annually in the Ringold Formation confined aquifer (see Section 2.9.3), the upper basalt-confined aquifer system (see Section 2.14), and in the deep basalt aquifers to support groundwater modeling and to provide a data archive in the event that contamination is discovered in these systems. The *Water-Level Monitoring Plan for the Hanford Groundwater Monitoring Project* (PNNL-13021) contains a detailed description of water-level monitoring, including the methods of data collection and analysis.

Groundwater in the unconfined aquifer generally flows west to east beneath the Hanford Site and discharges to the Columbia River.

2.1.1.1 March 2002 Water Table

Figure 2.1-1 presents the current water-table map for the Hanford Site and outlying areas. The map was prepared using data from March 2002 and is intended to depict the average annual flow conditions in the aquifer for the entire year. The Columbia River represents the largest, short-term external stress on the water-table elevation. Discharge in the Columbia River during March is typically near the average annual discharge, so it is thought that March measurements will best depict average annual flow in the aquifer.

Groundwater in the unconfined aquifer flows from regions where the water-table elevation is high (recharge areas) west of the Hanford Site to regions where it is low (discharge areas) near the Columbia River (see Figure 2.1-1). Steep gradients occur in the west, east, and north regions of the site, while shallow gradients occur within and west of the 100-B/C Area, southeast of the 100-F Area, and in the central portion of the Hanford Site. This is largely due to differences in hydraulic conductivity and aquifer thickness. Gradients increase as the hydraulic conductivity of the sediment and/or the aquifer thickness decreases.

Recharge to the unconfined aquifer consists of

- infiltration of rain and snowmelt across the Hanford Site and at higher elevations, primarily in the Cold Creek and Dry Creek Valleys and the Rattlesnake Hills
- irrigation of offsite agricultural land in the Cold Creek Valley
- inflowing water from the Columbia River west of the 100-B/C Area and potentially southeast of the 100-F Area
- inflowing water from the Yakima River in the southeast portion of the Hanford Site
- discharge of water from deeper aquifers
- artificial recharge to the soil column (e.g., wastewater disposal, injection wells, broken water pipes)

The water table is relatively flat beneath the 200 East Area. Flow is affected by high permeability sediment at the water table.

Steep gradients north and east of the Columbia River (see Figure 2.1-1) are attributed to long-term artificial recharge associated with irrigation of agricultural land and sediments of low hydraulic conductivity. Regionally, water-table elevations decrease while approaching the Columbia River from either side, indicating that groundwater flow converges and ultimately discharges to the river.

North of Gable Butte and Gable Mountain, groundwater generally flows from west to east and discharges to the Columbia River. Groundwater enters this region through the gap between Gable Butte and Gable Mountain and the gap between Umtanum Ridge and Gable Butte. The Columbia River recharges the aquifer west of the 100-B/C Area.

An apparent groundwater mound exists ~2 kilometers north of Gable Mountain. Long before the Hanford Site was established, Jenkins (1922) reported elevated groundwater levels in this area that have persisted to the present. One possible source of recharge is past seasonal use of the Hanford irrigation canal, which traverses the groundwater mound area and was active between 1908 and 1943. Other potential sources of recharge include flow from the upper basalt-confined aquifer system and infiltration from surface runoff. The slow dissipation of the recharge water is attributed to the presence of a significant thickness of clay in the Ringold Formation sediment. There is insufficient information to distinguish whether the groundwater in this area is locally perched or is part of the regional, unconfined flow system.

Past wastewater discharges to the ground on the Hanford Site, primarily in the 200 West and 200 East Areas, resulted in groundwater mounding and significantly affected the flow of groundwater. These discharges had largely ceased by the mid-1990s. However, the effects of past discharges at U Pond and lesser discharges to other 200 West Area facilities are still apparent from the shape of the water-table contours passing through the 200 West Area. Currently, the mound in the 200 West Area is ~12 meters above the estimated pre-Hanford water table. Scientists predict that when equilibrium conditions are established, the water table may be ~5 to 7 meters higher than the pre-Hanford water table because of artificial recharge from offsite irrigation (PNNL-11801).

Groundwater flow in the central portion of the Hanford Site, encompassing the 200 East Area, is significantly affected by the presence of a buried Pleistocene flood channel, which lies in a northwest to southeast orientation (PNNL-12261). The water table in this area is relatively flat because of the presence of highly permeable sediment of the Hanford formation at the water table. Groundwater flow in this region also is significantly affected by the presence of low permeability sediment of the Ringold Formation at the water table east and northeast of the 200 East Area, as well as basalt above the water table. There is a groundwater mound associated with B Pond, where liquid waste was discharged to the ground until fiscal year 1997. Currently, the mound occurs mainly within the Ringold confined aquifer (see Section 2.9.3). The water table beneath the 200 East Area is ~2.4 meters higher than pre-Hanford conditions. Scientists estimate that when equilibrium conditions are established in the 200 East Area, the water table will be near its pre-Hanford elevation (PNNL-11801).

The elevation of the water table in the region between the Yakima and Columbia Rivers is lower than the Yakima River stage elevation, which is ~122 meters above mean sea level at Wanawish (formerly Horn Rapids) Dam. This implies that infiltration from the Yakima River recharges the Hanford/Ringold aquifer system in this area. During the summer, leakage from the Horn Rapids Ditch and Columbia Canal, which originate from the Yakima River at Wanawish Dam, and irrigation in areas east of the Yakima River also may recharge the Hanford/Ringold aquifer system. Operation of the Richland North Well Field recharge ponds results in a groundwater mound in the Richland North Area.

The water table continued to decline beneath the central Hanford Site in fiscal year 2002, causing twelve wells in the 200 Areas to go dry. Forty-five wells in the 200 Areas have gone dry since fiscal year 1998.

2.1.1.2 Water-Table Elevation Changes from March 2001 to March 2002

The water-table elevation continued to fall over much of the Hanford Site between March 2001 and March 2002 (Figure 2.1-2). This long-term decline is due to the reduction of wastewater discharges to the ground since the peak discharge in 1984. Over the 1-year period, the water-table elevation declined by an average of 0.19 meter in the 200 East Area and 0.36 meter in the 200 West Area.

The water-table elevation increased in a broad region adjacent to the Yakima River, probably because discharge in the Yakima River was higher than normal during 1995 through 2000. Water levels declined in the Cold Creek and Dry Creek Valleys. The water table in these areas is believed to respond to offsite irrigation practices.

The water-table elevation increased in the vicinity of the 300 Area and declined in the 100 Areas. These areas are along the Columbia River, where water levels are influenced by river stage fluctuations. The largest water-level increase in the unconfined aquifer (0.34 meter) occurred in well 3099-47-18B, along the Columbia River south of the 300 Area.

The water level has been increasing for the past several years in well 699-59-80B along the south side of Gable Butte. Between March 2001 and March 2002, the water level in this well increased 0.16 meter, which is a smaller increase than seen in previous years. The rate of increase from 1996 through 2001 averaged 0.46 meter per year, which is the fastest rate of increase since measurements began at this well in 1948. The cause of this increase remains unknown.

Changes in the water-table elevation also occurred beneath active facilities (e.g., the State-Approved Land Disposal Site, near the 200 West Area, and the Richland North Well Field) and within groundwater pump-and-treat areas. These changes are attributed to operation of these facilities. The largest water-level decline in the unconfined aquifer (1.19 meters) occurred in well 1199-39-16E at the Richland North Well Field.

2.1.2 Groundwater Contaminants

The major sources of groundwater contamination on the Hanford Site are former liquid waste facilities in the 100, 200, and 300 Areas.

During fiscal year 2002, groundwater project staff sampled ~650 wells for radiological and chemical constituents (see Appendix C for additional details). Many of the wells were sampled multiple times, for a total of 1,783 well trips. Chromium was the most frequently analyzed constituent – analyzed 1,756 times (see Appendix C). Anions, hexavalent chromium, iodine-129, metals, technetium-99, strontium-90, and volatile organic compounds were other commonly analyzed constituents. The data from many wells on the Hanford Site are used to meet the objectives of multiple regulations, including RCRA, CERCLA, and the *Atomic Energy Act of 1954*. Sampling and analysis are coordinated to avoid unnecessary costs. Well location maps are included in Sections 2.2 through 2.14 and in Appendix A for RCRA units and other sites regulated under the Washington Administrative Code.

Tritium, nitrate, and iodine-129 are the most widespread contaminants associated with past Hanford Site operations. Their distribution in the unconfined aquifer is shown in Figures 2.1-3, 2.1-4, and 2.1-5. The most prominent portions of these plumes originated at waste sites in the 200 Areas and spread toward the southeast. Nitrate and tritium also have significant sources in the 100 Areas.

Chromium contamination is widespread in several of the 100 Areas and extends into the surrounding 600 Area. Strontium-90 contamination is present in the 100 Areas, but the plumes are smaller. Other contaminant plumes include

- carbon tetrachloride and associated trichloroethene in the 200 West Area
- chromium in the 600 Area south of the 200 Areas
- technetium-99 and uranium that extend eastward from the 200 West Area
- technetium-99 and uranium with minor amounts of cyanide and cobalt-60 northwest of the 200 East Area
- uranium in the 300 Area

Several other constituents are detected outside the boundaries of the operational areas, but the contamination is clearly linked to operations in the specific areas and is discussed with the source areas. Table 2.1-1 lists contaminants and refers to the sections in this report where they are discussed. The table highlights contaminants that exceed water quality standards. Analytical results including fiscal year 2002 and historical data are included in the data files accompanying this report.

Available data indicate that the vast majority of contamination on the Hanford Site remains near the water table. Relatively few wells are completed deeper in the aquifer, but in most cases, these detect lower levels of contamination than their shallow counterparts. A confined aquifer in the Ringold sediment east of the 200 East Area is contaminated with tritium at levels near those in the unconfined aquifer. However, tritium levels drop sharply a short distance downgradient, as discussed in Section 2.9.3. Deeper still, in the upper basalt-confined aquifer, contamination has been detected in only two wells, both near the 200 East Area (see Section 2.14).

Groundwater in the unconfined aquifer on the Hanford Site discharges to the Columbia River. Some samples at the river shore contained contaminants at levels above drinking water standards. Concentrations in river water remained far below standards.

For site characterization and cleanup, waste sites are grouped into source operable units, and the groundwater beneath the sites is divided into groundwater operable units. For the purposes of this report and for data review and interpretation in fiscal year 2002, the groundwater project divides the Hanford Site into geographic areas of interest for groundwater monitoring. Figure 2.1-6 illustrates these areas of interest and the operable units boundaries.

A number of Hanford waste sites have specific RCRA monitoring requirements (see Appendix A, Figure A.1). The results of monitoring at these facilities are integrated into the following discussions, and specific RCRA reporting requirements, such as indicator parameter evaluations, are included as needed. Appendix A discusses issues related to regulatory compliance and describes results of statistical evaluations for RCRA monitoring requirements. Appendix A also summarizes analytical results for wells monitoring RCRA- and state-permitted facilities that exceeded maximum contaminant levels or drinking water standards.

2.1.3 Groundwater Remediation

The U.S. Department of Energy (DOE) is working to clean up groundwater contamination that may pose a risk to human health or the environment. DOE and regulators have determined that the final cleanup action at one groundwater operable unit (1100-EM-1) will be monitored attenuation of the contaminant plumes. At six other groundwater operable units, interim actions reduce the movement of contaminants until final cleanup decisions are made. At four operable units, there is no imminent threat to human health or the environment, so no interim remedial actions are required. These operable units include 100-BC-5 (100-B/C Area), 100-FR-3 (100-F Area), 200-BP-5, and 200-PO-1 (200 East Area). Waste sites and plumes will continue to be monitored until there are final records of decision, which may stipulate active remediation or rely on natural processes. Table 2.1-2 and the text below summarize the status of remediation in each operable unit with interim remediation. Additional detail is provided elsewhere in Chapter 2.

DOE is working to clean up groundwater contamination that may pose a risk to human health or the environment. Interim actions reduce the movement of contaminants until final cleanup decisions are made.

- **100-HR-3 (100-D and 100-H Areas) and 100-KR-4 (100-K Area)** – Chromium may pose a threat to aquatic organisms in the Columbia River. In the 100-K, 100-D, and 100-H Areas, pump-and-treat systems reduce the amount of chromium reaching the river. Also in the 100-D Area, an innovative treatment method immobilizes chromium in the aquifer. In fiscal year 2002, chromium concentrations at all these interim action sites remained above cleanup targets.
- **100-NR-2 (100-N Area)** – Strontium-90 concentrations remained much higher than the drinking water standard in wells at the river shore in fiscal year 2002. DOE has operated a pump-and-treat system for strontium-90 as an interim action since 1995.

- **200-UP-1 (200 West Area)** – DOE has operated an interim action pump-and-treat system in this operable unit since 1995. In fiscal year 2002, some concentrations of technetium-99 and uranium remained above target levels. Many of the wells monitoring this area have gone dry, so the size of the current plumes is uncertain.
- **200-ZP-1 (200 West Area)** – DOE has operated an interim action pump-and-treat system to prevent carbon tetrachloride from spreading since 1994. In fiscal year 2002, the system continued to limit migration of the heart of the plume.
- **300-FF-5 (300 Area and satellite areas to the north)** – The interim action for this operable unit involves natural attenuation of the cis-1,2-dichloroethene, trichloroethene, and uranium plumes. In fiscal year 2002, concentrations of the organic contaminants were low, but uranium remained elevated.

2.1.4 Monitoring at River Shoreline

DOE monitors and protects groundwater to keep Columbia River water safe for use. Some contaminants, including chromium, strontium-90, tritium, and uranium, flow from specific parts of the shoreline called springs or seeps. Springs or seeps are small areas where the groundwater meets the river. Just beyond the seeps in the river, contamination is diluted far below levels of concern for human or ecological health. The Washington State Department of Ecology and the U.S. Geological Survey both gave the Columbia River the highest rating for water quality – Class A, meaning "Excellent" – from the Grand Coulee Dam to the Washington-Oregon border. A Class A rating means that the Columbia River is suitable for all types of water supplies, fish and shellfish habitat, wildlife habitat, human recreational activities, and commerce and navigation. The Columbia River is the city of Richland's main source of drinking water. It consistently meets all state and federal drinking water standards.

Groundwater monitoring in the zone of groundwater/Columbia River interaction is accomplished by periodic sampling of (a) aquifer sampling tubes located along the low river-stage shoreline, (b) river-bank seepage, and (c) nearshore river water.

A zone of groundwater/river water interaction is created where groundwater approaches the Columbia River system. Rapidly varying hydraulic gradients, which are caused by river stage fluctuations, and the infiltration of river water into the banks and riverbed sediment, join to create a zone of dynamic physical, chemical, and biological processes.

Because of the length of time since plumes were created by former disposal practices, the portion of some plumes with the highest concentration of contaminants may already have migrated past the near-river environment and discharged into the Columbia River. Therefore, the concentrations currently seen in plumes associated with these sites represent the waning portions of the plumes. Contamination at the levels seen today are likely to persist for many years as the result of slow leaching of overlying contaminated vadose zone sites.

Monitoring water movement and chemical/radiological characteristics in the zone of interaction requires several approaches. The various types of sampling sites available are illustrated in Figure 2.1-7. They include near-river monitoring wells, aquifer sampling tubes, riverbank seepage sites, and riverbed sediment pore water sites. Aquifer sampling tubes are polyethylene tubes installed at various depths to monitor near the water table, at mid-depth in the aquifer, and near the bottom of the aquifer (BHI-01153). The tubes, seeps, and river are sampled annually.

Groundwater movement varies dramatically in response to daily river stage cycles. At times of very high river stage, flow is reversed and the infiltration of river water is great enough to dilute contaminant concentrations in groundwater approaching the river. Because of infiltrating river water, water quality characteristics in the banks and riverbed sediment vary with river stage fluctuations. Specific conductance, which is a measure of the dissolved salts in water, is used to differentiate river water (lower conductance) from groundwater (higher conductance). Investigations to date have revealed that some mixing and dilution of contaminants occurs at the interface between groundwater and the free-flowing stream of the river. Consequently, the maximum contaminant concentrations detected in near-river wells, aquifer sampling tubes, and riverbank seepage (see Table 2.1-1) may not represent the maximum concentration in groundwater that approaches the river.

Contaminant concentrations in shoreline samples in fiscal year 2002 generally agreed with concentrations detected in monitoring wells, while concentrations in Columbia River water remained very low. Five contaminants exceeded drinking water standards in shoreline samples:

- Tritium exceeded the 20,000-pCi/L standard at the 100-B/C, 100-N, and 100-D Areas and the Hanford town site.
- Nitrate exceeded the 45-mg/L standard at the 100-F Area.
- Chromium exceeded the 100-µg/L maximum contaminant level in the 100-D Area. It exceeded the 10-µg/L aquatic standard in each of the 100 Areas.
- Strontium-90 exceeded the 8-pCi/L standard near the shore at the 100-B/C and 100-N Areas.
- Uranium exceeded the 30-µg/L standard at the shoreline in 300 Area.

Table 2.1-1. Maximum Concentrations of Groundwater Contaminants in Fiscal Year 2002

Contaminant (alphabetical order)	DWS or MCL [DCG][a]	Units	100-B/C Section 2.2		100-K Section 2.3		100-N Section 2.4		100-D Section 2.5		100-H Section 2.6		100-F Section 2.7		200 West Section 2.8
			Wells	Shore[b]	Wells	Shore[b]	Wells	Shore[b]	Wells	Shore[b]	Wells	Shore[b]	Wells	Shore	Wells
Carbon tetrachloride	5	µg/L													**6,900**
Carbon-14	2,000 [70,000]	pCi/L			**12,900**	ND									
Cesium-137	200 [3,000]	pCi/L													ND
Chloroform	100	µg/L													**680**
Chromium (dissolved)	100	µg/L	30	39	**1,310**	59	**170**	36[c]	**5,660**	**335**	**149**	46	98	18	**381**
Cobalt-60	100 [5,000]	pCi/L					37								
Cyanide	200	µg/L													
cis-1,2-Dichloroethene	70	µg/L													
Fluoride	4	mg/L													**4.4**
Gross alpha	15	pCi/L													**570**
Gross beta	50	pCi/L	**81**	41	**4,500**	5.5	**9,310**	**3,450**	**401**	3.5	**142**	14.5	**63**	9.4	**33,900**
Iodine-129	1 [500]	pCi/L													**32**
Nitrate (as NO_3^-)	45	mg/L	18.6	13.3	**94**	14	**75.9**	43.4	**90**	7.5	**87**	6.6	**106**	**56**	**1,740**
Nitrite (as NO_2^-)	3.3	mg/L							**9.9**						**7.6**
Plutonium	NA [30]	pCi/L													
Strontium-90	8 [1,000]	pCi/L	**39**	**12.8**	***2,100***		***18,500***	***4,810***	**13**		**38**	3.8	**33**	ND	**76**
Technetium-99	900 [100,000]	pCi/L			110	62					243				**99,700**
Trichloroethene	5	µg/L			**11**	2.7							**18**		**16**
Tritium	20,000 [2,000,000]	pCi/L	**30,600**	**45,000**	**588,000**	5,150	**39,300**	**21,500**	16,300	29,400	6,400	1,245	3,800	1,470	**1,690,000**
Uranium[d]	30 [790]	µg/L									23				***3,110***

Table 2.1-1. (contd)

Contaminant (alphabetical order)	DWS or MCL [DCG][a]	Units	200 East Section 2.9 Wells	200 East Section 2.9 Shore[b]	400 Section 2.10 Wells	600 Section 2.11 Wells	300 Section 2.12 Wells	300 Section 2.12 Shore[b]	300-FF-5 Section 2.12.7 Wells	Richland North Section 2.13 Wells
Carbon tetrachloride	5	µg/L				ND				
Carbon-14	2,000 [70,000]	pCi/L								
Cesium-137	200 [3,000]	pCi/L	**1,910**[e]							
Chloroform	100	µg/L				4.0				
Chromium (dissolved)	100	µg/L	**1,000**							
Cobalt-60	100 [5,000]	pCi/L	48.5							
Cyanide	200	µg/L	**321**							
cis-1,2-Dichloroethene	70	µg/L				ND	**160**			**92**[f]
Fluoride	4	mg/L								**4.1**[f]
Gross alpha	15	pCi/L	**241**				**45**			**95**[f]
Gross beta	50	pCi/L	**3,740**				**66**		20	40[f]
Iodine-129	1 [500]	pCi/L	**11.2**							
Nitrate (as NO_3^-)	45	mg/L	**611**	23	**81**	16.4	**90**			**251**[f]
Nitrite (as NO_2^-)	3.3	mg/L			0.29	ND				
Plutonium	NA [30]	pCi/L	***63***[e]							
Strontium-90	8 [1,000]	pCi/L	***11,900***[e]				3.6			
Technetium-99	900 [100,000]	pCi/L	**10,500**							
Trichloroethene	5	µg/L				0.97	4.3			3.5
Tritium	20,000 [2,000,000]	pCi/L	***4,170,000***	**58,400**	13,000		12,100		***4,230,000***	432
Uranium[d]	30 [790]	µg/L	**391**				**141**		15	15

Note: Table lists highest concentration for fiscal year 2002 in each geographic region. Concentrations in **bold** exceed drinking water standards. Concentrations in ***bold italic*** exceed DOE derived concentration guides. Blank spaces indicate the constituent is not of concern in the given area.

(a) DWS = drinking water standard; MCL = maximum contaminant level; DCG = DOE derived concentration guide. See PNNL-13080 for more information on these standards.

(b) Shoreline sampling includes aquifer sampling tubes, seeps, and shoreline wells from fall 2001. 200 East Area plumes monitored at the Hanford town site.

(c) Aquifer tube between 100-K and 100-N Areas.

(d) Uranium standard of 30 µg/L becomes effective December 2003.

(e) Wells with highest concentrations not sampled in fiscal year 2002. Fiscal year 2001 values listed.

(f) From offsite contaminant source.

ND = Not detected.

Table 2.1-2. Summary of Groundwater Remediation

Location	Startup Date	Contaminant	Objectives	Progress at End of Fiscal Year 2002
100-K Area (100-KR-4 Pump-and-Treat)	1997	Hexavalent chromium	(a) Protect aquatic receptors in the river bottom substrate from contaminants in groundwater entering the Columbia River; (b) Protect human health by preventing exposure to contaminants in the groundwater; and (c) Provide information that will lead to the final remedy (ROD 1996a).	Decreases chromium to river; 175 kilograms removed, 1,559 million liters treated since startup.
100-N Area (100-NR-2 Pump-and-Treat)	1995	Strontium-90	(a) Reduce strontium-90 contaminant flux from the groundwater to the Columbia River; (b) Evaluate commercially available treatment options for strontium-90; and (c) Provide data necessary to set demonstrable strontium-90 groundwater cleanup standards (Ecology and EPA 1994; ROD 1999a).	Diverts strontium-90 from river; insignificant aquifer cleanup; 1.3 curies removed, 755 million liters treated, ~12 curies naturally decayed since 1996.
100-D Area (100-HR-3 Pump-and-Treat)	1997	Hexavalent chromium	(a) Protect aquatic receptors in the river bottom substrate from contaminants in groundwater entering the Columbia River; (b) Protect human health by preventing exposure to contaminants in the groundwater; and (c) Provide information that will lead to the final remedy (ROD 1996a).	Two additional extraction wells added; decreases chromium to river; 120 kilograms removed, 679 million liters treated since startup.
100-D Area (100-HR-3 In Situ Redox)	1999	Hexavalent chromium	(a) Protect aquatic receptors in the river substrate from contamination in groundwater entering the Columbia River; (b) Protect human health by preventing exposure to contaminants in the groundwater; and (c) Provide information that will lead to the final remedy (ROD 1999b).	Barrier extended to 590 meters; decreases chromium concentration downgradient of barrier.
100-H Area (100-HR-3 Pump-and-Treat)	1997	Hexavalent chromium	(a) Protect aquatic receptors in the river bottom substrate from contaminants in groundwater entering the Columbia River; (b) Protect human health by preventing exposure to contaminants in the groundwater; and (c) Provide information that will lead to the final remedy (ROD 1996a).	Decreases chromium to river; 34 kilograms removed, 750 million liters treated since startup; overall decrease in concentrations.
200 West Area (200-ZP-1 Pump-and-Treat)	1994	Carbon tetrachloride	(a) Prevent further movement of contaminants from the highest concentration area of the plume (i.e., carbon tetrachloride inside the 2,000- to 3,000-µg/L contour); (b) Reduce contamination in in area of highest carbon tetrachloride concentrations; and (c) Provide information that will lead to a final remedy (ROD 1995).	Prevents high-concentration portion of plume from spreading; 6,874 kilograms removed, 1,891 million liters treated since startup; heart of plume contained.

Table 2.1-2. (contd)

Location	Startup Date	Contaminant	Objectives	Progress at End of Fiscal Year 2002
200 West Area (Soil-Vapor Extraction)	1992	Carbon tetrachloride	Not applicable	77,800 kilograms removed since startup; concentrations decreased, preventing movement to groundwater.
200 West Area (200-UP-1 Pump-and-Treat)	1995	Carbon tetrachloride	(a) Reduce contamination in areas of highest concentration to below 480 µg/L for uranium, and 9,000 pCi/L for technetium-99; (b) Reduce potential human health risks through reduction of contaminant mass; (c) Prevent further movement of contaminants from the highest concentration area; and (d) Provide information that will lead to a final remedy (ROD 1997).	23 kilograms removed; 609 million liters treated since startup.
		Nitrate		23,200 kilograms removed since startup.
		Technetium-99		90 grams removed since startup; concentrations at remedial action objective in extraction well.
		Uranium		158 grams removed since startup; concentrations remained above remedial action objective.
300 Area (300-FF-5)	Not applicable	Uranium and chlorinated hydrocarbons	(a) Monitor contaminants above health-based risk levels to ensure that concentrations continue to decrease and (b) Implement institutional controls to ensure that groundwater use is restricted to prevent unacceptable exposures (ROD 1996b).	Uranium above and trichloroethene below health-based levels. Work in progress to determine trends in levels.
Richland North Area (1100-EM-1)	Not applicable	Volatile organic compounds	(a) Attain trichloroethene concentrations <5 µg/L at point of compliance and (b) Protect environmental receptors in surface water by reducing groundwater concentrations to safe levels (ROD 1993).	Trichloroethene <5 µg/L at compliance point. Monitoring trends.

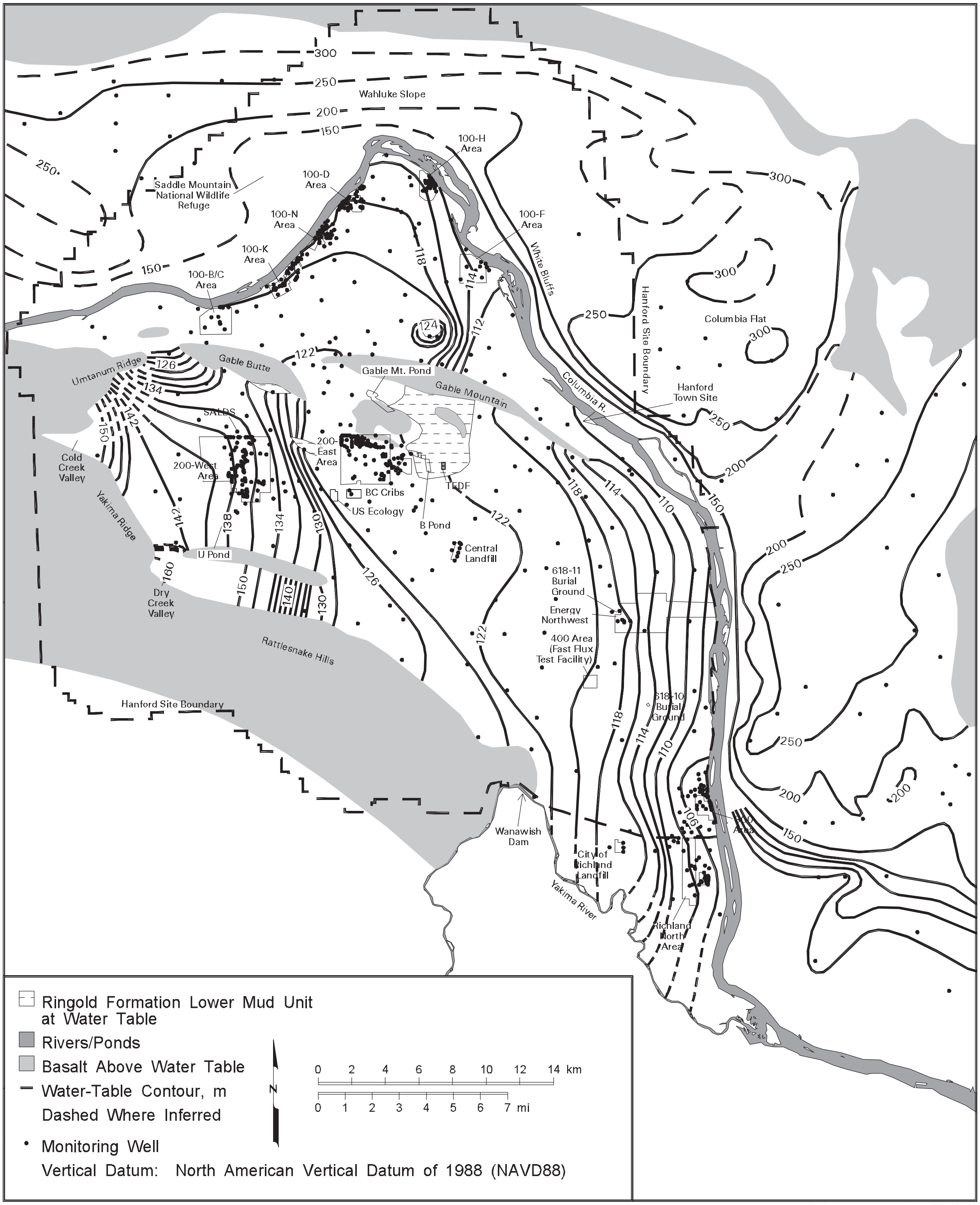

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Figure 2.1-1. Hanford Site and Outlying Areas Water-Table Map, March 2002

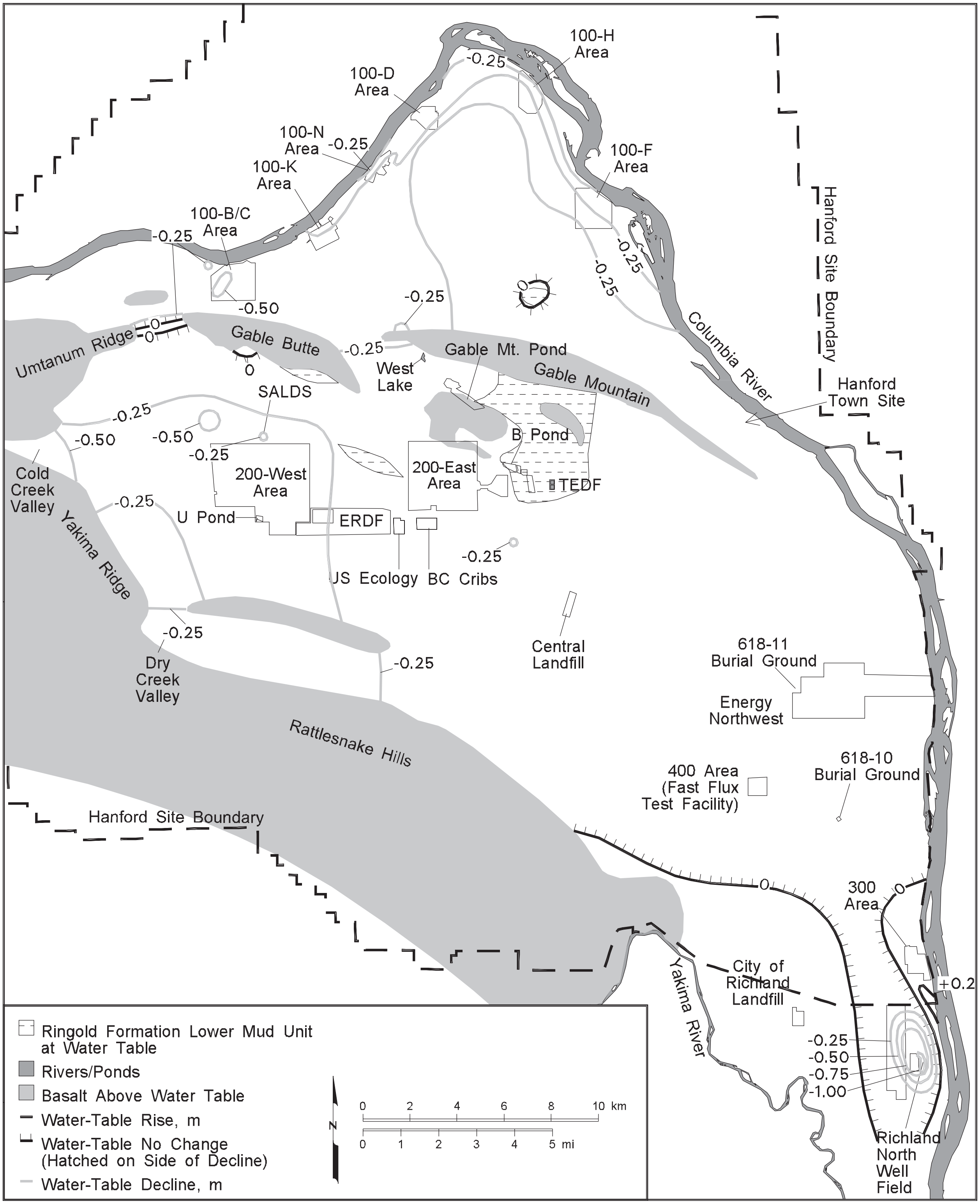

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Figure 2.1-2. Changes in Water-Table Elevations Between March 2001 and March 2002

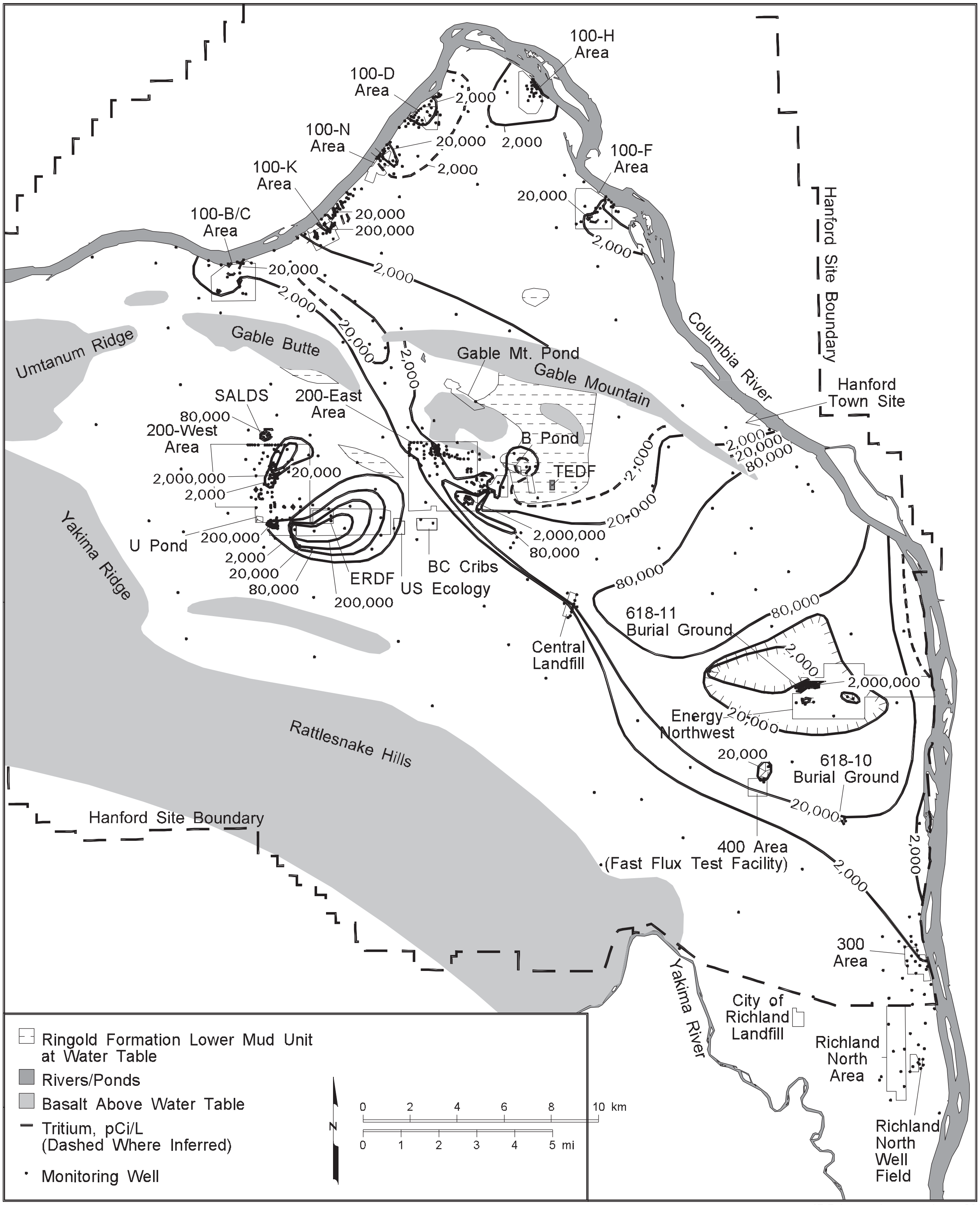

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Figure 2.1-3. Average Tritium Concentrations on the Hanford Site, Top of Unconfined Aquifer

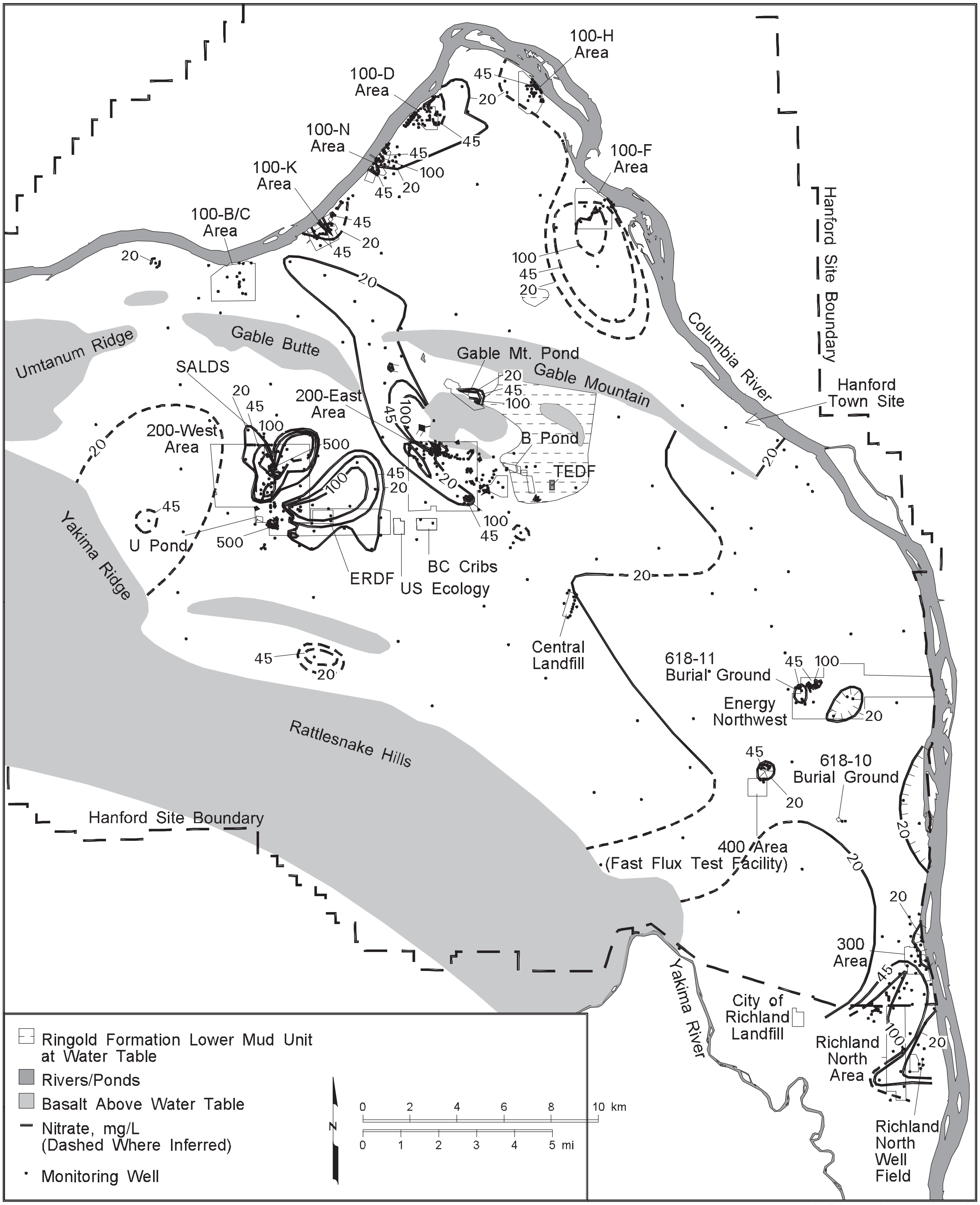

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Figure 2.1-4. Average Nitrate Concentrations on the Hanford Site, Top of Unconfined Aquifer

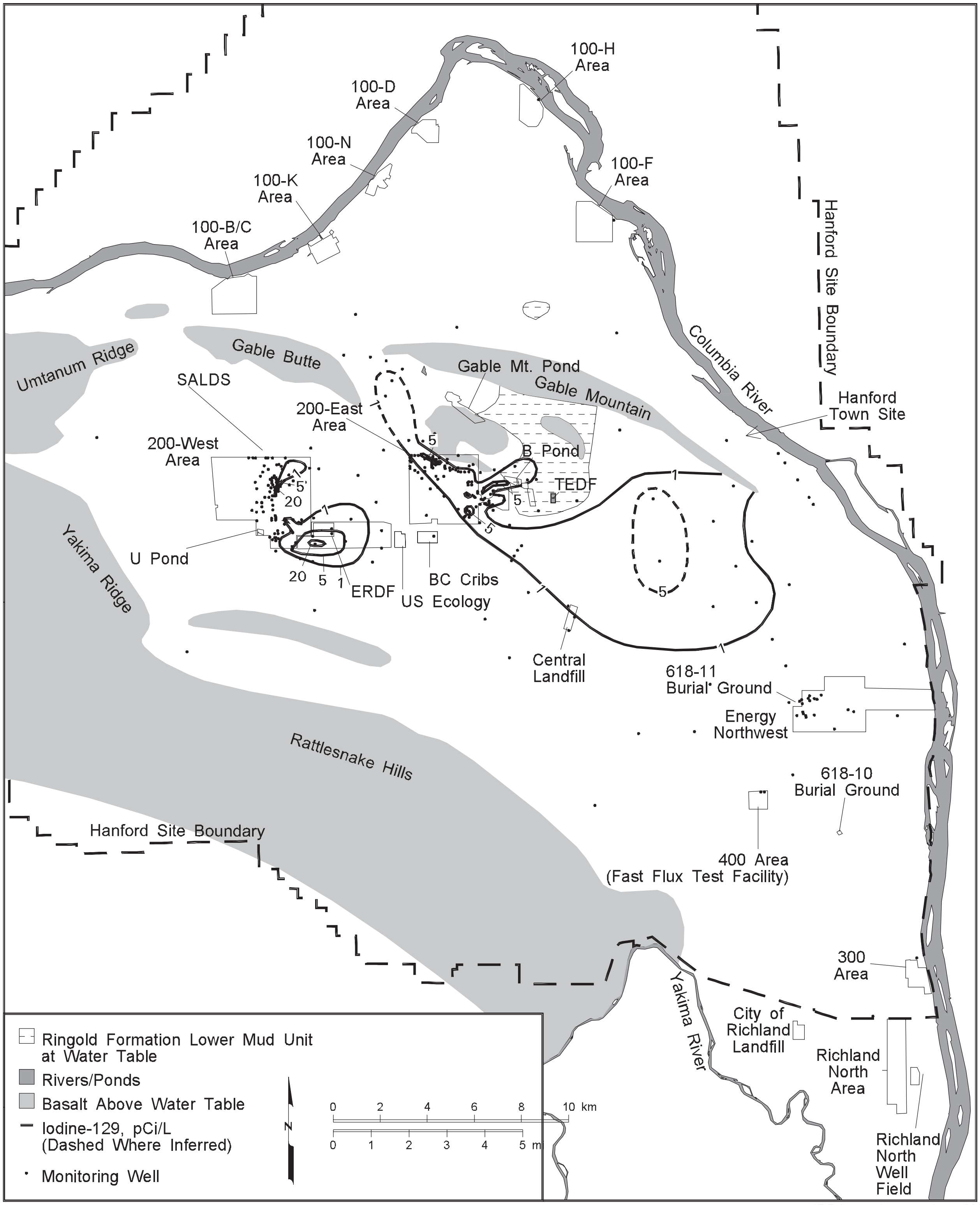

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Figure 2.1-5. Average Iodine-129 Concentrations on the Hanford Site, Top of Unconfined Aquifer

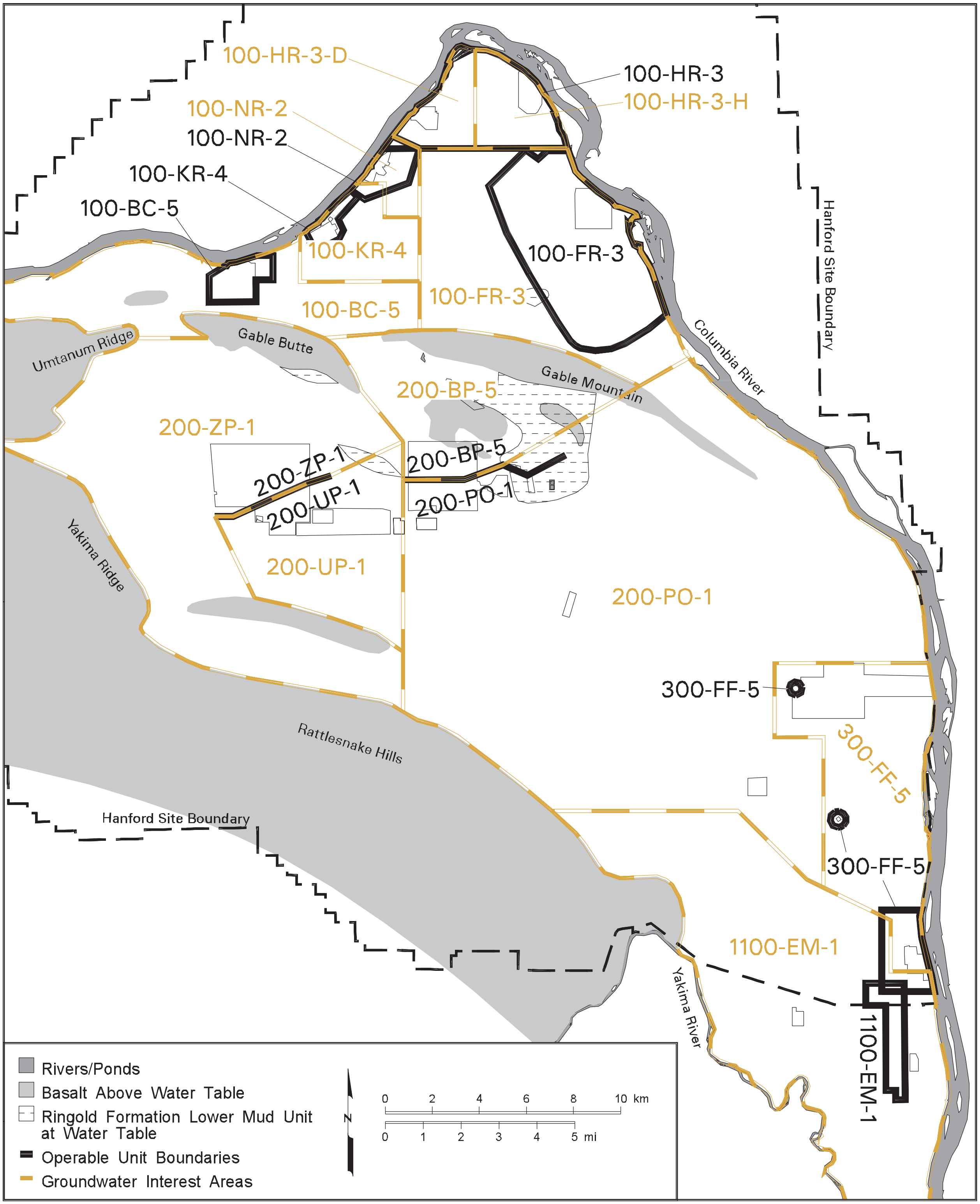

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Figure 2.1-6. Groundwater Operable Units and Groundwater Interest Areas on the Hanford Site

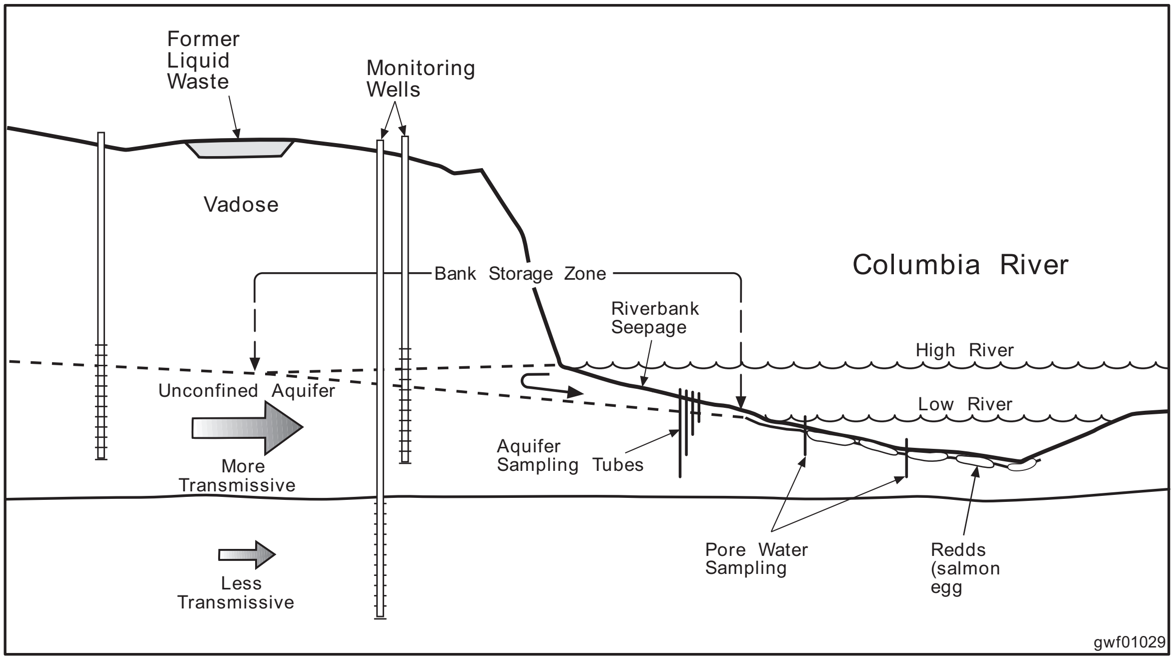

Figure 2.1-7. Principal Features of Groundwater/Columbia River Zone of Interaction

2.2 100-B/C Area

M. D. Sweeney and M. J. Hartman

Strontium-90 and tritium exceeded drinking water standards in groundwater at the 100-B/C Area in fiscal year 2002.

The 100-B/C Area is the reactor area farthest upstream along the Columbia River. B Reactor was placed in service in 1944 and operated until 1968. C Reactor operated from 1952 to 1969. The B and C Reactors used a single-pass system for cooling water (i.e., cooling water passed through the reactor and was eventually discharged to the Columbia River). Groundwater contaminants in this area include nitrate, tritium, strontium-90, and chromium. The contaminants are not widespread at levels above drinking water standards. Fiscal year 2002 results indicate that contamination concentrations continue to decline throughout the 100-B/C Area.

Groundwater in the 100-B/C Area is part of the 100-BC-5 Operable Unit. Planning is underway to integrate monitoring for *Comprehensive Environmental Response, Compensation, and Liability Act* and the *Atomic Energy Act of 1954*. Figure 2.2-1 shows the location of monitoring wells in the 100-B/C Area. Some wells in the 600 Area also are monitored near the 100-B/C Area and are shown in Figure 2.2-2.

2.2.1 Groundwater Flow

Groundwater flow within the unconfined aquifer was north toward the Columbia River in March 2002 (Figure 2.2-3). The average gradient between

02040098-42cn

The environmental restoration contractor continued to excavate waste sites in the 100-B/C Area, shown above. Contaminated soil was removed and disposed in the Environmental Restoration Disposal Facility. Remediation of these sites lessens the potential for contamination to reach the river.

C Reactor and the Columbia River was ~0.001 in March 2001. The hydraulic conductivity of the unconfined aquifer in the 100-B/C Area ranges from 4.3 to 17 meters per day (BHI-00917). Using these values and an effective porosity of 0.1 to 0.3, the flow rate ranges from 0.014 to 0.17 meter per day.

2.2.2 Nitrate

Nitrate concentrations in groundwater are lower in the 100-B/C Area than in the other reactor areas, generally <20 mg/L. The maximum concentration was 18.6 mg/L in well 199-B3-47, near the Columbia River, a decrease from fiscal year 2001. Levels declined in nearly all wells.

2.2.3 Tritium

Monitoring Objective in 100-B/C Area

Groundwater monitoring is conducted in the 100-B/C Area biannually to annually to describe the nature and extent of contamination.

Tritium exceeded the 20,000-pCi/L drinking water standard in two wells in the 100-B/C Area in fiscal year 2002. The distribution of tritium indicates that tritium had multiple sources within the 100-B/C Area (Figure 2.2-4).

Wells in various parts of the 100-B/C Area showed tritium peaks in the mid-to-late 1990s and decreased since then (Figures 2.2-5 and 2.2-6). The peaks in wells in the central and north 100-B/C Area could represent drainage from the vadose zone beneath liquid waste sites near the reactor buildings or near the Columbia River. However, well 199-B8-6, located in the southwest 100-B/C Area, also shows a peak in tritium concentration at about the same time.

East of the 100-B/C Area, tritium declined in fiscal year 2002 in well 699-72-73, after rising above the drinking water standard in fiscal year 2001 (Figure 2.2-7). The source of this tritium is believed to be waste sites in the 200 East Area. The plume has migrated between Gable Butte and Gable Mountain.

2.2.4 Strontium-90

Strontium-90 contamination had sources near the B Reactor building and at retention basins and disposal trenches near the Columbia River. The plume has not changed significantly in recent years.

Five wells in the 100-B/C Area continued to exceed the 8-pCi/L drinking water standard for strontium-90. The contaminant sources were in two distinct regions in the 100-B/C Area that has subsequently merged to form a single plume extending from B Reactor north to the Columbia River. The maximum concentrations were 38 to 39 pCi/L in wells near the 116-B-1 and 116-C-1 trenches (Figure 2.2-8). Concentrations in all wells are variable or declining.

2.2.5 Chromium

Hexavalent chromium was a minor contaminant in the 100-B/C Area groundwater in the past. However, concentrations have been declining in recent years. During the last three fiscal years, all concentrations were below the maximum contaminant level of 100 μg/L. The highest concentration in fiscal year 2002 was 30 μg/L in well 199-B3-47.

2.2.6 Waste Site Remediation

The environmental restoration contractor continued to excavate waste sites in the 100-B/C Area in fiscal year 2002. Contaminated soil was disposed in the 200 Areas Environmental Restoration Disposal Facility, and the sites were backfilled with clean soil. Remediation of these sites lessens the potential for movement of contaminants from the sediment to groundwater in the future. Sites excavated or backfilled in fiscal year 2002 are listed in Table 2.2-1.

Water (obtained from fire hydrants) was applied as necessary to control dust. Application of water was held to the minimum amount necessary for worker safety and preventing airborne dispersal of contaminants.

2.2.7 Monitoring at River Shoreline

Groundwater near the Columbia River is sampled annually in the late fall via aquifer sampling tubes and riverbank seeps. The sampling tubes are polyethylene tubes that were installed in the aquifer at locations near the low water shoreline. Seeps are natural areas of groundwater discharge above the water line.

At the 100-B/C Area, tritium concentrations at one aquifer tube exceeded the drinking water standard. At the other shoreline sampling points, tritium concentrations were well below the drinking water standard.

Two aquifer tubes and two seeps were sampled in the 100-B/C Area in fiscal year 2002 (Table 2.2-2). Samples from one of the aquifer tubes, 06-M, exceeded the drinking water standard for strontium-90 in fiscal year 2002, at 12.8 pCi/L. The specific conductance of the sample was 410 µS/cm, indicating the groundwater was relatively undiluted with river water. Tube 06-M is located downgradient of waste sites in the north 100-B/C Area that have strontium-90 contaminated groundwater.

The tritium concentrations in aquifer tube 06-M (45,000 pCi/L) also exceeded the drinking water standards (20,000 pCi/L), and was higher than fiscal year 2002 samples from groundwater (see Figure 2.2-4). Chromium was elevated (39 µg/L) but did not exceed the maximum contaminant level.

The two seeps that were sampled are located outside of the groundwater contaminant plumes. Contaminant concentrations in the seeps were low or undetected (see Table 2.2-2).

Table 2.2-1. 100-B/C Area Waste Sites Remediated in Fiscal Year 2002

Waste Site Designation	Fiscal Year Excavated	Fiscal Year Backfilled	Maximum Depth of Excavation (m)
132-C-2 Outfall	2001	2002	~8.5
132-B-6 Outfall	2001	2002	~7
116-B-7 Outfall	2001	2002	~8.8
100-B-8 Pipeline	2001-2004	2004-2005[a]	>8
100-C-6 Pipeline	2001-2004	2004-2005[a]	>8
100 B-12 Filter Box	2001	NA	Surface

(a) Projected.
NA = Not applicable.

Table 2.2-2. Shoreline Monitoring Data for the 100-B/C Area, Fiscal Year 2002

Location Name	Sample From[a]	Sample Date	Specific Conductance (µS/cm)[b]	Chromium (µg/L)[c]	Gross Beta (pCi/L)	Nitrate (mg/L)	Strontium-90 (pCi/L)	Tritium (pCi/L)
04-S	Tube	11/28/01	366	9	7.5		0.027 U	6,760
06-M	Tube	11/26/01	410	39	41.3		12.8	45,000
SB-037-1	Seep	10/22/01	355	9	7.4	13.3	0.0696 U	7,990
SB-037-1	Seep	09/16/02	304		5.7	9.7	-0.00188 U	4,330
SB-038-3	Seep	10/22/01	347	11	23.9	6.6	0.0134 U	6,380

U = Below detection limit.
(a) Tube = aquifer sampling tube near shoreline; Seep = riverbank seepage.
(b) Specific conductance provides an indication of the amount of river water in the sample; uncontaminated groundwater is typically in the range of 350 to 450 µS/cm and river water in the range of 120 to 150 µS/cm.
(c) Chromium includes hexavalent chromium and total chromium for filtered samples.
Data sources: Hanford Environmental Information System and various project records.

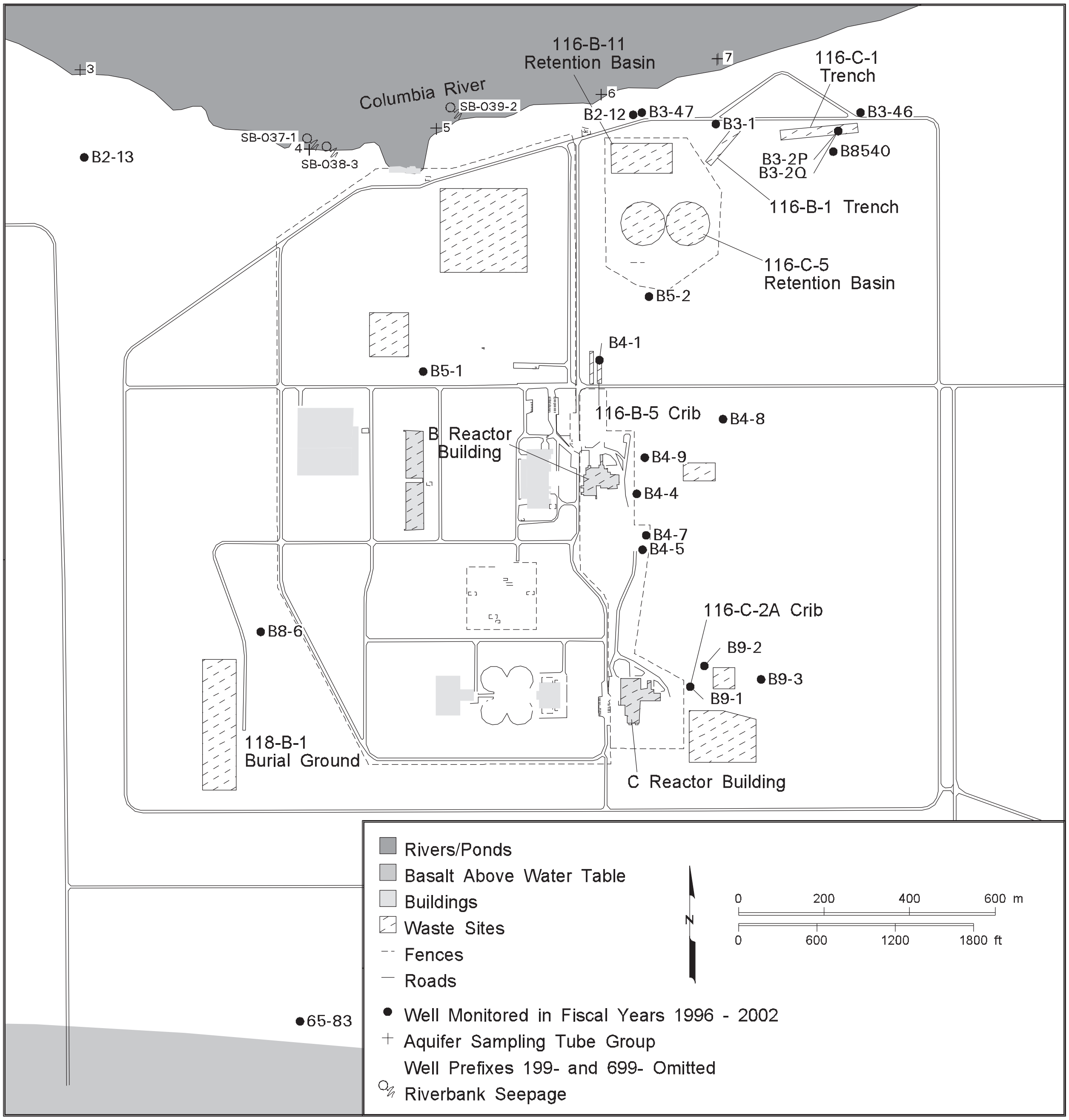

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Figure 2.2-1. Groundwater Monitoring Wells in the 100-B/C Area

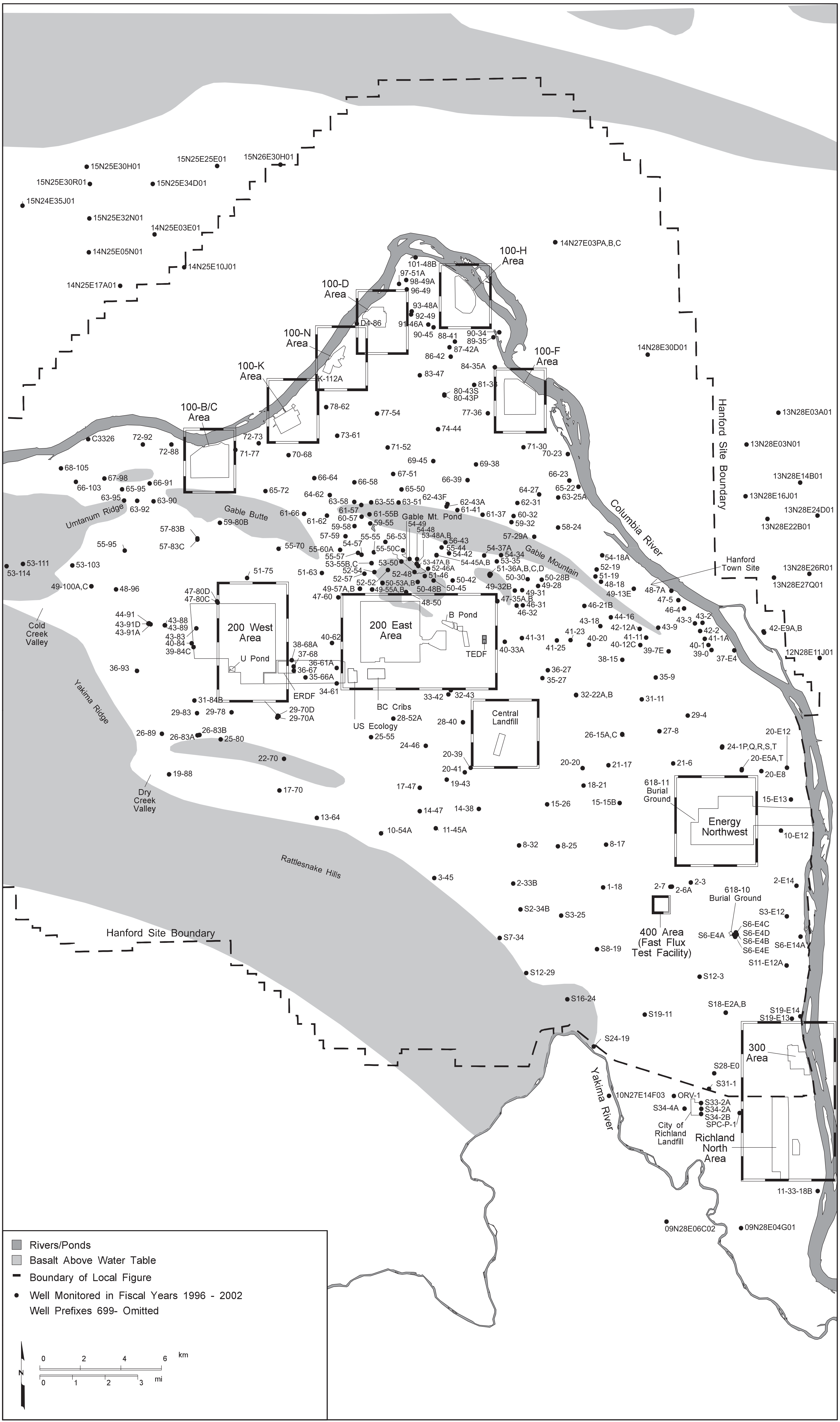

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Figure 2.2-2. Groundwater Monitoring Wells in the 600 Area

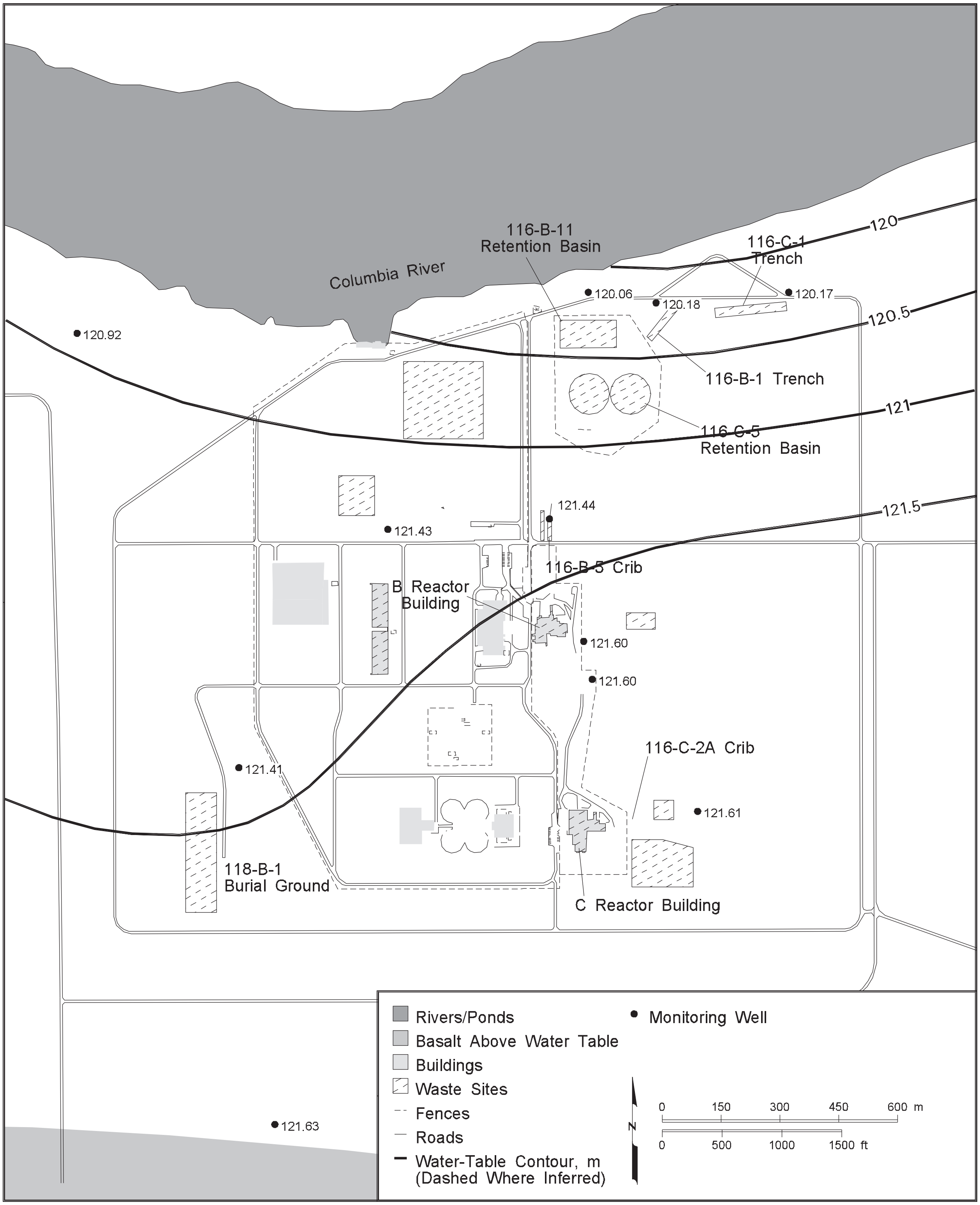

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Figure 2.2-3. 100-B/C Water-Table Map, March 2002

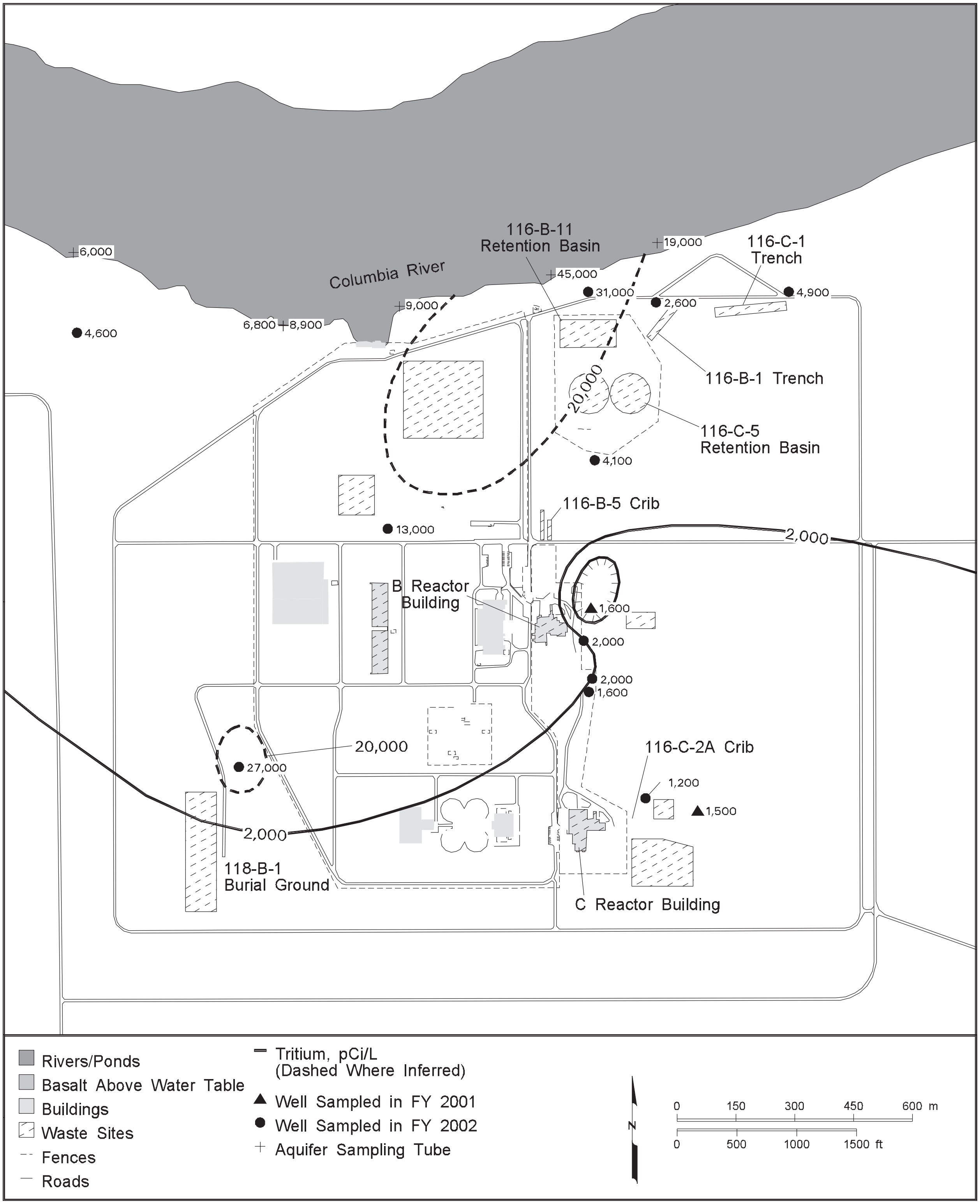

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Figure 2.2-4. Average Tritium Concentrations in the 100-B/C Area, Top of Unconfined Aquifer

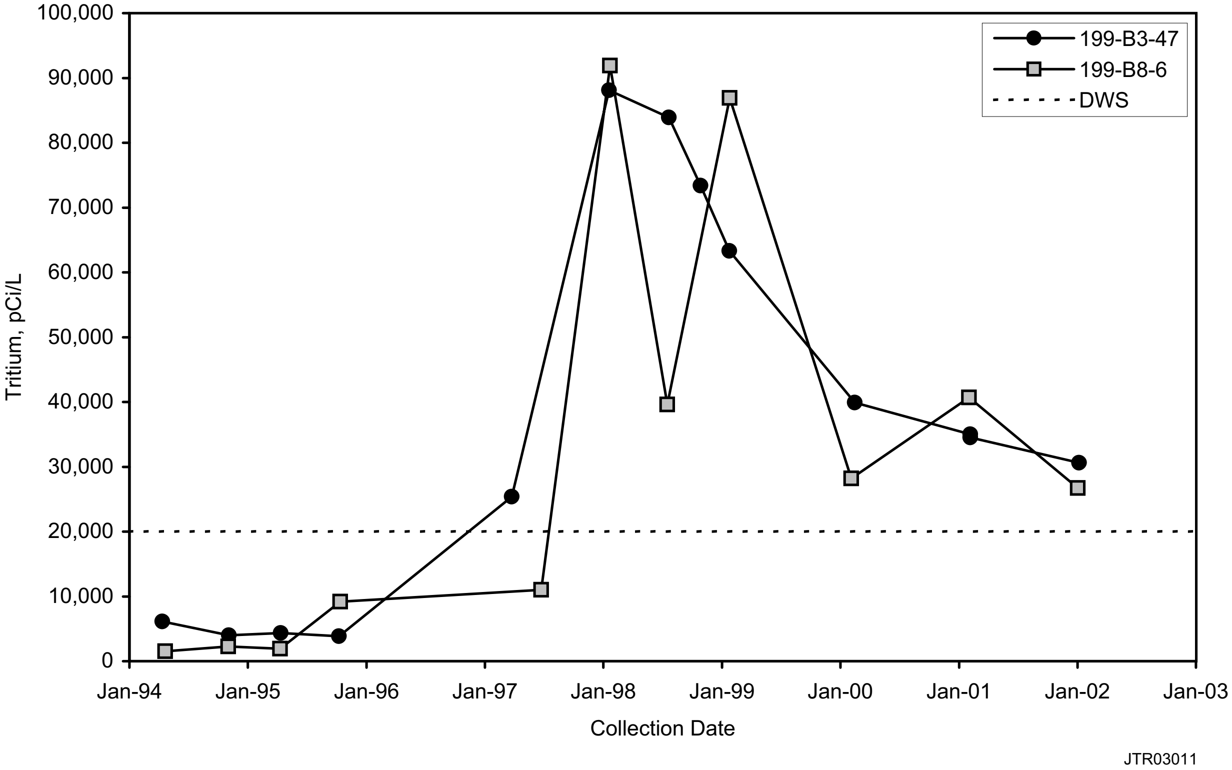

Figure 2.2-5. Tritium Concentrations in Well 199-B3-47, Near 116-B-11 Retention Basin, and Well 199-B8-6, Near 118-B-1 Burial Ground

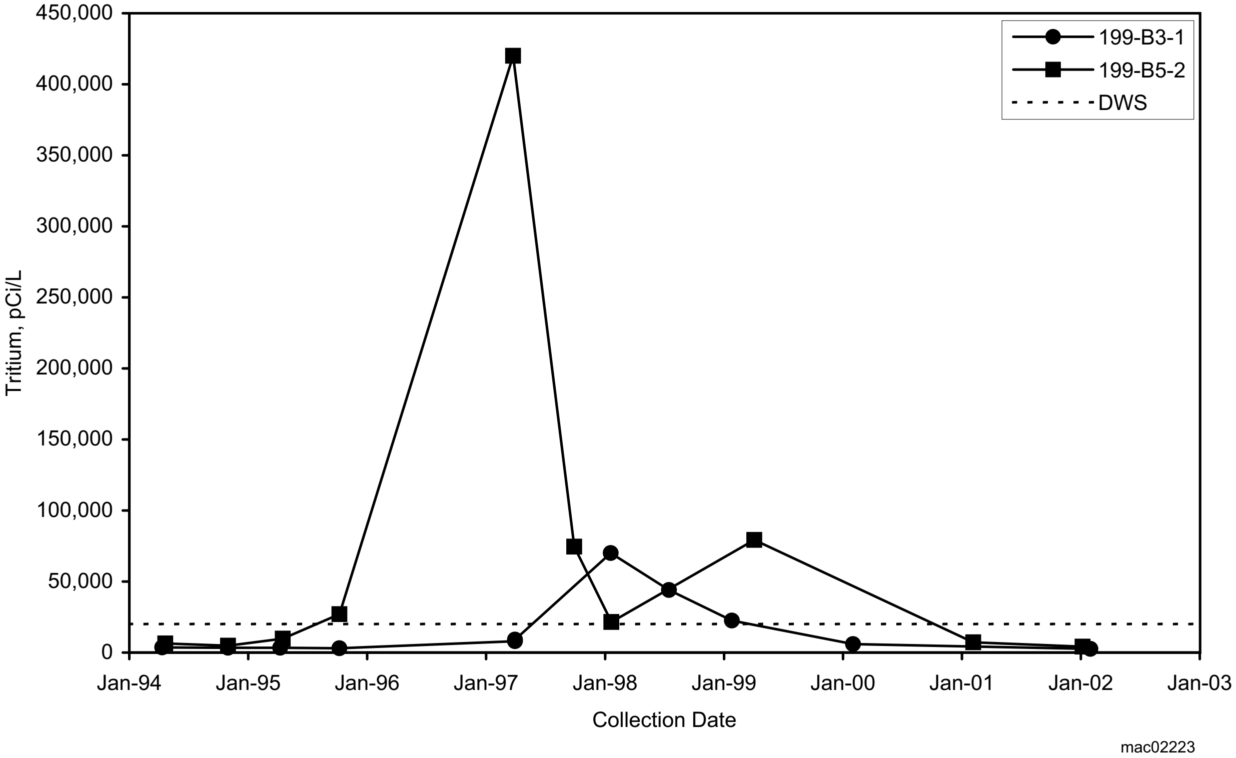

Figure 2.2-6. Tritium Concentrations in Wells in the Northeast 100-B/C Area

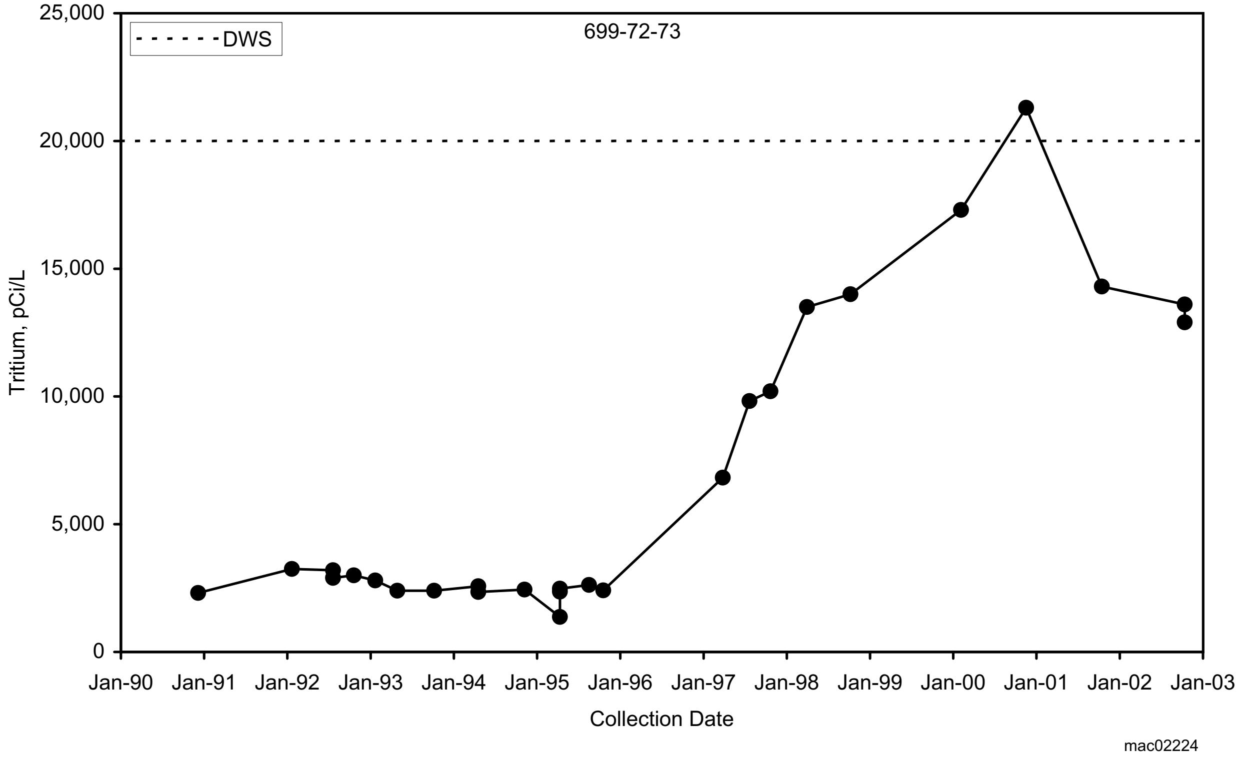

Figure 2.2-7. Tritium Concentrations in Well 699-72-73, East of 100-B/C Area

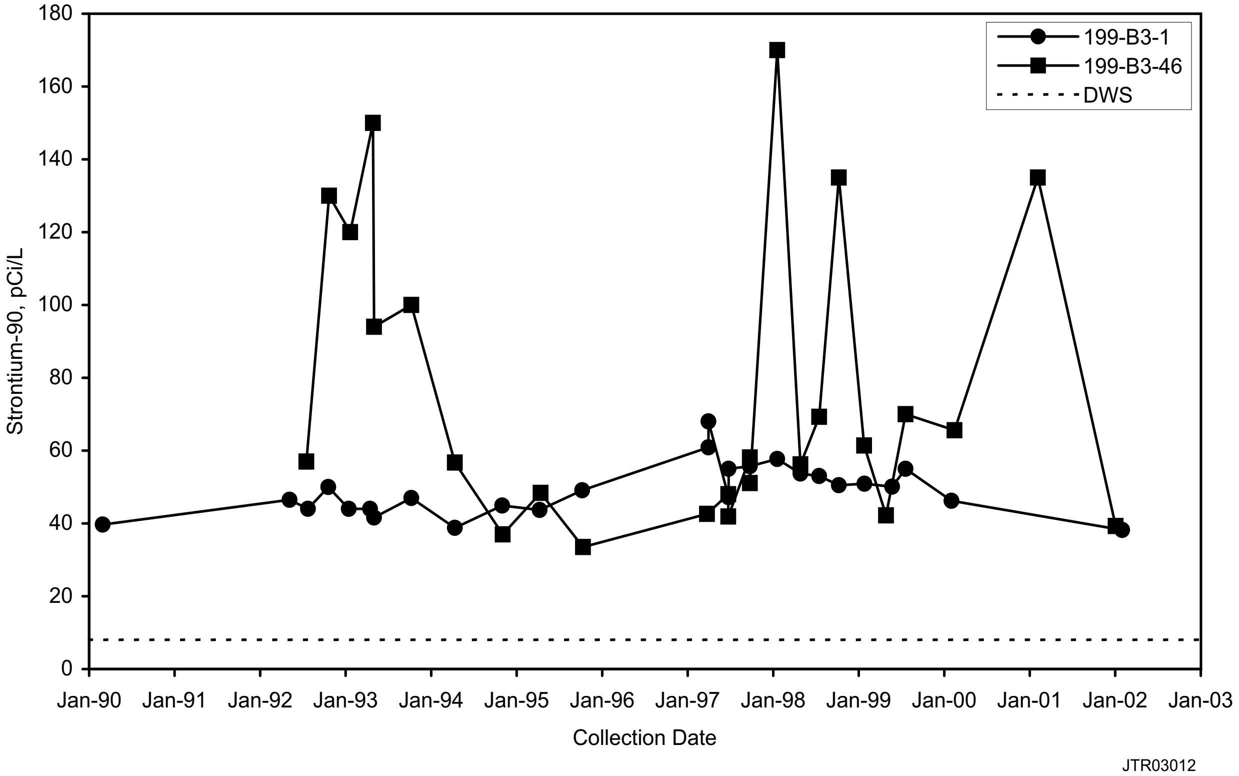

Figure 2.2-8. Strontium-90 Concentrations in Wells 199-B3-1 and 199-B3-46 Near 116-C-1 Trench

2.3 100-K Area

R. E. Peterson and R. F. Raidl

The KE and KW Reactors were the largest of the original group of eight plutonium production reactors. They operated between 1955 and 1971.

Figure 2.3-1 is an index map that shows existing facilities, former waste disposal facilities, monitoring wells, and river shore monitoring sites. The fuel storage basins that are integral parts of each reactor building are still in use for temporary storage of spent nuclear fuel, though remediation activities are underway that involve removing the fuel from the basins, encapsulating it for storage, and moving it to a better storage facility located in the Central Plateau.

The principal groundwater contamination concerns in the 100-K Area today involve (a) chromium in groundwater near the Columbia River; (b) operating facilities that contain highly radioactive spent fuel, shielding water, and sludge; and (c) carbon-14, strontium-90, and tritium associated with past-practice liquid waste disposal sites. The most prominent of these latter sites is the 100-K trench (116-K-2 liquid waste disposal trench), which received reactor coolant and decontamination solutions. This liquid waste disposal trench was the largest soil column disposal facility in the 100 Area. An interim remedial action using a pump-and-treat system is in progress to reduce the amount of chromium in groundwater between the trench and the Columbia River. An emerging issue involves the unexplained presence of tritium near the 100-K burial ground (118-K-1 burial ground).

Principal groundwater issues in the 100-K Area include (1) a chromium plume that is currently undergoing remediation by a pump-and-treat system, (2) monitoring for potential loss of highly radioactive shielding water from fuel storage basins, and (3) unexplained increased tritium concentrations in groundwater near the 118-K-1 burial ground.

Several sources exist that could potentially contribute additional contamination to the currently mapped groundwater plumes or possibly create new plumes. These

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This photo shows a well that is used to extract groundwater as part of a pump-and-treat system in the 100-K Area. This interim remedial action is reducing chromium contamination near the Columbia River.

sources include locations where the vadose zone contains significant inventories of radionuclides from past disposal of liquid waste during the reactor operating years and from previous leakage of shielding water from the KE Fuel Storage Basin (KE Basin). A second source involves the potential new loss of shielding water from either the KE or KW Fuel Storage Basin (KE or KW Basin). Removal of spent nuclear fuel, shielding water, and sludge from the fuel storage basins is a top priority for the Hanford Site and work is underway under Tri-Party Agreement Milestone M-34-00 (Ecology et al. 1998). Finally, waste sites not previously suspected of contributing to groundwater contamination may be present; an example is the 118-K-1 burial ground (waste site 118-K-1). Detailed characterization of buried materials at that waste site started during fiscal year 2002.

A detailed characterization of the 118-K-1 burial ground began in fiscal year 2002 to determine what materials are buried at that site.

Background information on the geology of the 100-K Area, regulatory issues, and monitoring methods is presented in the Hanford Groundwater Monitoring Project's report on the setting, sources, and methods for groundwater monitoring (PNNL-13080). The operational history and waste sites at 100-K Area are described in the technical baseline report for the 100-KR-4 Operable Unit (WHC-SD-EN-TI-239). Engineering details for the reactor plant components and operations are available in historical documents that are publicly available (e.g., HW-74095, Volume 3).

2.3.1 Groundwater Flow

The pattern of groundwater movement beneath the 100-K Area can be inferred from the water-table elevation contours for March 2002 (see Figure 2.3-1). Groundwater flow is roughly perpendicular to the contour lines on the map, i.e., generally toward the northwest and the Columbia River. Trend-surface analysis of water-table elevations, which calculates the direction and gradient of movement, was performed to better define plume movement in the vicinity of the 118-K-1 burial ground (PNNL-14031). Analysis of water-table elevation data from wells 199-K-30, 199-K-32A, and 199-K-111A for the period 1994 to 2002 indicates an average flow direction of 325 degrees (relative to true north) and average gradient of 0.0043. For hourly data collected in September 2001 from these same wells, the average direction is 318 degrees and average gradient is 0.0047. Hourly data for a second triad of wells (199-K-18, 199-K-30, and 199-K-111A) also were analyzed, producing an average direction of 321 degrees and average gradient of 0.0049.

Groundwater flow velocity is estimated using the Darcy equation, which gives an average linear flow velocity in the aquifer based on hydraulic conductivity, effective porosity, and the hydraulic head gradient. Typical values for 100-K Area aquifer properties and hydraulic gradients are: hydraulic conductivity in the range 5 to 25 meters per day, an effective porosity of 15%, and average gradients between 0.003 and 0.006 (PNNL-14031). The Darcy equation indicates velocities in the range 0.10 to 1.00 meter per day for these parameters.

Monitoring Objectives in 100-K Area

Groundwater monitoring is conducted in the 100-K Area:

- describe the nature and extent of contamination in support of environmental restoration issues (annual sampling)
- detect potential leakage and characterize the movement of past leakage from the KE and KW Fuel Storage Basins (quarterly sampling)
- evaluate the performance of the pump-and-treat system for chromium near the 116-K-2 liquid waste disposal trench (various sampling frequencies)

Direct measurements of flow direction and velocity have been made in 100-K Area monitoring wells in the past. Results obtained during the test of the KV Associates borehole flowmeter in 1993 and 1994 are consistent with the general pattern and rates suggested by contour lines and the Darcy equation (results are summarized in PNNL-14031).

Plume movement rates may be estimated using the arrival times of plume fronts at wells downgradient of contaminant sources. Recent evidence for the area between the KE Reactor complex and the Columbia River suggests a rate of ~0.12 meter per day (PNNL-13404). This estimate is based on the migration of a tritium plume associated with leakage from the KE Basin in 1993. Figure 2.3-2 shows tritium concentrations in well 199-K-27, located adjacent to the KE Basin on the downgradient side, and in well 199-K-32A, located along the downgradient flowpath from the KE Basin to the Columbia River. The assumption is made that the pulse in tritium concentrations in each well represents the release of shielding water from the KE Basin in early 1993. Its arrival at well 199-K-32A ~6 years later is used to infer travel time and plume migration velocity. This implies a travel time of ~12 years between KE Reactor complex sources and the river for non-attenuated contaminants.

Near the KW Reactor complex, a tritium pulse appeared in well 199-K-106A near the KW condensate crib in 1995, and was subsequently detected at downgradient well 199-K-33, suggesting a migration rate of ~0.89 meter per day (Figure 2.3-3). This rate implies a travel time between KW Reactor complex sources and the river for non-attenuated contaminants of ~2 years. There is greater uncertainty in the KW estimate because of fewer data points to define the trends in the wells involved. The rate estimate may be too high and travel time too low by a factor of two (i.e., 0.45 meter per day and 4 years to the river are possible).

Groundwater flow beneath the K Reactors and disposal sites is toward the river. Travel time to the Columbia River is apparently faster at KW Reactor than at KE Reactor. Water-table mounds that developed during operations, and more recently during remediation activities, have influenced flow directions locally.

Although the horizontal movement of groundwater predominates in the flow field, vertical movement also occurs in response to the fluctuating Columbia River stage. The water table typically moves up and down through a range of ~2 meters in 100-K Area wells located within several hundred meters of the river, decreasing to a range of ~0.3 meter in wells located farthest inland (BHI-00917). The vertical movement of the water table may cause remobilization of contaminants held in the normally unsaturated vadose zone, as has been demonstrated previously at the 100-K Area (PNNL-12023) and also the 100-N Area (DOE/RL-98-38).

Monitoring wells in the 100-K Area do not provide extensive and uniform coverage, so the configuration of the water table cannot be described with a high degree of confidence for all portions of the area. The general direction of groundwater flow is fairly clear; however, the fine-scale details for direction and rate of flow between known contaminant sources and the Columbia River are less well defined. The presence of engineered backfill and heterogeneity in hydraulic properties of the aquifer contribute to uncertainty in describing pathways for contaminant transport. Near the Columbia River, the rate and direction of groundwater flow vary through wide ranges because of changing hydraulic gradients caused by the fluctuating river stage.

During the operating years 1955 to 1971, a large mound formed beneath the 116-K-2 liquid waste disposal trench (HW-77170). A radial flow pattern developed around the mound and modified the natural flow field beneath the entire 100-K Area. Radial flow distributed hexavalent chromium and tritium widely throughout the area. The implication of the mound with respect to current groundwater conditions is that residual contaminated moisture from the previously saturated mound areas is believed to slowly migrate downward to the water table, thus providing continual recharge to contaminant plumes in groundwater. A more recent mound buildup is occurring beneath the interim action injection wells, which are located south of the 116-K-2 liquid waste disposal trench. Treated effluent has been injected into these wells since October 1997 (see Section 2.3.9). An analysis of the possible extent of the mound was completed in September 2001 (PNNL-14031). The results suggest that hydraulic head increases of ~0.4 meter are possible out to distances of ~500 meters from the injection site.

2.3.2 Chromium

Chromium was introduced to 100-K Area groundwater from multiple sources. Infiltration of reactor coolant that contained 700 µg/L hexavalent chromium created the most widespread contamination because of mounding beneath the 100-K trench. Additional sources include leakage and/or spillage of sodium dichromate stock solutions near railcar transfer stations, storage tanks, and mixing facilities during the water treatment process. By early 1971, these sources no longer contributed new contamination, and the nearly 30 years of groundwater movement since then has allowed the original plumes to disperse. Residual amounts of chromium likely remain in vadose zone moisture beneath waste sites, and with downward movement, continue to slowly maintain the mapped plumes.

The hexavalent form of chromium is highly soluble in groundwater as the chromate anion (CrO_4^{2-}). The contaminant is not attenuated in the aquifer by adsorption onto solid materials, nor does it convert to a less mobile form (e.g., trivalent chromium) under natural conditions at Hanford, and, therefore, migrates at the same rate as groundwater. Hexavalent chromium is the more toxic form, with aquatic organisms being especially sensitive receptors. The maximum contaminant level for drinking water supplies is 100 µg/L total chromium in a water sample. The level for protection of freshwater aquatic organisms for chronic toxicity is 10 µg/L hexavalent chromium under the Washington State Administrative Code (11 µg/L under U.S. Environmental Protection Agency [EPA] guidelines).

Groundwater beneath the 100-K Area is contaminated by chromium in three areas: a plume between the 116-K-2 liquid waste disposal trench and the Columbia River and two smaller areas of contamination near the reactor buildings.

The distribution of chromium during fiscal year 2002 in 100-K Area groundwater is shown in Figure 2.3-4. Three areas of concern are apparent: (1) a relatively large area of contamination associated with the 116-K-2 liquid waste disposal trench, (2) an area near the southeast side of the 183-KE water treatment plant settling basins, and (3) an area centered on the KW Reactor. Concentrations of chromium in these mapped areas have generally remained constant or shown slightly decreasing trends during recent years.

The first area is the plume targeted for interim remedial action using a pump-and-treat system (DOE/RL-99-13). The extent to which this contamination was moved inland by mound buildup during the operating years is not clearly defined, though it appears to have moved at least to well 699-78-62, located ~1,600 meters inland. Chromium concentrations in the target plume typically range from 75 to just under 200 µg/L, thus exceeding the 100-µg/L drinking water standard in some areas and the 10-µg/L standard for the protection of freshwater aquatic organisms. The treated effluent from the pump-and-treat system, which is essentially free of chromium, is returned to the aquifer at wells upgradient of the 116-K-2 liquid waste disposal trench. Additional information on the operating characteristics and performance of the interim action pump-and-treat system is presented in Section 2.3.9.

The second area of chromium contamination, near the southeast side of the settling basins for the 183-KE water treatment plant, is a consequence of past leaks or spills of sodium dichromate stock solution during railcar transfer operations or from storage tanks located in the area (WHC-SD-EN-TI-239). Subsequent remobilization of sodium dichromate from the vadose zone may periodically occur as the result of water leakage from the nearby settling basins. The maximum chromium concentration detected in groundwater at well 199-K-36 occurred in January 1996 and was 2,710 µg/L (Figure 2.3-5). The most recent concentrations are in the range of 550 to 1,300 µg/L and are generally decreasing. An anomalously low concentration was detected in a sample collected in July 2001 (485 µg/L). This low value may reflect dilution of groundwater in the area by clean water that had leaked from nearby #5 settling basin, which is known to have lost a significant volume of water during the late summer 2001.

The third area of concern is near the KW Reactor, where concentrations in recent years have ranged up to ~600 µg/L (Figure 2.3-6). The specific source for the chromium in this plume is not known. Leakage and/or spillage of sodium dichromate stock solution in upgradient areas may have occurred during the operating years. One potential site is the railcar transfer station and storage tanks located at the southeast side of the settling basins for the 183-KW water treatment plant. The changing trends in wells 199-K-107A and 199-K-34, which are located downgradient of the KW Reactor building, suggest plume movement. The low concentrations of chromium at well 199-K-108A are the result of dilution, which is caused by infiltration of clean water from a leaking fire hydrant system (see Section 2.3.7.3).

The plume near KW Reactor does not appear to have reached the Columbia River, as shown by data from wells 199-K-31 and 199-K-33, which are located between KW Reactor and the Columbia River. Also, there is no evidence for elevated chromium in riverbank seepage or aquifer sampling tubes along this segment of 100-K shoreline. The travel time between KW Reactor and well 199-K-33 has been estimated to be several years (see Figure 2.3-3). Increasing chromium concentrations first appeared at KW Reactor in mid-1994, so sufficient time apparently has passed for the plume to move downgradient to well 199-K-33, assuming the well is within the flow path. Because a distinct increase in concentrations in that well is not apparent, it appears that the well is not within the flow path of the chromium plume or that the travel time is much longer than expected.

2.3.3 Strontium-90

Strontium-90 is not distributed widely in 100-K Area groundwater, though there are several waste sites where the vadose zone may be contaminated, thereby creating a potential source for future groundwater contamination. Strontium-90 contamination is anticipated wherever liquid effluents associated with irradiated nuclear fuel were disposed. The principal sites for soil column disposal were the 116-K-2 liquid waste disposal trench and the fuel storage basin drain fields/injection wells associated with each reactor (waste sites 116-KE-3 and 116-KW-2). The radionuclide is adsorbed onto sediment in the vadose zone and aquifer. Strontium-90 is considered a moderately mobile radionuclide in groundwater and has a radioactive decay half-life of 28.8 years. The drinking water standard is 8 pCi/L and the U.S. Department of Energy (DOE) derived concentration guideline is 1,000 pCi/L.

Current levels of strontium-90 contamination in groundwater between the 116-K-2 liquid waste disposal trench and the Columbia River range up to a maximum near 40 pCi/L (Figure 2.3-7). The recent peaks in several wells may have been caused by the anomalously high water table during 1996 and 1997, which is suspected of having remobilized strontium-90 held in the normally unsaturated lower vadose zone in some areas. The radionuclide is a co-contaminant with chromium in the plume targeted for interim remedial action. However, strontium-90 is not removed by the ion exchange resin that removes chromium from extracted groundwater and is, therefore, returned to the aquifer via the injection wells. The most recent measurements for strontium-90 in the treated effluent are 4.31 and 4.09 pCi/L (May 8, 2001), and concentrations have remained essentially constant since startup of the pump-and-treat system in October 1997.

Near the KE Reactor, groundwater samples from well 199-K-109A revealed a variable trend in strontium-90 and tritium concentrations during 1997, with the highest values well above the DOE derived concentration guideline. The highest strontium-90 value detected at this well in 1997 was 18,600 pCi/L. Since 1997, concentrations have shown a gradual decline, with concentrations dropping below the DOE derived concentration guideline with the August 6, 2002 sample (Figure 2.3-8). The source for the strontium-90 detected is most likely the result of past-practices disposal to the nearby KE fuel storage basin drain field/injection well (waste site 116-KE-3). Increased infiltration of water from leaking fire hydrant lines, and possibly an elevated water table during 1997, apparently remobilized

Strontium-90 in groundwater near the KE Reactor originated from past disposal of effluent from a fuel storage basin to a nearby drain field. Concentrations vary as a consequence of water movement downward through the contaminated vadose zone.

contamination held in the normally unsaturated vadose zone (PNNL-12023). For wells most likely to detect current leakage from the KE Basin (i.e., wells 199-K-27 and 199-K-29), strontium-90 remains undetected. The strontium-90 concentration in KE Basin shielding water is ~1 million pCi/L.

Strontium-90 also is elevated somewhat above the drinking water standard near the KW Reactor, with concentrations ~40 pCi/L in several wells (Figure 2.3-9). The suspected source of contamination at the KE Basin is the adjacent drain field/ injection well (waste site 116-KW-2). Strontium-90 is the primary contributor to gross beta activity at this location; the concentration of strontium-90 is approximately one-half that of the gross beta concentration. Concentrations of strontium-90 and gross beta in groundwater at well 199-K-34 have shown a slightly increasing trend since 1998, while concentrations in nearby well 199-K-107A have remained constant. Strontium-90 concentrations in KW Basin shielding water are ~20,000 pCi/L.

2.3.4 Tritium

Tritium is a common and widespread radiological contaminant in Hanford Site groundwater, with a radioactive decay half-life of 12.3 years. The distribution of tritium in 100-K Area groundwater during fiscal year 2002 is shown in Figure 2.3-10. The known locations where tritium was (and still may be) introduced to groundwater include the KE and KW Reactor complexes and the 116-K-2 liquid waste disposal trench. Two principal past-practices sites are located near the northeast side of each reactor building, where condensate from reactor atmosphere gas apparently continues to migrate downward through the soil column beneath the KW and KE condensate cribs (waste sites 116-KW-1 and 116-KE-1, respectively). Carbon-14 is a co-contaminant with tritium in the effluent disposed to these cribs.

The tritium distribution in groundwater during fiscal year 2002 illustrates that principal sources include several sites near the reactor complexes, along with the 116-K-2 liquid waste disposal trench and possibly the 118-K-1 burial ground.

Concentration trends for tritium in groundwater near the KE and KW condensate cribs are included here to illustrate the other major sources for tritium in groundwater near the reactors. Figure 2.3-11 shows the tritium concentrations and specific conductance values for groundwater immediately downgradient of the KE condensate crib. The concentrations at that location are believed to represent the downward migration of tritium (and carbon-14) in vadose zone moisture. The strong positive correlation between tritium concentrations and specific conductance values suggests that downward migration is promoted by increased infiltration of water from the surface. The increase in specific conductance in groundwater at the KE condensate crib has been attributed to infiltration of precipitation (e.g., snowmelt) containing ice control salt (WHC-SD-EN-TI-280).

Figure 2.3-12 shows the same constituents for the KW condensate crib. A similar correlation between tritium and specific conductance is absent at this location. There is currently no clear explanation for the tritium peak that appeared in well 199-K-106A during 1995 (~600,000 pCi/L). Leakage from the KW Basin is not considered a possible source because basin water concentrations were only one-tenth the concentrations observed in the well at that time. Specific conductance at the KW condensate crib is significantly higher than natural background (~650 versus ~350 µS/cm for background).

A second source for the currently observed plume between the KE Basin and the Columbia River is past leakage from the KE Basin (see Section 2.3.8), with the most recent leakage having occurred in early 1993. The plume created by the 1993 leakage moved north-northwest past well 199-K-27 and is believed to have arrived at downgradient well 199-K-32A (see Figure 2.3-2). KE Basin shielding water lost in 1993 also contained technetium-99, which is used to help distinguish this tritium plume from those associated with other sources, such as the condensate cribs.

A rapid rise in tritium concentrations in groundwater at well 199-K-111A, located at the northwest corner of the 118-K-1 burial ground, started in late summer 2000 (Figure 2.3-13). Investigations were immediately undertaken to determine the source for the tritium, because radiological contamination had not been previously observed at this well. Technetium-99, a constituent of KE Basin shielding water, has not been detected at the well. Carbon-14, which is unique to the KE condensate crib, is detected, but changes in concentration do not correlate with those observed for tritium. An analysis of groundwater flow direction from known tritium sources suggests that plumes from the KE Basin and KE condensate crib sources are unlikely to pass by well 199-K-111A. Soil-gas samples were collected from existing sampling sites near well 199-K-111A (PNNL-13217) and helium-3, an indicator of nearby tritium, continues to be somewhat elevated in the area near the well.

Most evidence to date suggests that the tritium detected in groundwater at well 199-K-111A is from a previously unidentified plume located to the east or southeast of the well. There is circumstantial evidence to suggest that tritium-producing irradiated metallic waste may have been placed in silos at the 118-K-1 burial ground (WHC-SD-EN-TI-239). The possibility exists that tritium is being produced by conditions analogous to those at the 618-11 burial ground (PNNL-13675). If a tritium plume is present in groundwater beneath the 118-K-1 burial ground, some way of displacing it laterally to the west to well 199-K-111A is needed. Radial flow associated with the mound buildup beneath the 100-KR-4 treated effluent injection site to the east is one potential mechanism. However, a model for the extent of that mound has thus far produced inconclusive results as to whether buildup to date would be sufficient to influence plume movement at the distance of the burial ground. The results of the various investigations undertaken to identify the source for the tritium detected at well 199-K-111A are described in a report published during the year (PNNL-14031).

In previous groundwater annual reports, the cause for the relatively high tritium concentrations detected in the vicinity of monitoring well 199-K-18 and extraction well 199-K-120A (see Figure 2.3-10) was described as not fully understood. Possible explanations included (a) vadose zone moisture containing tritium from past disposal to the 116-K-2 liquid waste disposal trench continuing to feed a small groundwater plume in the vicinity of these wells, and (b) shielding water from the KE Basin lost during the period 1976 to 1979 or groundwater from beneath the KE condensate crib. The recent new data from well 199-K-111A, along with new information from the various investigations to identify a source (PNNL-14031), add a third possibility, i.e., that a tritium plume extending from beneath the 118-K-1 burial ground has reached the two downgradient wells.

Treated effluent from the 100-KR-4 pump-and-treat system is returned to the aquifer via injection wells located south of the trench. The effluent includes tritium, which is not removed by the treatment system. The tritium concentration in this effluent was measured at ~6,500 pCi/L in spring 2001. Most of this tritium comes from groundwater extracted at well 199-K-120A. Based on tritium trends, it appears that the treated effluent injected back into the aquifer has migrated from the injection sites to the nearest downgradient well (extraction well 199-K-119A), indicating a migration rate of ~0.6 meter per day (PNNL-14031). Tritium is also increasing in extraction well 199-K-125A, although the increase is not believed to be the injected effluent; the trend is probably related to the redistribution of tritium initially disposed to the trench—as a consequence of pumping.

Carbon-14 is present in groundwater at two condensate disposal sites near the KW and KE Reactors. These areas represent the most significant levels of this radionuclide in Hanford Site groundwater.

2.3.5 Carbon-14

This radionuclide was present along with tritium in the condensate from reactor atmosphere gas that was disposed to the cribs located on the northeast side of the

KE and KW Reactors. The drinking water standard for carbon-14 is 2,000 pCi/L and the DOE derived concentration guide is 70,000 pCi/L. The half-life is relatively long (5,730 years), suggesting that the existing plumes will eventually be exposed at the Columbia River before they decay. The radionuclide may disperse more slowly than tritium because of interaction with carbonate minerals, so the distribution patterns for the two contaminants are not identical (see Figure 2.3-10). Because of the different geochemical characteristics for carbon-14 and tritium, the ratio of the two constituents cannot be used as a reliable indicator of effluent from the condensate cribs. Carbon-14 was not a significant component of liquid effluent sent to the 116-K-2 liquid waste disposal trench.

Carbon-14 concentrations in groundwater tended to be lower during fiscal year 2002 than in previous years. The highest concentrations are found in wells near and downgradient of the condensate cribs. Figure 2.3-14 shows the concentration trends in wells downgradient of the KE condensate crib (waste site 116-KE-1) and Figure 2.3-15 shows concentrations near the KW condensate crib (waste site 116-KW-1). The relatively greater level of carbon-14 contamination near KW reactor may be a consequence of more rapid groundwater movement than near the KE reactor.

One of the few wells that shows an increasing trend for fiscal year 2002 is well 199-K-111A (see Figure 2.3-13), which is located near the 118-K-1 burial ground; the concentrations are low relative to wells near the KE condensate crib (i.e., >250 pCi/L at the well, compared to thousands of picocuries per liter near the crib). The presence of carbon-14 in groundwater at well 199-K-108A remains an enigma. The well is upgradient of the principal known source for carbon-14 (i.e., the KW condensate crib), and co-contaminant tritium is not present at well 199-K-108A at concentrations suggestive of a condensate crib source. Carbon-14 concentrations at well 199-K-108A have been anomalously low during the past 3 years because of infiltration of clean water from a surface source.

2.3.6 Nitrate

Nitrate concentrations in groundwater exceed the drinking water standard at numerous 100-K Area wells. Concentration trends are variable, depending on location.

Nitrate is widely distributed in groundwater beneath all the reactor areas. There are multiple sources that potentially contribute to the plumes, including septic system drain fields and past-practice disposal to the soil column of decontamination solutions such as nitric acid (WHC-SD-EN-TI-239). The maximum contaminant level for drinking water supplies is 45 mg/L, and this level is exceeded in numerous 100-K Area wells.

Nitrate concentration trends at wells near the KE Reactor building for fiscal year 2002 are shown in Figure 2.3-16. Current values are in the range 50 to 60 mg/L. To the north of the KE Reactor, concentrations have gradually increased to ~60 mg/L at well 199-K-111A, but the trend is not coincident with the recent, rapidly increasing trend for tritium at that well. The most recent results at the well suggest the increasing trend has stopped. Near the KW Reactor, nitrate concentrations appear to be gradually decreasing with time (Figure 2.3-17). The highest current value is ~70 mg/L at well 199-K-106A, followed by ~55 at well 199-K-33. Well 199-K-108A, located near the southeast corner of KW Reactor, continues to show anomalously low concentrations as the result of dilution by infiltrating clean water from leaking fire hydrant lines.

In the vicinity of the 116-K-2 liquid waste disposal trench, concentrations are generally below the 45-mg/L standard with the exception of conditions at the southwest end of the trench. There, concentrations at well 199-K-18 are ~100 mg/L and show a slight downward trend with time.

In addition to local 100-K Area sources for nitrate, the distribution also is being affected by the arrival of nitrate plumes from distant sources. Groundwater from the 200 East Area has traveled toward the northwest through Gable Gap and is now passing just to the west of 100-K Area, as indicated by the nitrate plume shown on the site-wide groundwater map (see Figure 2.1-4). Increasing nitrate trends in wells south and west of 100-K Area record the arrival of this plume. Technetium-99 is a co-contaminant with nitrate in this plume.

2.3.7 Other Constituents of Interest

The groundwater constituents chromium, strontium-90, tritium, carbon-14, and nitrate described in Sections 2.3.2 through 2.3.6 have been identified previously as contaminants of concern with regard to environmental restoration decisions. Two additional constituents of interest that are or have been detected in 100-K Area groundwater are discussed in this section, along with a description of any area where increased infiltration of surface water is suspected, thus causing dilution of the underlying groundwater.

2.3.7.1 Trichloroethene

This organic constituent is a minor contaminant resulting from the past disposal/spillage of organic solvents. Groundwater samples from two wells downgradient of the KW condensate crib contain trichloroethene at levels above the 5-µg/L maximum contaminant level for drinking water supplies. At well 199-K-106A, the concentration was 11 µg/L in October 2002 and at well 199-K-33, the concentration was 8.8 µg/L. Concentrations at each of these wells appear to be gradually decreasing with time.

2.3.7.2 Nickel

Nickel has not been identified as a contaminant of concern for human or ecological health reasons (DOE/RL-93-79). However, concentrations in filtered groundwater samples have exceeded the 100-µg/L secondary drinking water standard in several wells in the past, including wells 199-K-36, 199-K-109A, and 199-K-110A. All exceedances have been reported previously; the standard was not exceeded in any 100-K Area well during fiscal year 2002. There is no obvious waste site source for nickel contamination, and its occurrence is scattered. Nickel appears to be elevated only in relatively new monitoring wells that have stainless steel casings and screens. Therefore, a sampling anomaly is the suspected source of the contamination, perhaps the result of corrosion of the stainless steel (Hewitt 1994). Chloride concentrations are correlated positively with nickel concentrations in those wells, which supports the suggestion of corrosion.

Infiltration of water from surface sources, such as precipitation, leaking utility lines, and application of water for dust control, may influence contaminant concentrations in the underlying groundwater. Infiltration is indicated near the KW Reactor during fiscal year 2002.

2.3.7.3 Influence of Moisture from Surface Sources

The influence of moisture infiltrating downward from the surface on groundwater conditions has been described previously at several sites at 100-K Area (e.g., PNNL-12023). Above-normal infiltration rates may be caused by natural precipitation events (e.g., heavy rainfall or rapid snow melt) or by leaking underground water lines. Continued downward movement of tritium and carbon-14 beneath the KE and KW condensate cribs and remobilization of strontium-90 near the drain field at the KE (and possibly KW) Basin are two examples where above-normal infiltration of water from the surface or near surface has played a role in moving contamination downward to groundwater.

One additional site where infiltration of clean water through the vadose zone has diluted the underlying groundwater is at well 199-K-108A, near the southeast corner of the KW Reactor. Rapidly decreasing trends for chloride and nitrate at this well started in late summer 1999 (Figure 2.3-18) and continue as of fall 2002.

Because contamination indicators also are decreasing, the overlying vadose zone is believed to be free of contaminants. In October 2002, evidence was discovered to indicate possible clean water leakage from a fire hydrant located near the well.

2.3.8 100-K Fuel Storage Basins Monitoring

Irradiated nuclear fuel from the N Reactor is stored in water-filled basins in the 100-K Area. The shielding water has become highly contaminated and constitutes a potential source for groundwater contamination if a basin leaks. Removal of nuclear fuel from the basins began in December 2000 and continued during 2002.

The Hanford Groundwater Monitoring Project provides services to the Spent Nuclear Fuel Project to (a) help detect the loss of basin shielding water and (b) characterize the impact of lost shielding water on groundwater conditions. The groundwater monitoring strategy and data quality objectives for the fuel storage basins task are presented in a recently updated monitoring and assessment plan (PNNL-14033).

The 100-K fuel storage basins are operating facilities that currently store spent nuclear fuel from the N Reactor, along with minor amounts of spent fuel from the cleanout of basins at other reactors. The KE Basin contains fuel stored in unsealed canisters, while KW Basin contains fuel stored in sealed containers (HNF-SD-SNF-TI-009). Because of the unsealed containers and greater proportion of damaged fuel elements, the KE Basin is the more contaminated facility. A shielding water re-circulation system includes exchange resins that remove some of the radionuclides, but concentrations of many fuel degradation products remain very high. At the KE Basin, recent concentrations of key radionuclides for tracking leakage in groundwater are tritium (~3 million pCi/L) and strontium-90 (~1.2 million pCi/L). At the KW Basin, recent concentrations are: tritium (~70,000 pCi/L) and strontium-90 (~20,000 pCi/L). Technetium-99, an additional indicator for tracking leakage in groundwater, was recently measured in each basin. The concentration in KE Basin is ~900 pCi/L and in KW Basin ~1,500 pCi/L.

Removal of fuel from the K Basins is a high priority Hanford Site cleanup project (ROD 1999c). Actual removal of fuel began in December 2000 at the KW Basin and continued during fiscal years 2001 and 2002. The removed fuel is dried and repackaged at the Cold Vacuum Drying facility in the 100-K Area. It is then transported to the Canister Storage Building, which is an interim storage facility located in the 200 Area. Removal of fuel from the basins is scheduled for completion by 2004, followed by removal of sludge and shielding water, and finally demolition of the concrete structure, which should all be completed by 2007 under Tri-Party Agreement Major Milestone M-34-00A (Ecology et al. 1998). Background information on the Spent Nuclear Fuels Project can be found in a feasibility study report that provides detailed information on the fuel, shielding water, and sludge, along with a description of alternatives for cleanup (DOE/RL-98-66).

2.3.8.1 Groundwater Flow Near the Basins

The general movement of groundwater beneath the KE and KW Basins is from the south-southeast to the north-northwest, i.e., toward the Columbia River. Travel time from the basins to the Columbia River is estimated to be in the range of 4 to 12 years (see Section 2.3.1 for a more complete discussion). Several factors may influence groundwater movement beneath the basins, including the presence of backfill associated with building foundations and underground pipelines, and heterogeneity in the hydraulic properties of the aquifer. Infiltration of water from the ground surface is a concern because of the potential to remobilize contamination that remains in the vadose zone in some areas as a consequence of past disposal practices and/or leakage.

Travel time for groundwater between the KE Basin and the Columbia River is estimated to be ~12 years, while at the KW Basin it is faster, i.e., possibly in the range of 2 to 4 years.

In an effort to determine the origin of tritium detected in groundwater at well 199-K-111A, located ~260 meters north of the KE Basin, a detailed evaluation of flow direction from each of the known tritium sources was undertaken in June 2001 (PNNL-14031). Flow direction corridors were estimated from water-table contours and conceptual representations of tritium distribution from each source were developed, following earlier similar work for the KE Basin (WHC-SD-EN-AP-174). The results are summarized in Figure 2.3-19. The dashed gray lines represent the central path traced by plume movement downgradient from each source. The red outlined areas are where plumes from various sources are expected to be found currently, based on the presumed shift in flow path direction caused by seasonal changes in gradients (lateral dispersion would increase the width of these areas somewhat).

Area A in Figure 2.3-19 represents the plume created by the 1993 leakage from KE Basin, which has now migrated downgradient as far as well 199-K-32A. The travel time for this plume from the basin to the well is ~6 years. Technetium-99, a co-contaminant with tritium in shielding water, also is detected at well 199-K-32A. Area B represents tritium recently remobilized from the vadose zone; the likely origin for the tritium is the former storage basin drain field/injection well (waste site 116-KE-3). Strontium-90 is a co-contaminant in this plume, which is inferred from groundwater conditions observed at well 199-K-109A. Area C is the presumed distribution corridor for tritium from the KE condensate crib, which operated from 1955 to 1971. The crib and underlying vadose zone are assumed to still contribute contamination to groundwater via slow downward migration of moisture. Carbon-14 is a co-contaminant in this plume.

Two additional flow paths from potential, but as yet undocumented, tritium sources are shown in Figure 2.3-19. One extends from the central portion of the 118-K-1 burial ground, where past disposal of irradiated fuel components may create tritium-producing conditions similar to those observed at the 618-11 burial ground (PNNL-13228). The second extends from the southwest end of the 116-K-2 liquid waste disposal trench and is presumed to represent residual contamination from past disposal to the trench, which ended in 1971.

2.3.8.2 Tritium as an Indicator of Shielding Water Loss

Tritium is a key constituent for monitoring potential leakage from the KE and KW Basins, because the concentrations in each basin are relatively high. Tritium concentrations decrease with distance from the source because of radioactive decay (half-life of 12.3 years) and dispersion, but not by adsorption onto solids, as occurs with strontium-90 and cesium-137.

Figure 2.3-20 shows the tritium concentration record for two wells near the KE Basin. The record for these wells, which were constructed in 1980, suggests that the plume from major leakage during the period 1976 through 1979 must have already passed these wells by the time of their installation because there is no indication of a plume. The volume of water lost during that period is estimated at ~57 million liters (WHC-SD-SNF-TI-013), and the tritium concentration in KE Basin shielding water at the time was ~600,000 pCi/L. A subsequent period of documented leakage in 1993 is clearly revealed by the tritium pulse that passed well 199-K-27. That leakage is estimated at ~341,000 liters (WHC-SD-SNF-TI-013), and the basin water concentration at the time was ~3 million pCi/L. (Note: The cause for the 1990 tritium pulse in well 199-K-27 is not known.)

Because of high tritium concentrations in basin shielding water, tritium in groundwater is used as a key indicator for tracking shielding water loss from the basins. Monitoring results for fiscal year 2002 do not suggest current leakage from either KE or KW Basins.

Recent tritium concentrations in several wells adjacent to the KE Basin are shown in Figure 2.3-21. The highest concentrations are found at well 199-K-109A, which is located at the northwest corner of the basin and near the former drainfield for basin effluent. The two “spikes” in that well’s trend are believed to be related to leaks from the fire hydrant system. The recent increase at well 199-K-29 is believed to be related to the plume associated with the KE condensate crib, not to leakage from the KE Basin. Technetium-99, an indicator of shielding water, is not detected at well 199-K-29.

Tritium concentrations in groundwater near the KW Basin are generally lower than near the KE Basin (Figure 2.3-22). There has been no readily identifiable leakage from the KW Basin. The tritium detected in well 199-K-34 may be related to the KW condensate crib.

2.3.9 Groundwater Remediation

A groundwater pump-and-treat system began operating in the 100-K Area in October 1997 as an interim remedial action. The system reduces the amount of hexavalent chromium that reaches the river via groundwater flow, thereby protecting aquatic organisms from this toxic constituent in groundwater. The extraction wells are located within a chromium plume that lies between the 116-K-2 liquid waste disposal trench and the Columbia River. The treatment system removes chromium from the extracted groundwater and the treated effluent is returned to the aquifer at a location upgradient of the trench.

One goal of the pump-and-treat system in the 100-K Area is to reduce the amount of hexavalent chromium reaching the Columbia River, where the chemical may adversely affect aquatic organisms that use the riverbed as habitat.

2.3.9.1 Interim Remedial Action Objectives

The record of decision (ROD 1996a) for interim remedial action to address chromium contamination in groundwater at the 100-K Area contains the following objectives for operating the pump-and-treat system:

- protect aquatic receptors in the river bottom substrate from contaminants in groundwater entering the Columbia River
- protect human health by preventing exposure to contaminants in the groundwater
- provide information that will lead to the final remedy

The record of decision stipulates that the interim action pump-and-treat system will continue to operate until the U.S. Environmental Protection Agency and Washington State Department of Ecology are satisfied that termination (or intermittent operation) is appropriate. Criteria for ending the operation include (a) sampling results demonstrate that the concentration of hexavalent chromium is below 22 µg/L in the compliance wells, and (b) evidence to conclude that the concentration will remain below the compliance value. Other criteria for terminating pump-and-treat operations involve the effectiveness of the treatment technology and the availability of a superior treatment technique (ROD 1996a).

2.3.9.2 Remediation Progress During Fiscal Year 2002

Progress was made toward achieving the remedial action objectives at the 100-KR-4 Operable Unit in fiscal year 2002. The pumping operation captures groundwater that contains hexavalent chromium at concentrations above the Washington State standard to protect aquatic organisms (i.e., 10 µg/L), thus preventing further transport of the contaminant to exposure sites within the river. Although designed primarily to prevent or reduce the amount of contaminated groundwater that discharges into the Columbia River, the pump-and-treat system also reduces the level of contamination by removing contaminant mass from the aquifer.

During fiscal year 2002, the pump-and-treat system at 100-K Area extracted 400.7 million liters of groundwater and removed 33.8 kilograms of hexavalent chromium from the aquifer.

During fiscal year 2002, the pump-and-treat system extracted 400.7 million liters of groundwater and removed 33.8 kilograms of hexavalent chromium. Extraction well operating flow rates averaged between 54 and 161 liters per minute for the year, with maximum sustained pumping rates ranging between 60 and 170 liters per minute at the different wells. Average concentrations for hexavalent chromium in groundwater from the extraction wells ranged between 60 and 138 µg/L, with an average treatment system influent concentration of 90 µg/L. The effluent concentration averaged 4 µg/L hexavalent chromium.

Concentrations of hexavalent chromium remain above the target level of 22 µg/L in the extraction and compliance wells, so the annual summary report for the remedial action (DOE/RL-2002-05) recommends continued operation of the pump-and-treat system. In response to a finding included in the first 5-year review of the *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA) remediation activities for the Hanford Site (EPA 2001), new extraction and injection wells were installed in early 2002. New extraction well 199-K-127 was installed between existing extraction wells 199-K-119A and 199-K-120A. New injection well 199-K-128 was installed between existing injection wells 199-K-121A and 199-K-122A. A replacement for extraction well 199-K-112A and a new performance monitoring well are planned for installation during early 2003, at the northeast end of the 116-K-2 liquid waste disposal trench.

The interim action pump-and-treat project collects data on hydraulic gradients, contaminant levels (including co-contaminants strontium-90, tritium, carbon-14, and nitrate), and treatment system operating parameters. These data are used to evaluate treatment system performance and to provide a technical basis for selecting a final remedy for groundwater remediation in the operable unit. A complete description of the progress and effectiveness of the interim remedial action to date is presented in the annual summary report for calendar year 2001 (DOE/RL-2002-05).

2.3.9.3 Influence on Aquifer Conditions

Several characteristics of the chromium plume are reviewed to help determine the influence of the remedial action on aquifer conditions. These include trends in the areal extent, volume of contaminated groundwater, and mass of contaminant in the plume. Concentration trends at individual monitoring sites are also used. The areal extent of the 100-KR-4 chromium plume as mapped has not changed appreciably during recent years. There is considerable uncertainty as to the location of the plume's boundary in some areas because of limited monitoring well coverage. For this reason, an accurate description of the volume of contaminated groundwater is not available. However, some information related to chromium mass is available.

In response to the CERCLA 5-year review of interim remedial actions for groundwater, the pump-and-treat system at 100-K Area will continue to operate. New extraction and injection wells were installed during fiscal year 2002, and additional wells will be installed during early 2003 to provide more complete capture of the plume.

At the end of fiscal year 2002, the 100-KR-4 pump-and-treat system had removed ~184 kilograms of hexavalent chromium from groundwater (Data source: Project Specific Database for the 100-KR-4 Operable Unit). The breakdown of removal by calendar year is as follows: 1997 (11 kilograms); 1998 (31 kilograms); 1999 (38 kilograms); 2000 (34 kilograms); 2001 (36 kilograms); and 2002 (34 kilograms, as of September 30). A very rough estimate for the total amount of chromium in the mapped extent of the plume targeted for remedial action suggests a mass of 250 kilograms (DOE/RL-94-95). Uncertainty in this estimate is high, primarily as a consequence of limited data on (a) the vertical distribution of chromium in the aquifer and (b) the distance inland to which the plume extends. Also, the rate of chromium discharge from the overlying vadose zone is unknown, so the total amount of chromium in the environment is probably larger than the rough estimate listed above. However, it does appear reasonable to infer from these numbers that the mass of chromium removed by the treatment system is significant compared to the total mass likely to be present in groundwater. Whatever chromium is removed by the system is not available for discharge through potentially sensitive habitat at the groundwater/river interface.

The concentration of hexavalent chromium in groundwater at the extraction wells has generally declined since the start of operations in October 1997. Trend charts for each extraction well are provided in Figures 2.3-23 and 2.3-24. A decreasing trend may occur for several reasons, including reduction of the level of contamination by the pumping operation, dispersal of the plume by natural processes, lateral shifting of plume boundaries, and removal of sources that re-supply the groundwater plume. The decreasing trends observed in extraction wells, along with the removal of significant amounts of chromium from the extracted groundwater, suggest that the pump-and-treat system is reducing the level of contamination in the aquifer, although the rate of re-supply from the potentially contaminated vadose zone is unknown. If the decreasing trends continue at the extraction wells, concentrations would reach the 22-µg/L target set in the record of decision (ROD 1996a) during the 2004 to 2008 time frame.

The concentration of hexavalent chromium in groundwater at the extraction wells has generally declined since 1997. A decreasing trend may occur for several reasons, including reduction of the level of contamination by the pumping operation, dispersal of the plume by natural processes, and removal of sources that re-supply the groundwater plume.

Concentration trends at four of the five wells designated as compliance monitoring wells are shown in Figures 2.3-25 and 2.3-26. The decreasing concentration trends revealed at the extraction wells are not as evident in the compliance wells, although there is a general sense of a decrease with time, with two exceptions. At wells 199-K-18 and 199-K-126 (not shown on the figures), concentrations have been increasing with time. The cause for the increasing trends is probably related to shifting plume boundaries as a consequence of pumping operations, i.e., higher concentration groundwater is being drawn toward those compliance wells. At wells 199-K-114A and 199-K-117A, which are located near the Columbia River, concentrations are highly variable because of infiltrating river water during high river stage. Withdrawal of groundwater by extraction wells farther inland may enhance the infiltration of river water into the aquifer.

Reduction in risk posed by the target chromium plume is occurring as a result of the interim remedial action pump-and-treat system. Reduction also is occurring as a consequence of (a) natural processes, which include dispersion of the contaminant by groundwater movement, and (b) dilution at the groundwater/river interface and within the free-stream of the river. However, slow downward movement of chromium-contaminated moisture from the vadose zone is likely to continue for many years beneath the footprint of former liquid waste disposal sites, thus maintaining some level of contamination in the aquifer. There is no evidence of chromium-bearing groundwater approaching the 100-K Area from source regions upgradient, other than the groundwater that was pushed upgradient because of radial flow associated with the original mound beneath the 116-K-2 liquid waste disposal trench.

2.3.10 Monitoring at River Shoreline

Groundwater samples are collected annually from aquifer sampling tubes located near the low river stage shoreline and from riverbank seepage sites during the seasonal low river stage, which occurs during the fall months. The tubes were re-sampled during the October to November time period in 1998, 1999, 2000, and 2001 to support the Environmental Restoration Program objectives. Samples from aquifer tubes reflect conditions in the zone of interaction between the groundwater flow system and the river flow system, thus providing a representative sample of groundwater from locations close to the point of discharge into the riverbed.

Riverbank seepage is monitored by the Surface Environmental Surveillance Project, with additional sampling and analysis conducted under the Environmental Restoration program in support of groundwater operable unit investigations. River water is collected along the Hanford Site shoreline at least annually, as part of the Surface Environmental Surveillance Project river monitoring task. Table 2.3-1 lists the analytical results for key constituents in samples collected during fall 2001 from aquifer sampling tubes, riverbank seepage, and nearshore river water (when available). Riverbank seepage is typically a mixture of river water and groundwater. When exposed at the surface during low river stage, it presents a potential human health and ecological risk in areas where groundwater is contaminated.

2.3.10.1 Aquifer Sampling Tubes

Samples collected from the tubes during October and November 2001 were screened for 100-K Area contamination indicators carbon-14, hexavalent chromium, gross beta, strontium-90, sulfate, and tritium (BHI-01624). Hexavalent chromium concentrations ranged from 15 to 59 µg/L downgradient of the 116-K-2 liquid waste disposal trench; samples were not obtained from tubes located opposite the K Reactor complexes. Strontium-90 was not detected in a sample from tube 19-D, located near the 100-K crib (116-K-1). A tritium measurement was made at a site just upstream of 100-K Area (tube 14-D; 7,290 pCi/L), and the result probably represents the arrival of a groundwater plume that has migrated northward through Gable Gap. Tritium and carbon-14 were measured in a tube downgradient from the 118-K-1 burial ground and KE Reactor complex (tube 19-D) with results of 2,020 and 5.33 pCi/L, respectively. The sample's specific conductance indicates the sample contained a significant proportion of groundwater. Nitrate was not measured in any of the tube samples during fall 2001.

Most of the results from the aquifer sampling tubes reflect at least some dilution by river water, as indicated by the specific conductance of the samples relative to groundwater. Consequently, the groundwater approaching the river may contain contaminants at greater concentrations than those listed in Table 2.3-1.

Chromium, strontium-90, and tritium were detected in aquifer sampling tubes or groundwater seeps discharging to the Columbia River shore in the 100-K Area in fiscal year 2002.

2.3.10.2 Riverbank Seepage

Samples of riverbank seepage were collected at three locations adjacent to 100-K Area facilities and waste sites during October 2001 and September/October 2002 Maximum concentrations for contaminants of concern were: 46 µg/L hexavalent chromium; 5.5 pCi/L gross beta; 13.7 mg/L nitrate; and 5,800 pCi/L tritium (see Table 2.3-1). Strontium-90 was detected at a very low concentration (2 pCi/L) at one seepage area adjacent to the 116-K-2 liquid waste disposal trench. Concentrations at all seepage sites sampled are consistent with observations in previous years.

Table 2.3-1. Shoreline Monitoring Data for the 100-K Area, Fiscal Year 2002

Location Name	Sample From[a]	Sample Date	Specific Conductance (µS/cm)[b]	Carbon-14 (pCi/L)	Chromium (µg/L)[c]	Gross Beta (pCi/L)	Nitrate (mg/L)	Technetium-99 (pCi/L)	Trichloroethene (µg/L)	Tritium (pCi/L)
14-D	Tube	11/08/01	341		6			61.9		7,290
19-D	Tube	11/12/01	325	5.33 U	15			-1.1 U		2,020
22-M	Tube	11/12/01	264		56					
23-D	Tube	11/13/01	276		59					
25-D	Tube	11/13/01	289		18					5,150
26-D	Tube	11/13/01	371		36					4,690
SK-063-1	Seep	10/25/01	210		33	4.7	7.53	2.3	2.0	1,200
SK-063-2	Seep	09/16/02	306			5.5	13.7	1.1	2.7	1,440
SK-077-1	Seep	10/25/01	147		3	5.1	0.89	0.0347 U	0.29 U	91 U
SK-082-2	Seep	10/25/01	330		46	2.3	6.86			5,800

U = Below detection limit.

(a) Tube = aquifer sampling tube near shoreline; Seep = riverbank seepage.

(b) Specific conductance provides an indication of the amount of river water in the sample; uncontaminated groundwater is typically in the range of 350 to 450 µS/cm and river water in the range of 120 to 150 µS/cm.

(c) Chromium includes hexavalent chromium and total chromium for filtered samples.

Data sources: Hanford Environmental Information System and various project records.

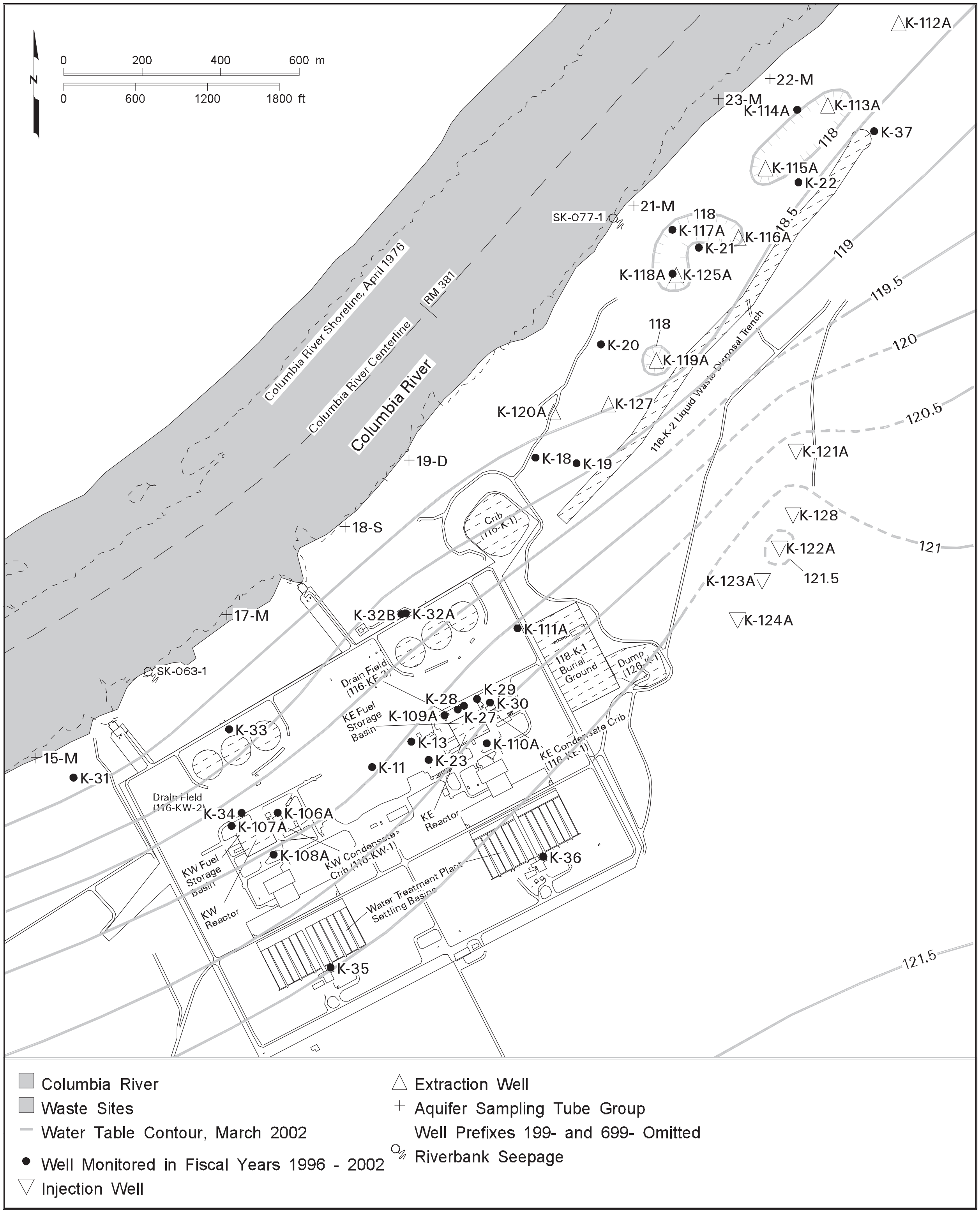

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Figure 2.3-1. Monitoring Wells, Shoreline Monitoring Sites, and Water-Table Contours in the 100-K Area

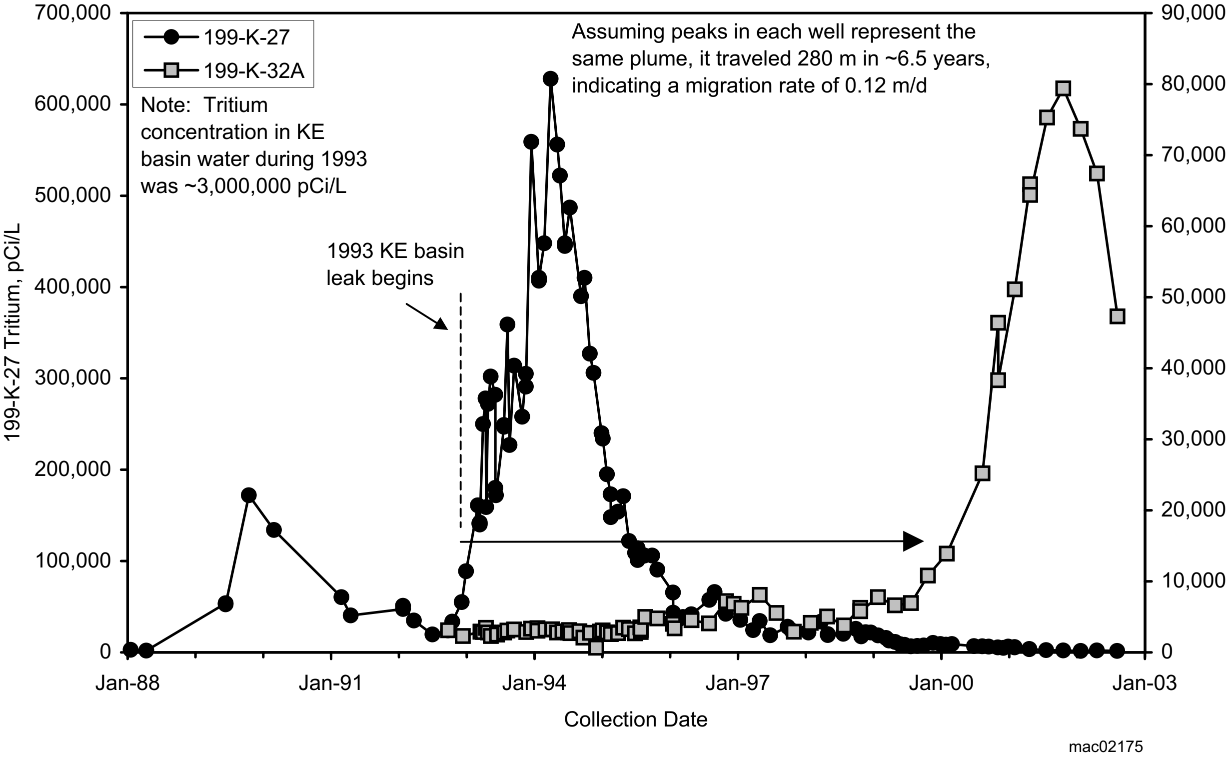

Figure 2.3-2. Tritium Plume Movement Between KE Fuel Storage Basin and the Columbia River

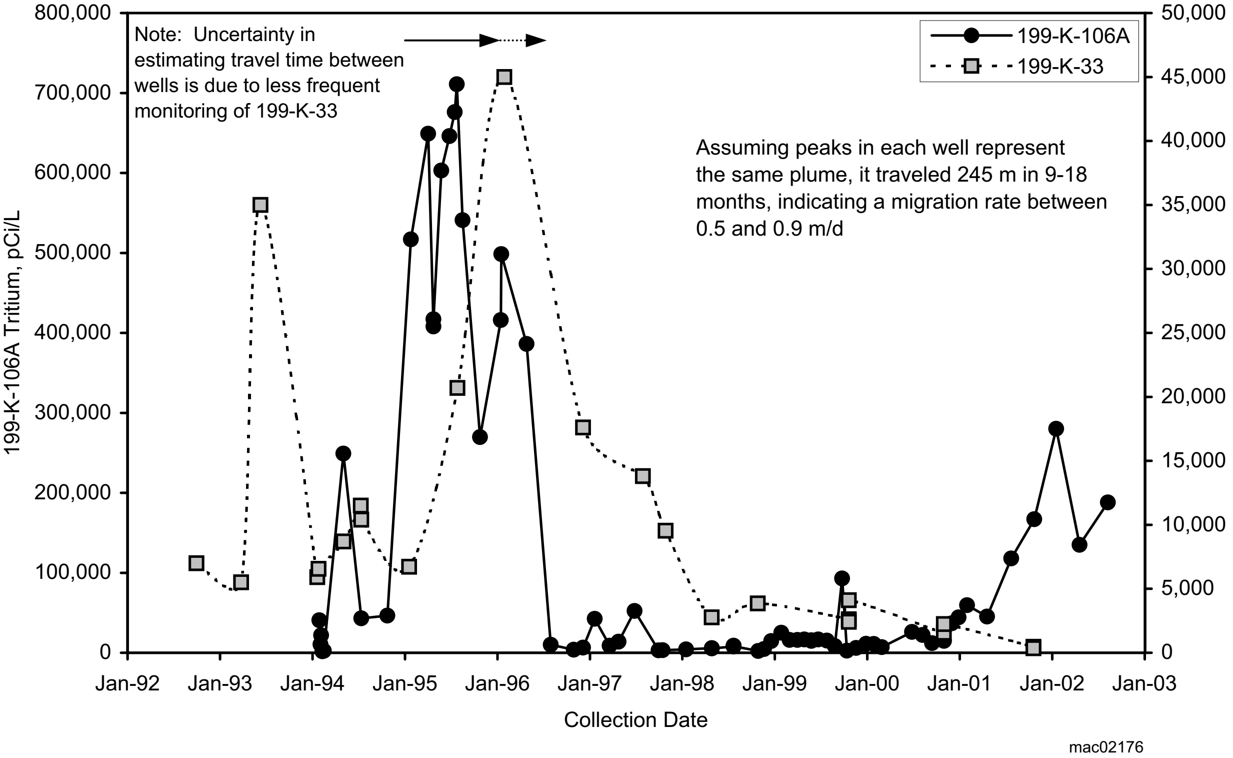

Figure 2.3-3. Tritium Plume Movement Between KW Condensate Crib and the Columbia River

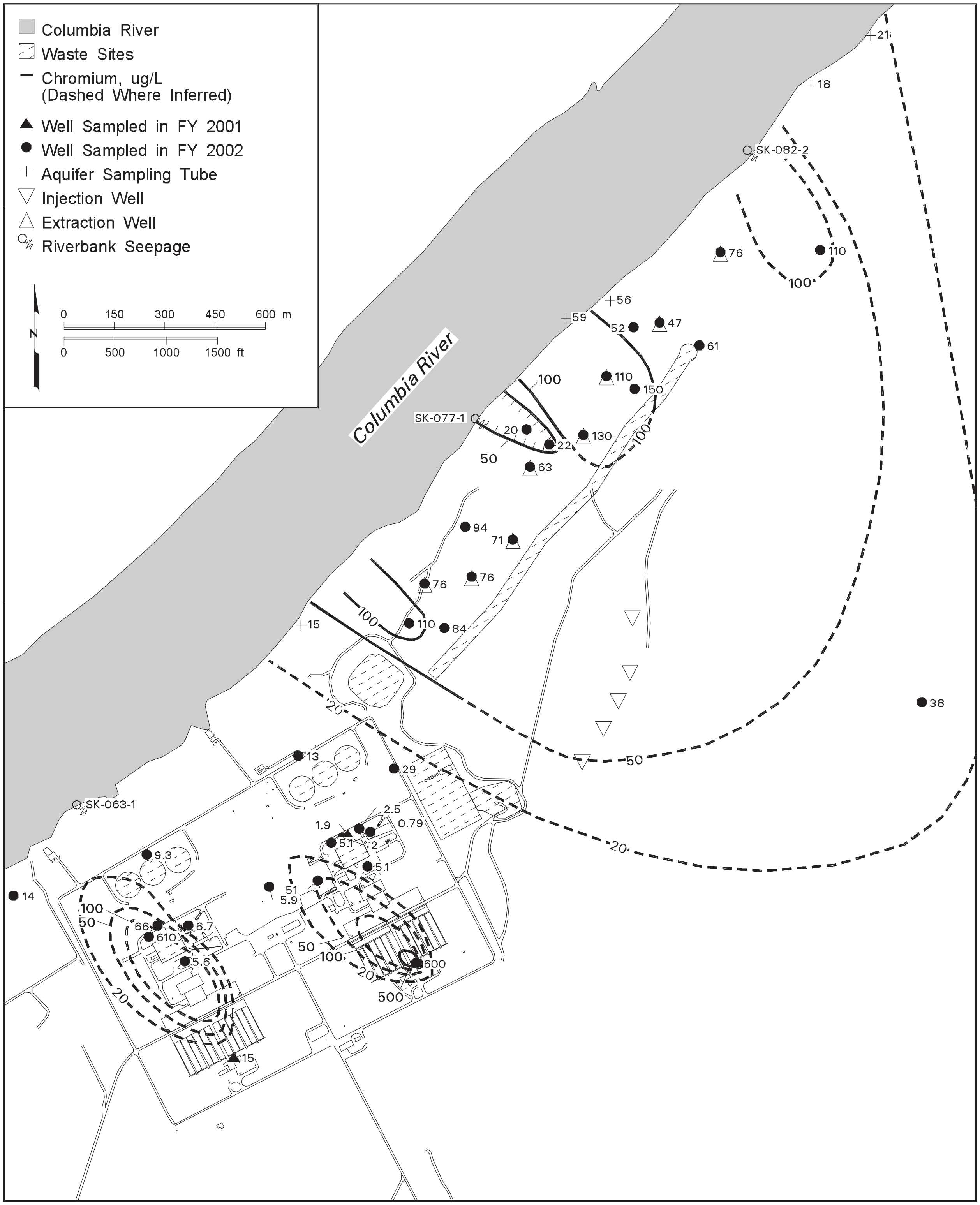

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Figure 2.3-4. Distribution of Chromium in Groundwater Beneath the 100-K Area, Fiscal Year 2002

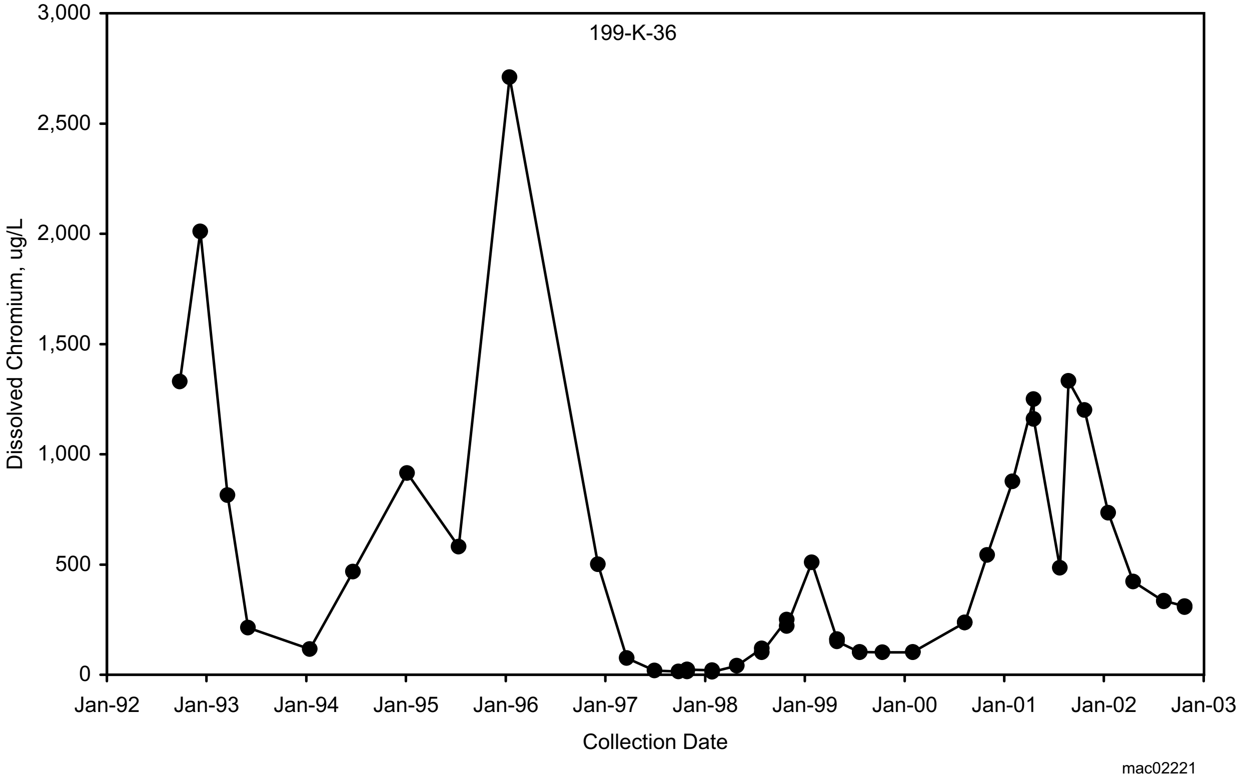

Figure 2.3-5. Dissolved Chromium Concentrations in Groundwater Near the Sodium Dichromate Storage Facilities at the KE Water Treatment Plant

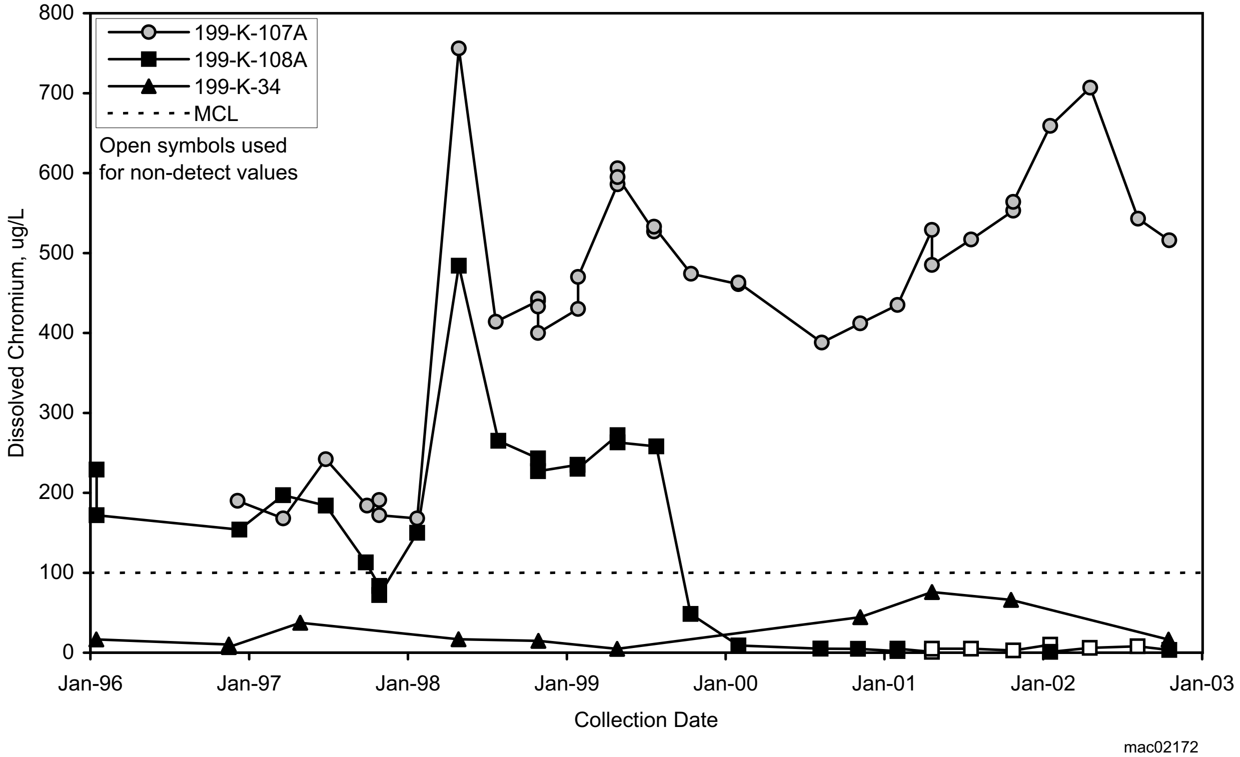

Figure 2.3-6. Dissolved Chromium Concentrations in Wells Near the KW Reactor

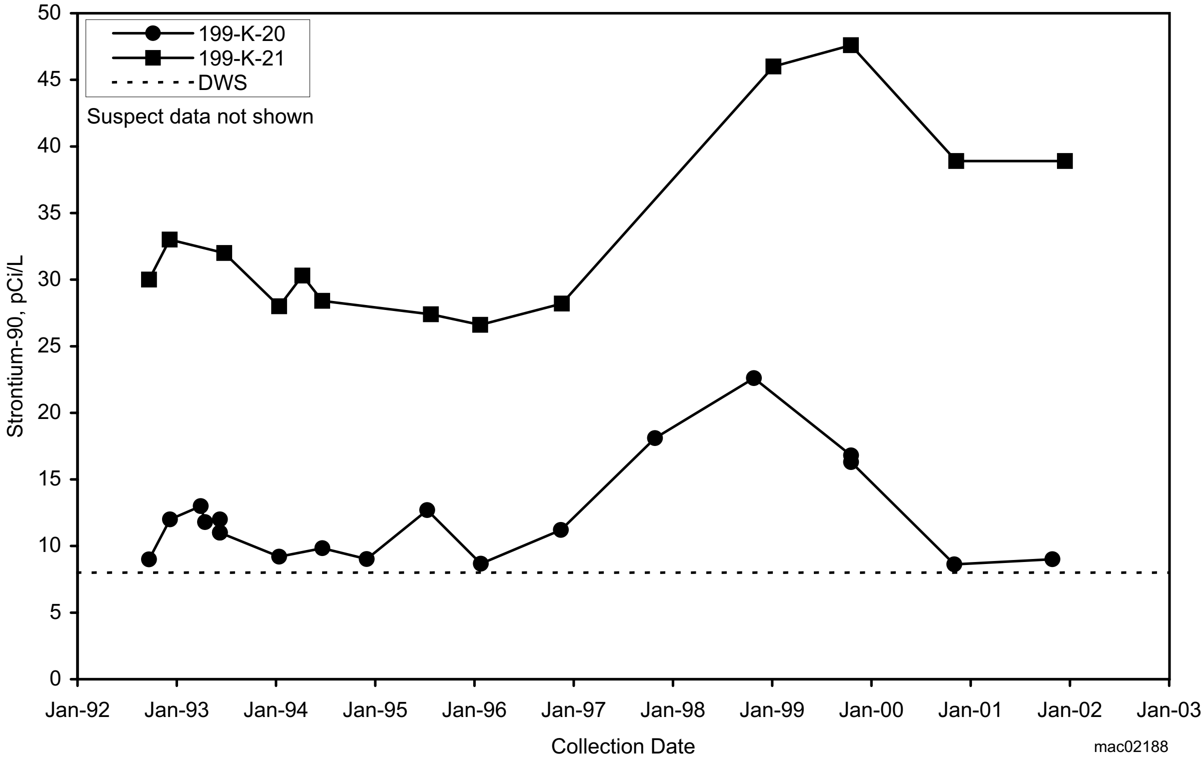

Figure 2.3-7. Strontium-90 Concentrations in Wells Between 116-K-2 Liquid Waste Disposal Trench and the Columbia River

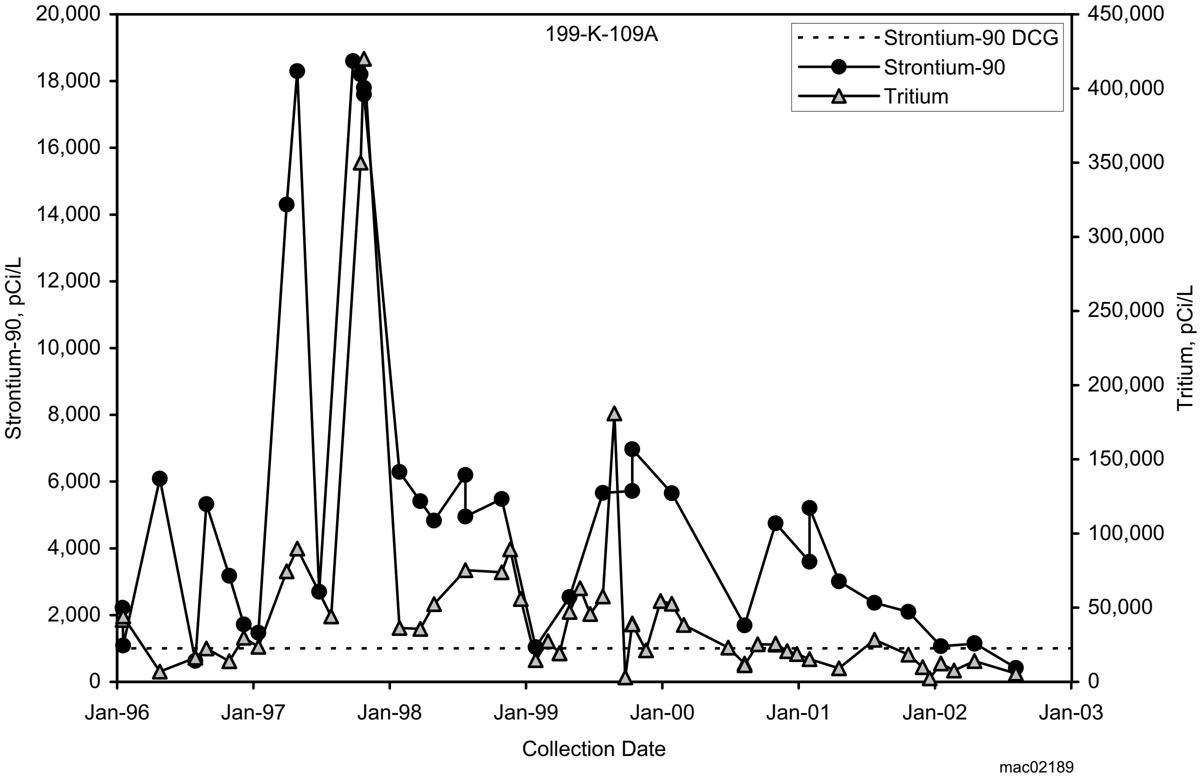

Figure 2.3-8. Strontium-90 and Tritium Concentrations Near the KE Fuel Storage Basin

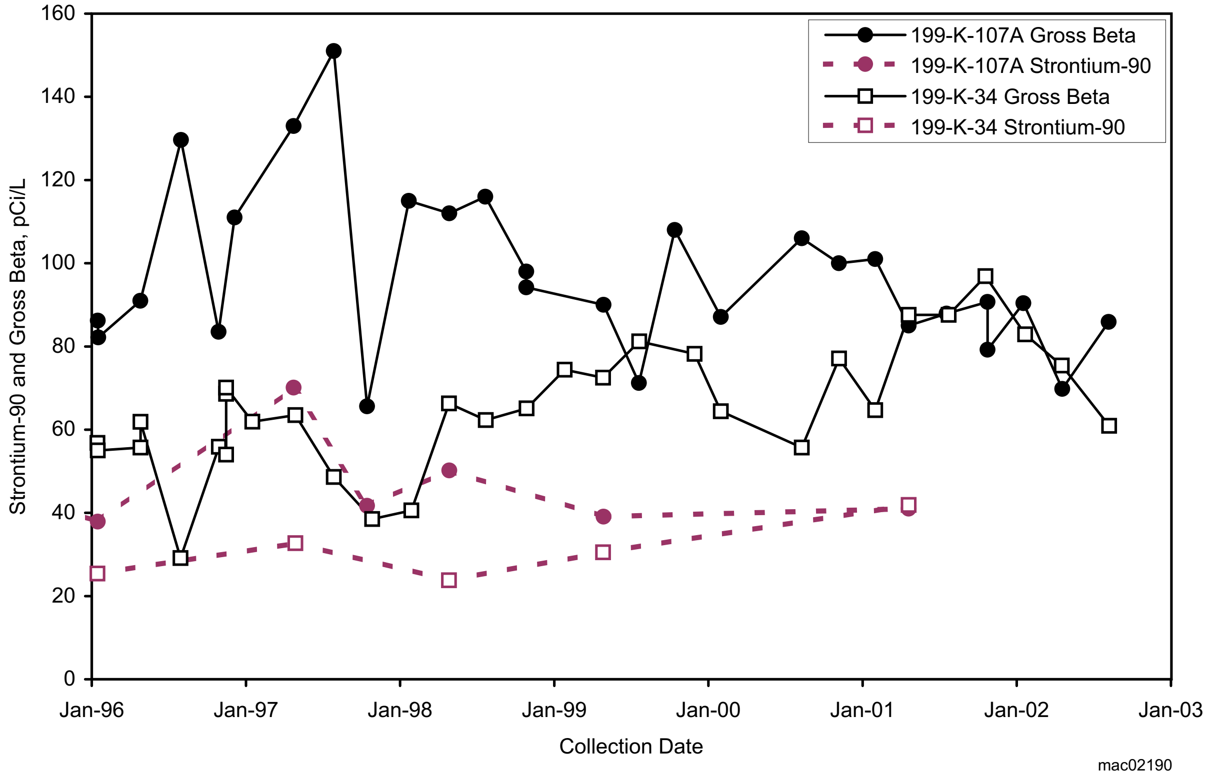

Figure 2.3-9. Strontium-90 and Gross Beta Concentrations in Wells Near the KW Fuel Storage Basin

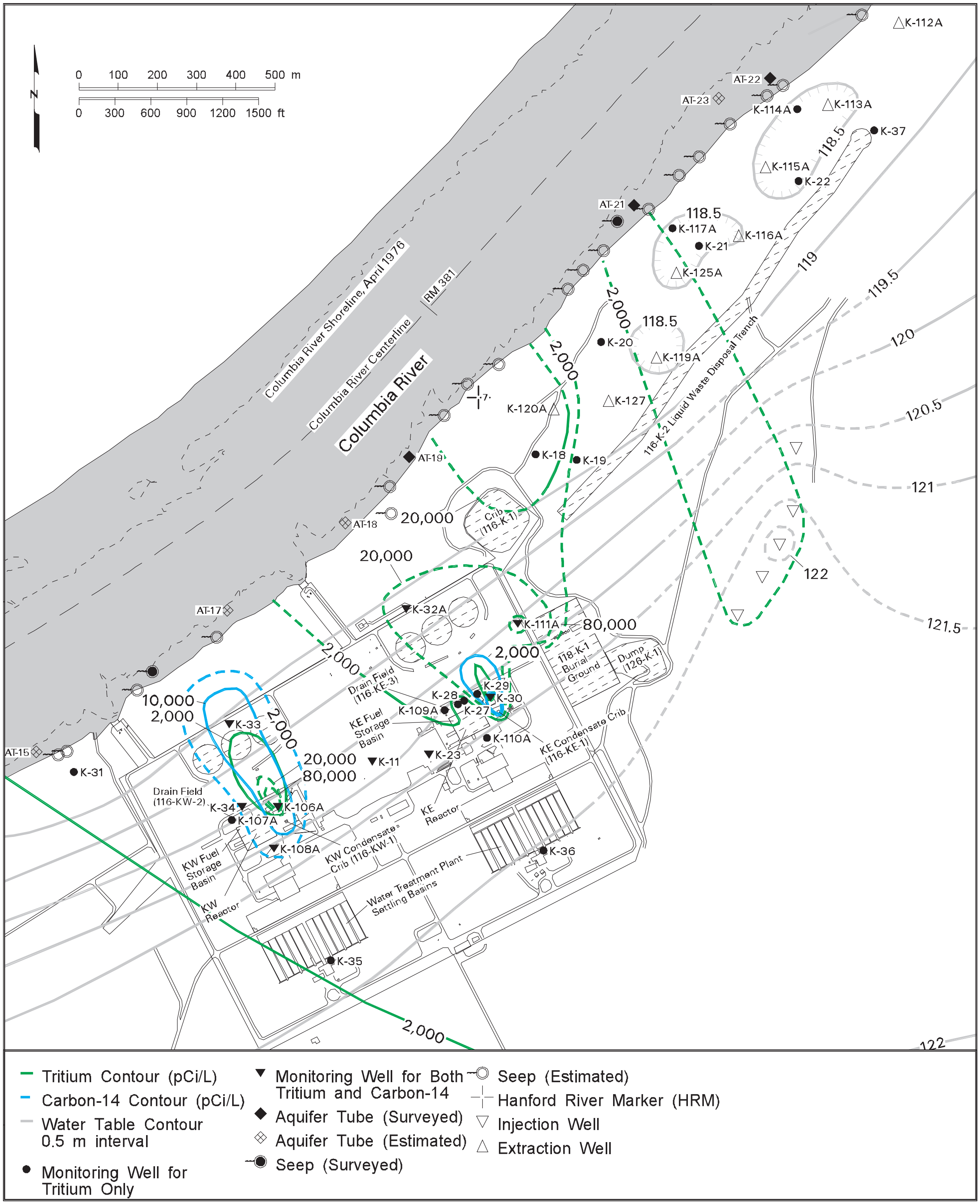

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Figure 2.3-10. Distribution of Tritium and Carbon-14 Beneath the 100-K Area, Fiscal Year 2002

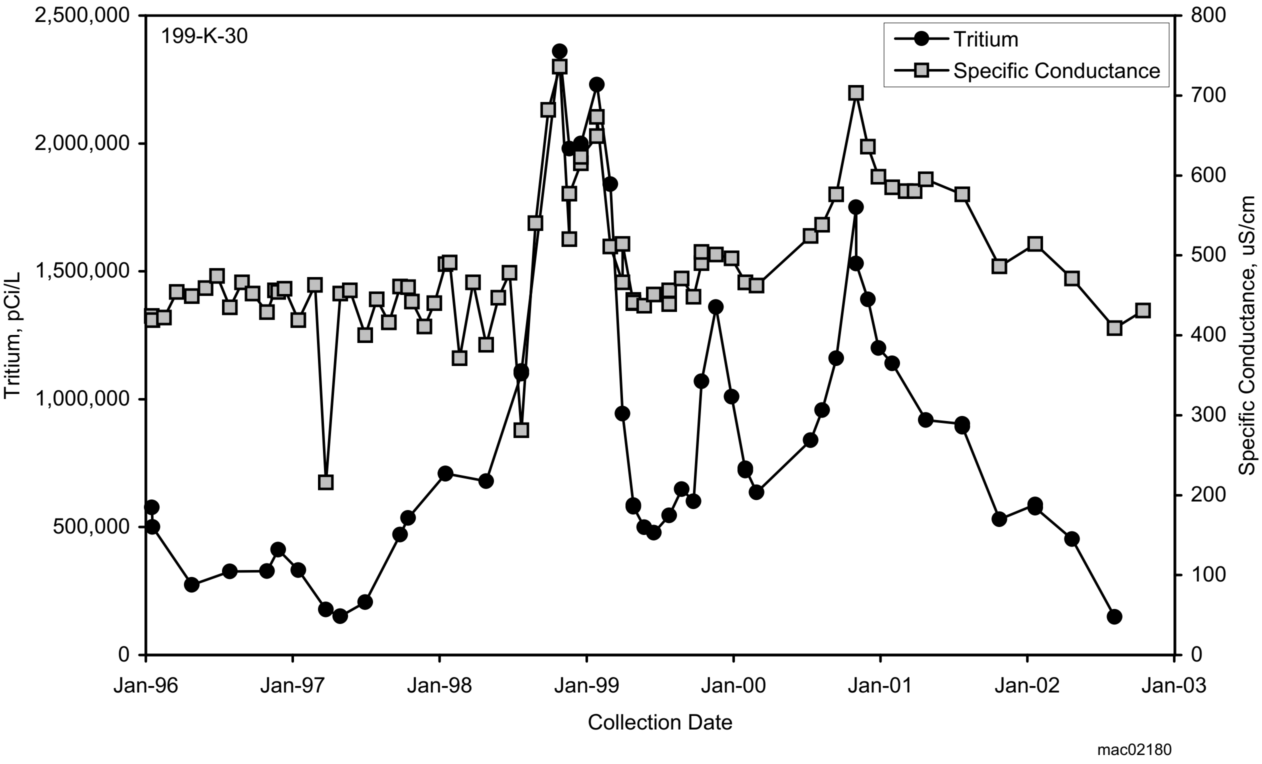

Figure 2.3-11. Tritium Concentrations and Specific Conductance Downgradient of the 116-KE-1 Crib

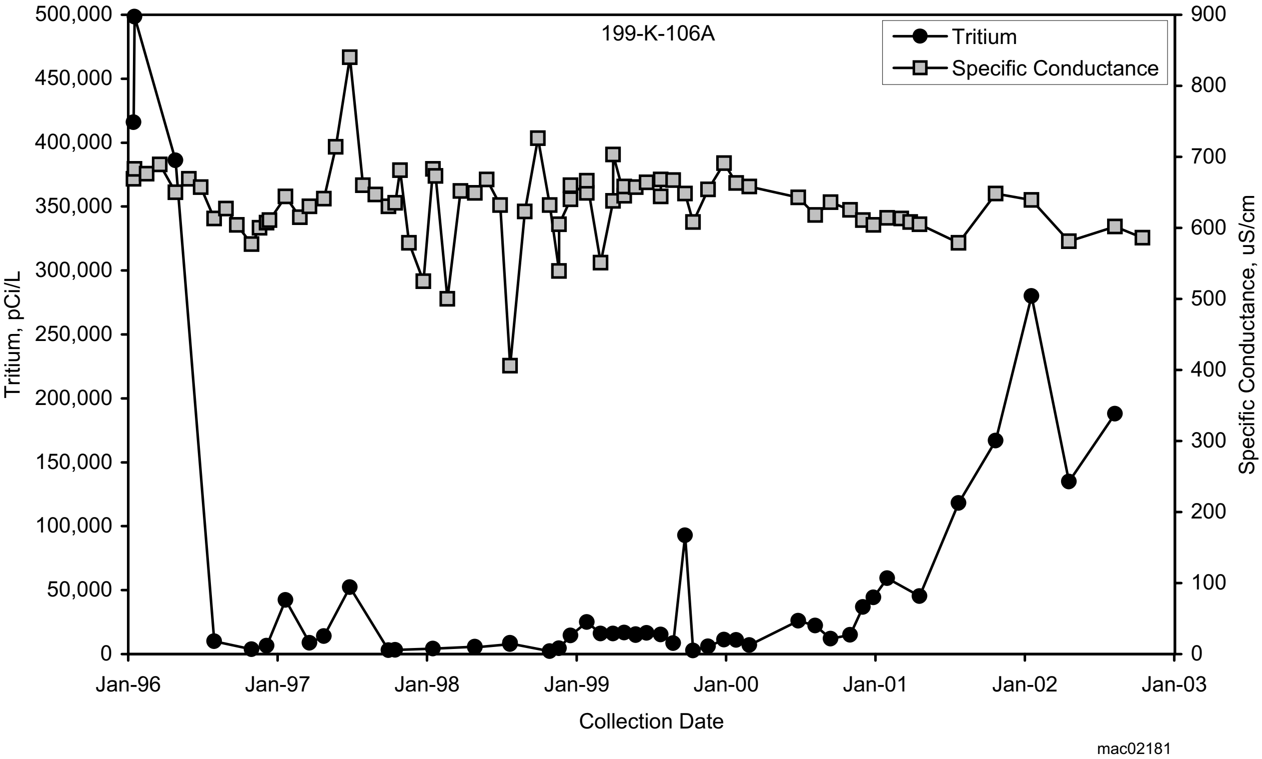

Figure 2.3-12. Tritium Concentrations and Specific Conductance Near the 116-KW-1 Crib

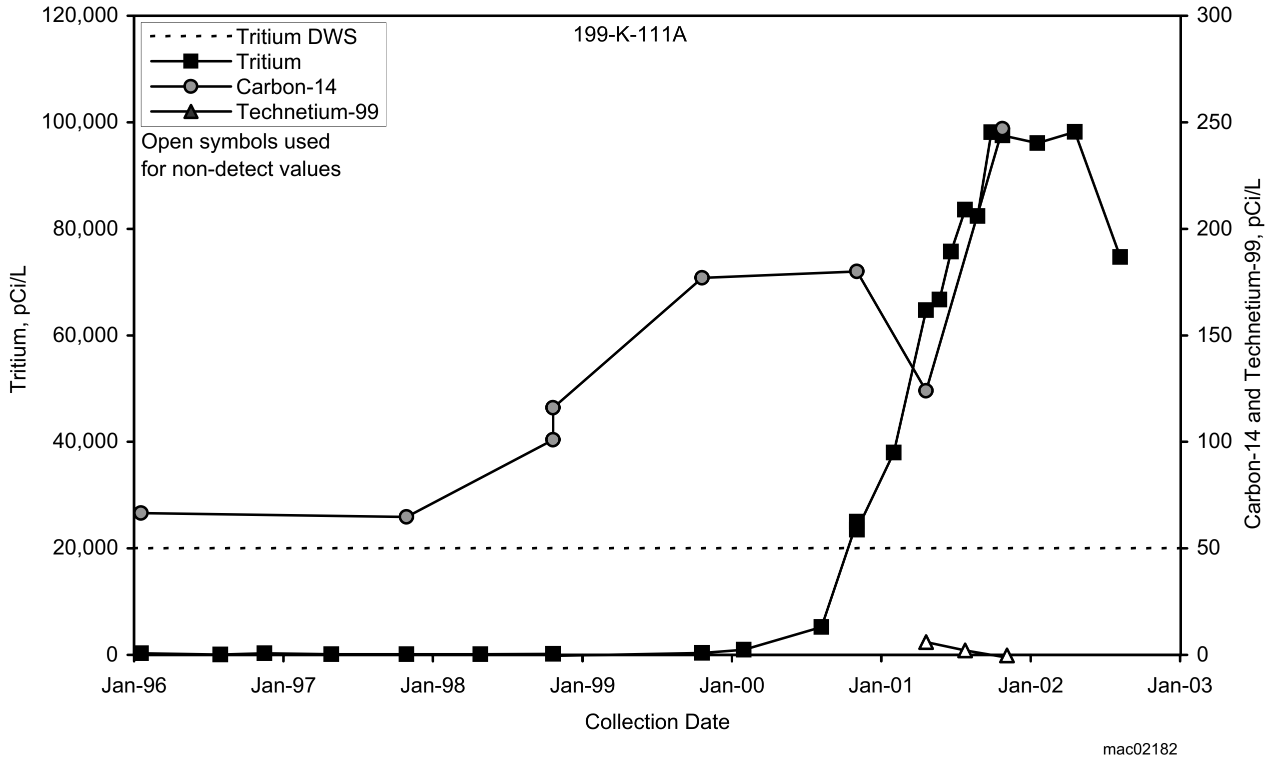

Figure 2.3-13. Tritium, Carbon-14, and Technetium-99 Concentrations at Well 199-K-111A Near the 118-K-1 Burial Ground

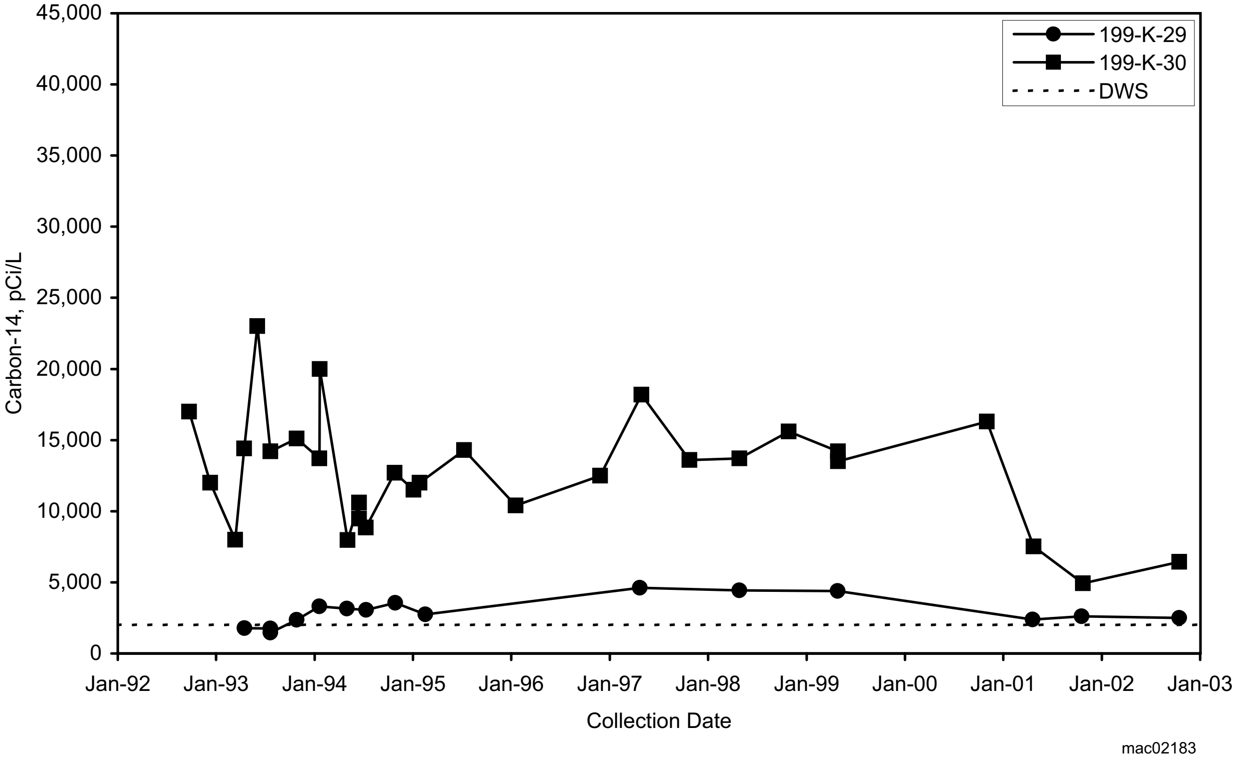

Figure 2.3-14. Carbon-14 Concentrations in Wells Downgradient of the 116-KE-1 Crib

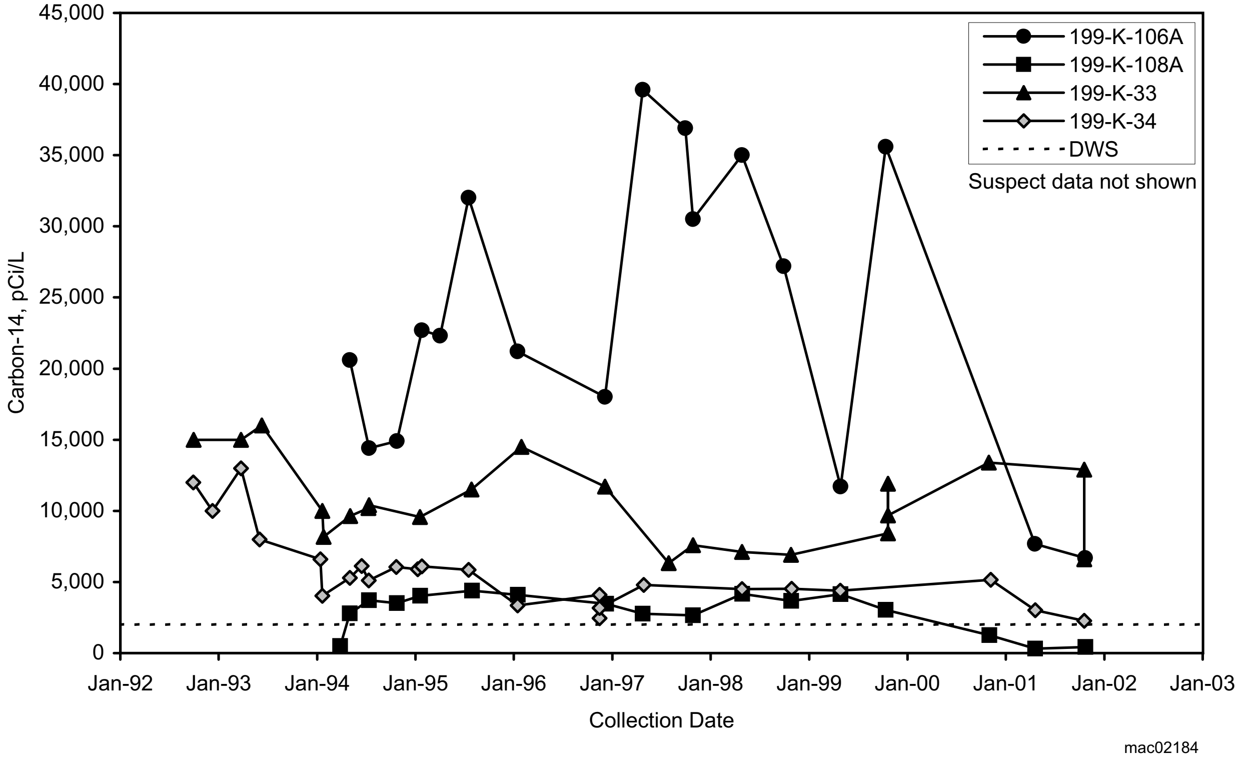

Figure 2.3-15. Carbon-14 Concentrations in Wells Near the 116-KW-1 Crib

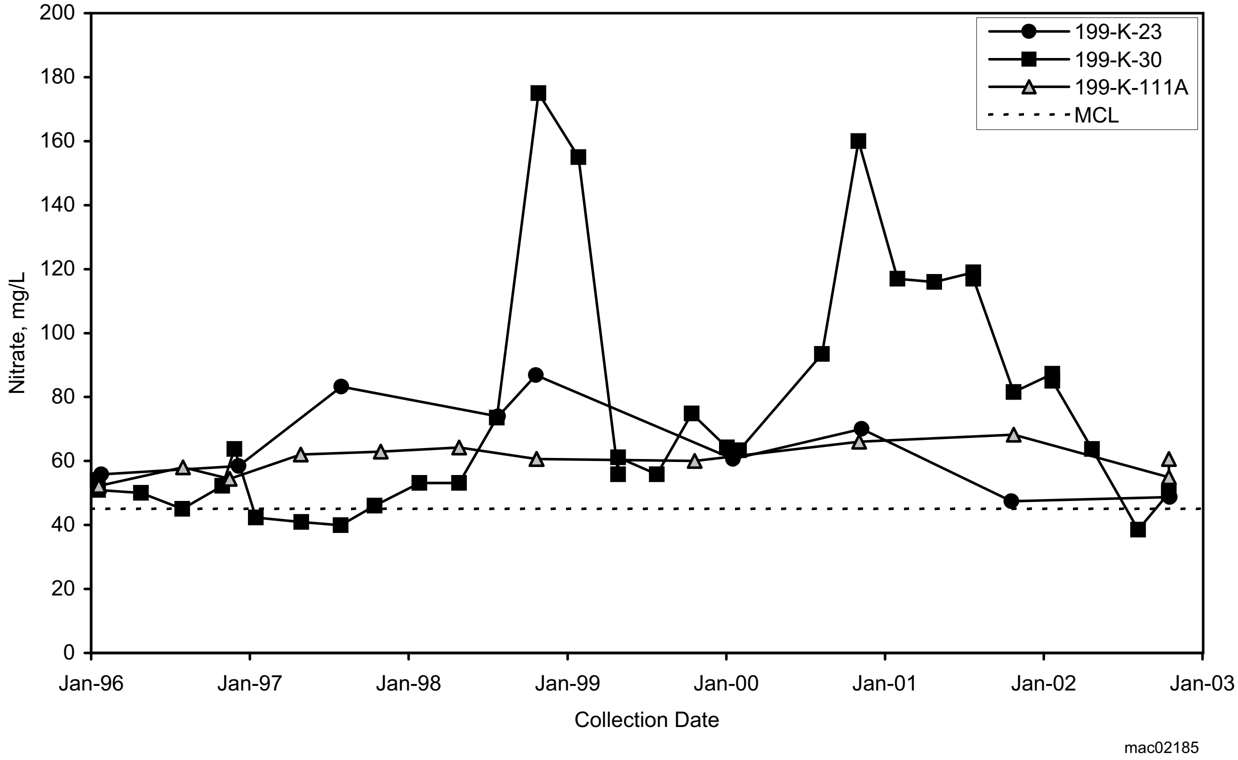

Figure 2.3-16. Nitrate Concentrations in Wells Near the KE Reactor Building

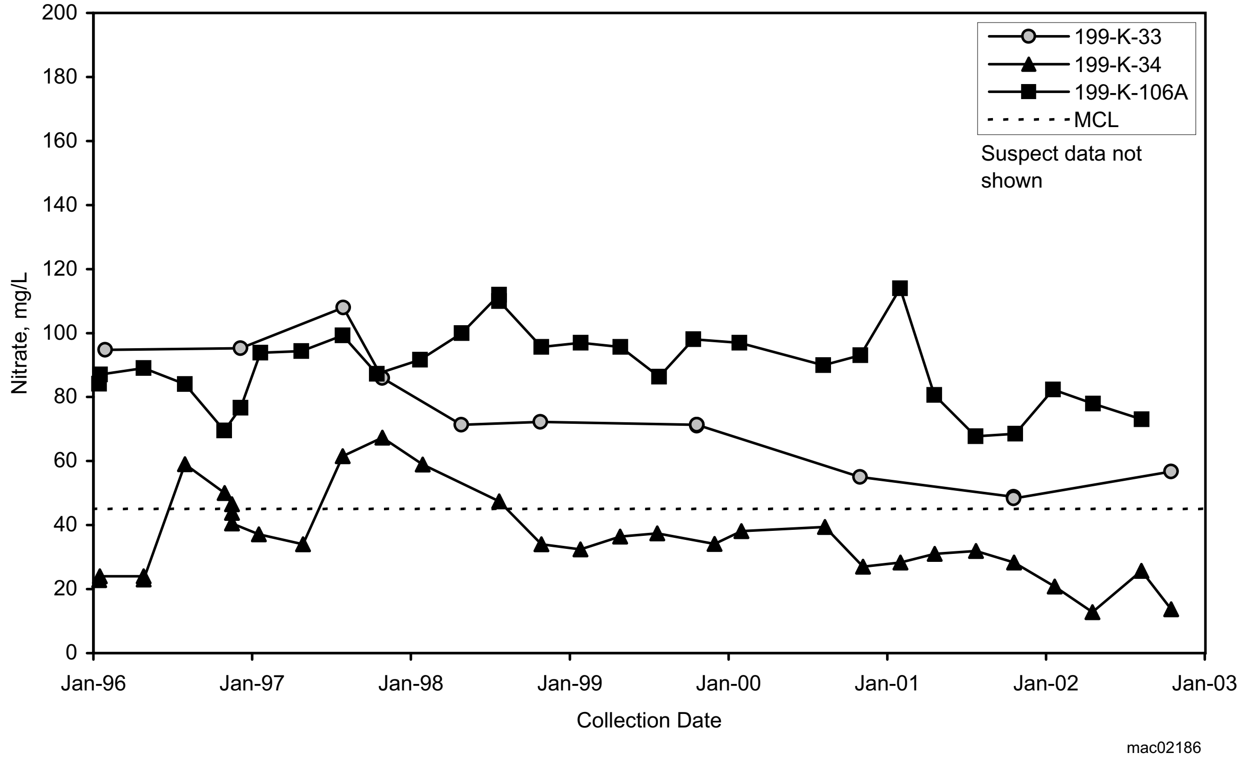

Figure 2.3-17. Nitrate Concentrations in Wells Near the KW Reactor Building

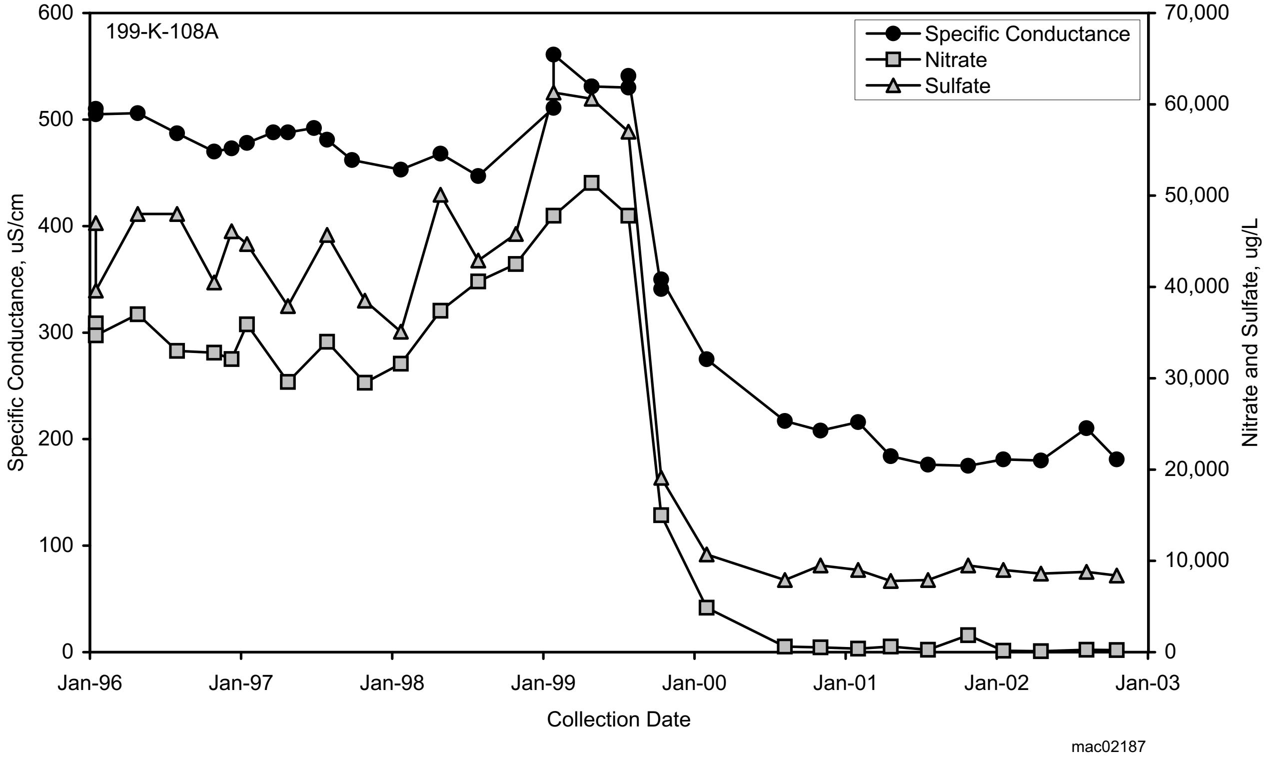

Figure 2.3-18. Dilution of Groundwater by Clean Water Near the KW Reactor Building

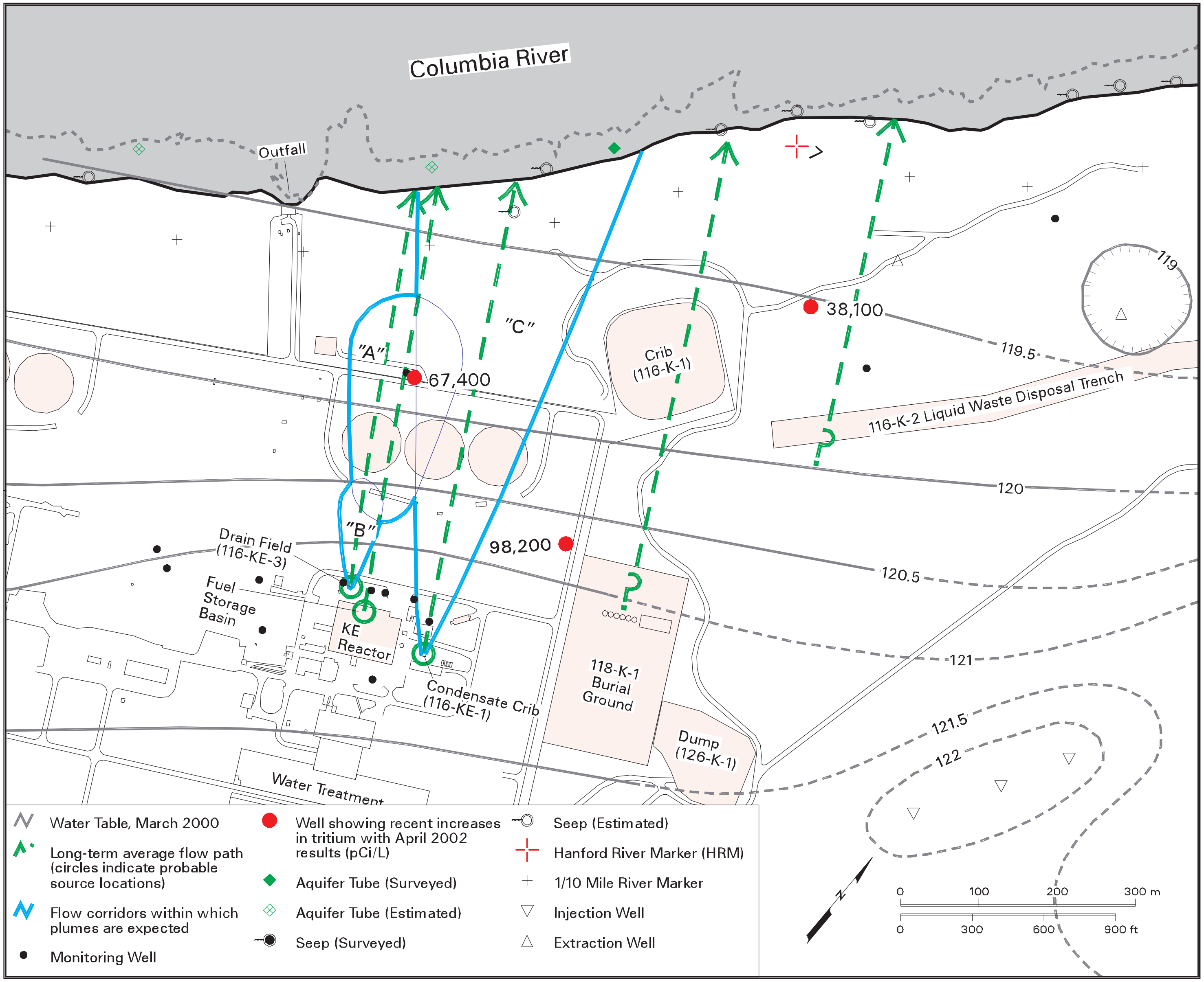

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Figure 2.3-19. Flow Direction Corridors from Tritium Sources Near the KE Reactor Complex

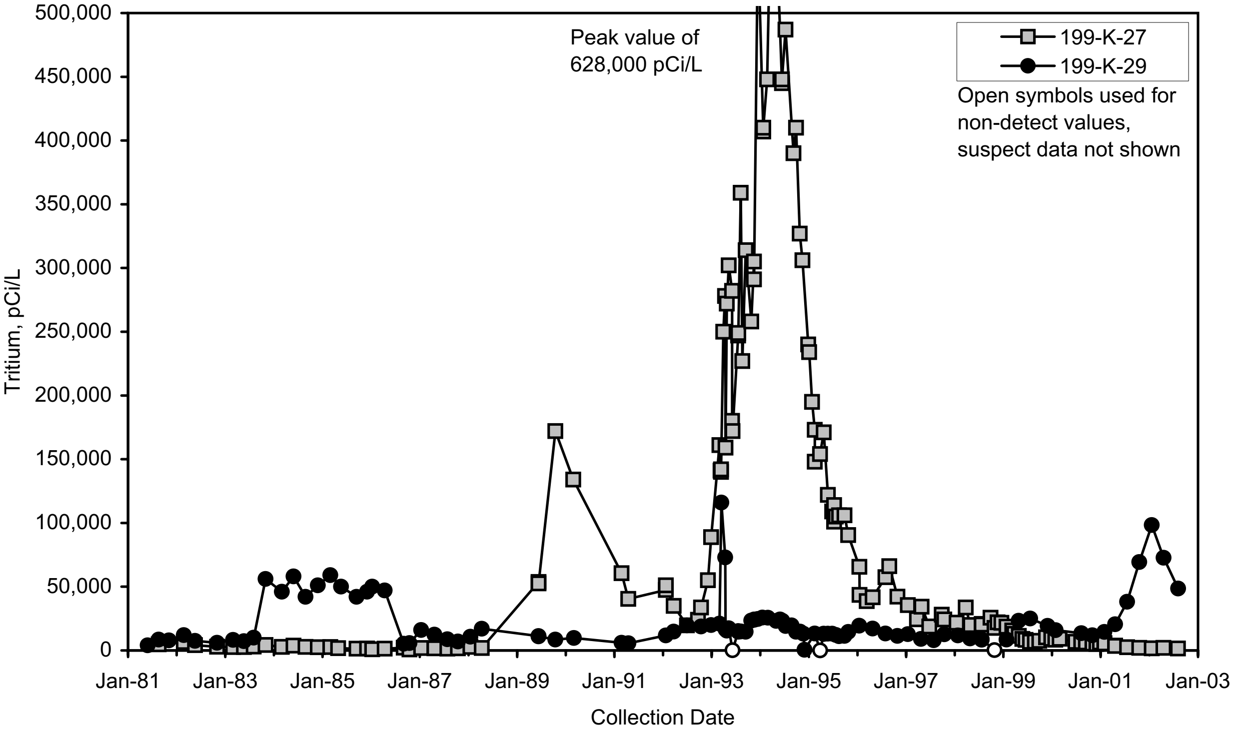

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Figure 2.3-20. Historical Record of Tritium Concentrations in Groundwater Near the KE Fuel Storage Basin

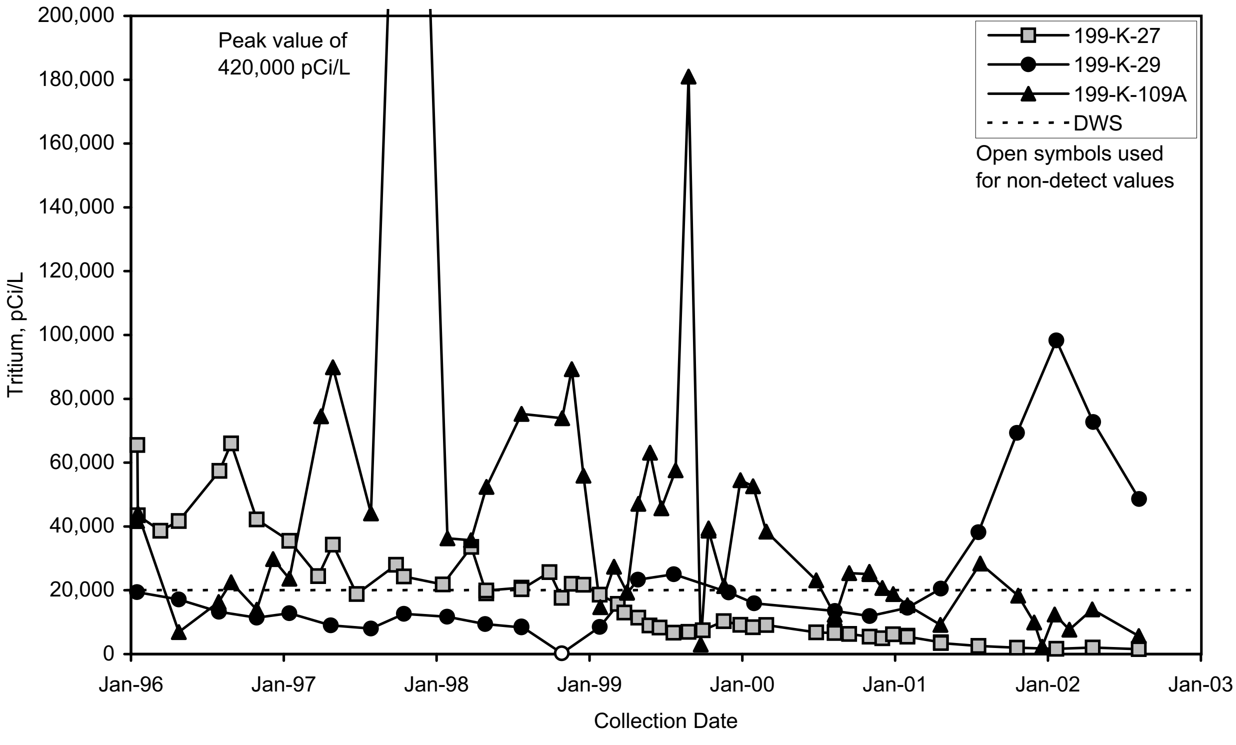

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Figure 2.3-21. Recent Tritium Concentrations in Wells Near the KE Fuel Storage Basin

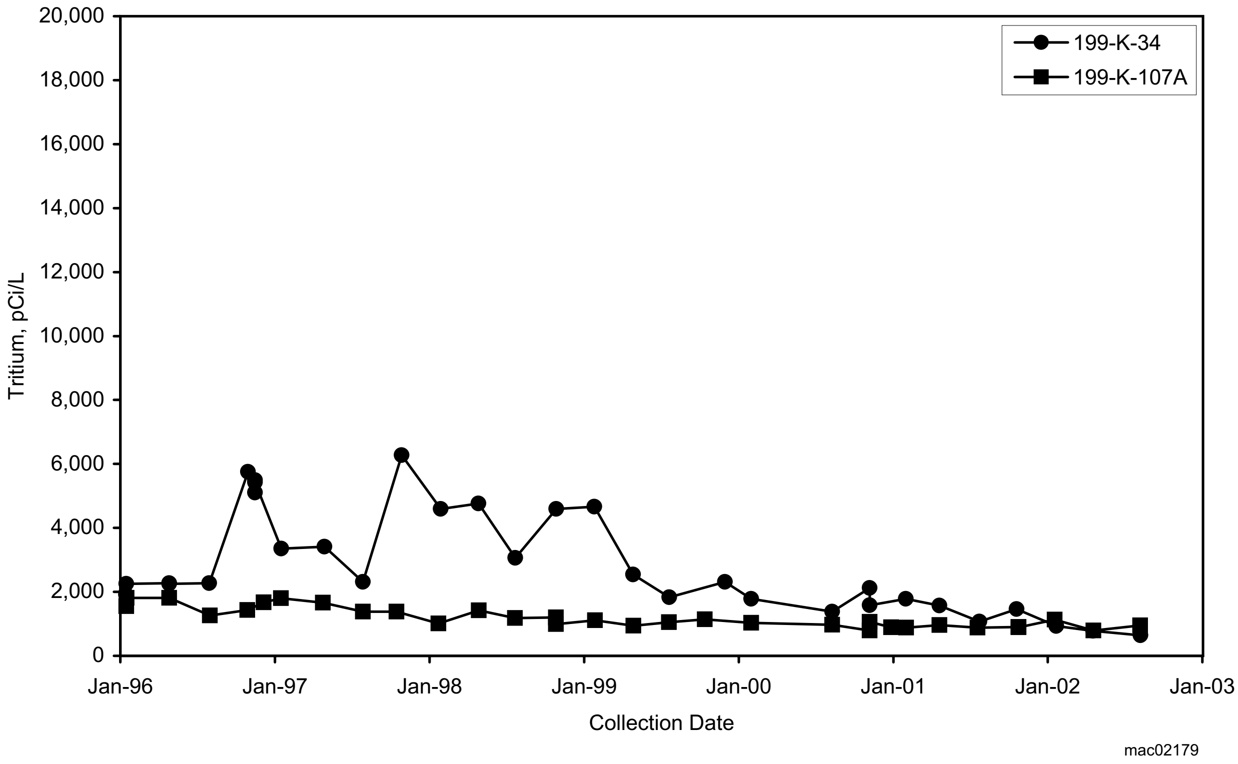

Figure 2.3-22. Recent Tritium Concentrations in Wells Near the KW Fuel Storage Basin

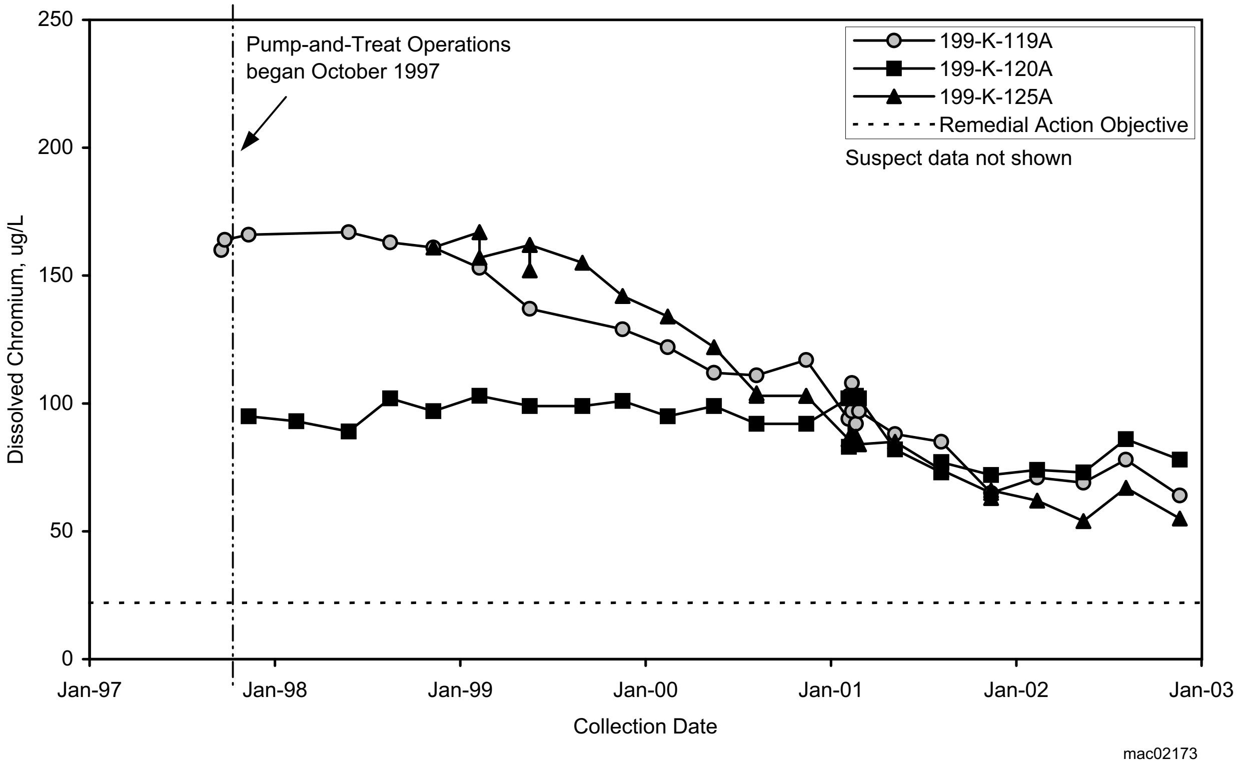

Figure 2.3-23. Dissolved Chromium Concentrations in Extraction Wells at the Southwest End of the 116-K-2 Liquid Waste Disposal Trench

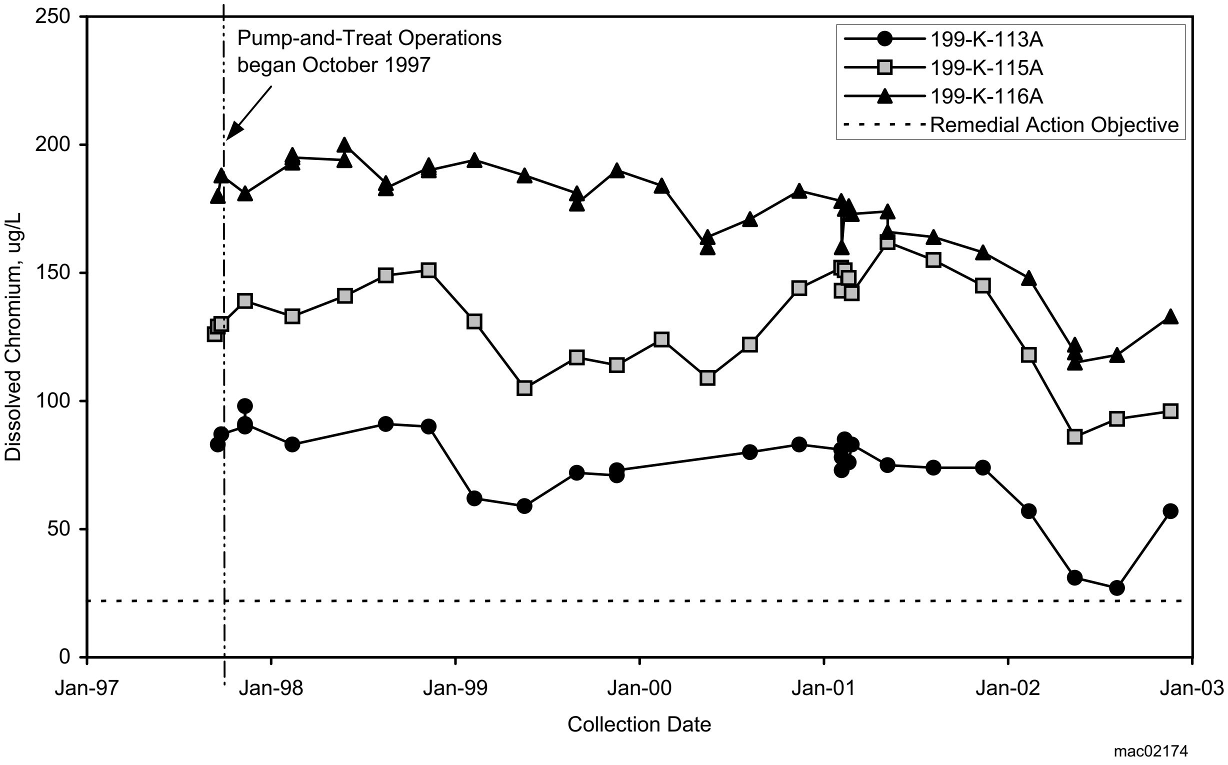

Figure 2.3-24. Dissolved Chromium Concentrations in Extraction Wells at the Northeast End of the 116-K-2 Liquid Waste Disposal Trench

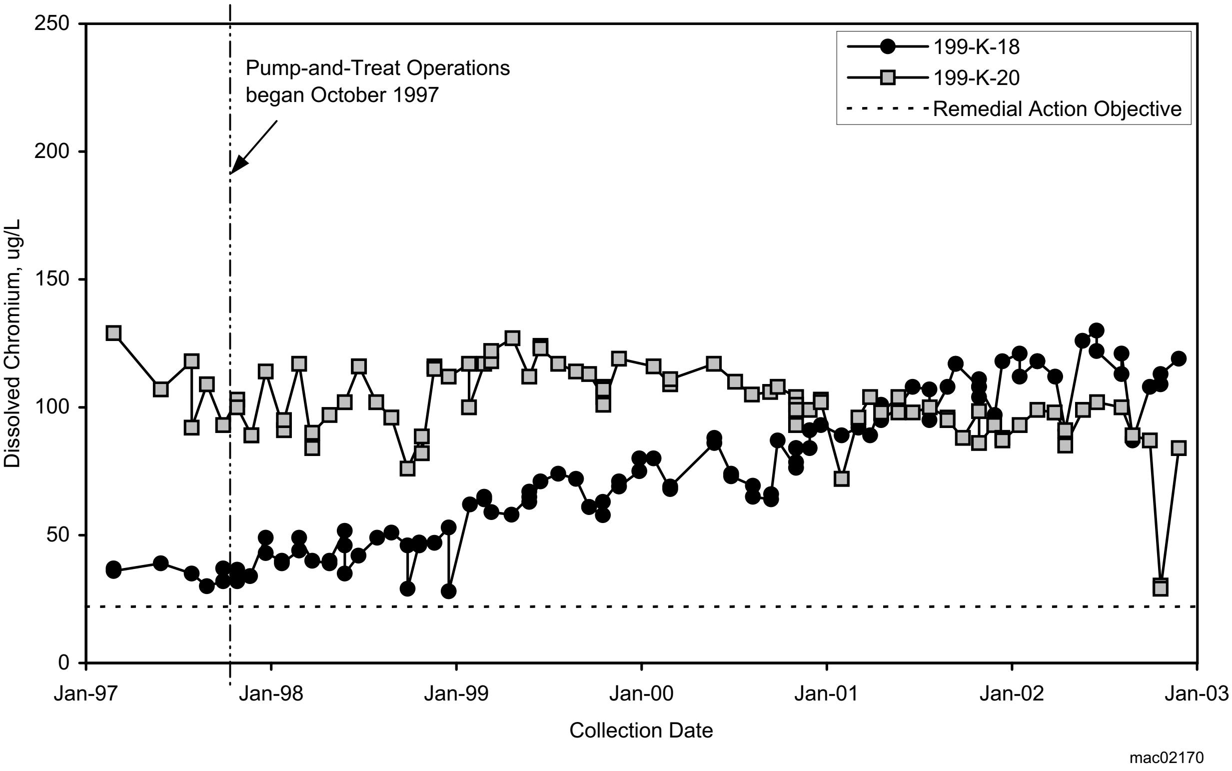

Figure 2.3-25. Dissolved Chromium Concentrations Between Extraction Wells and the Columbia River at the Southwest End of the 116-K-2 Liquid Waste Disposal Trench

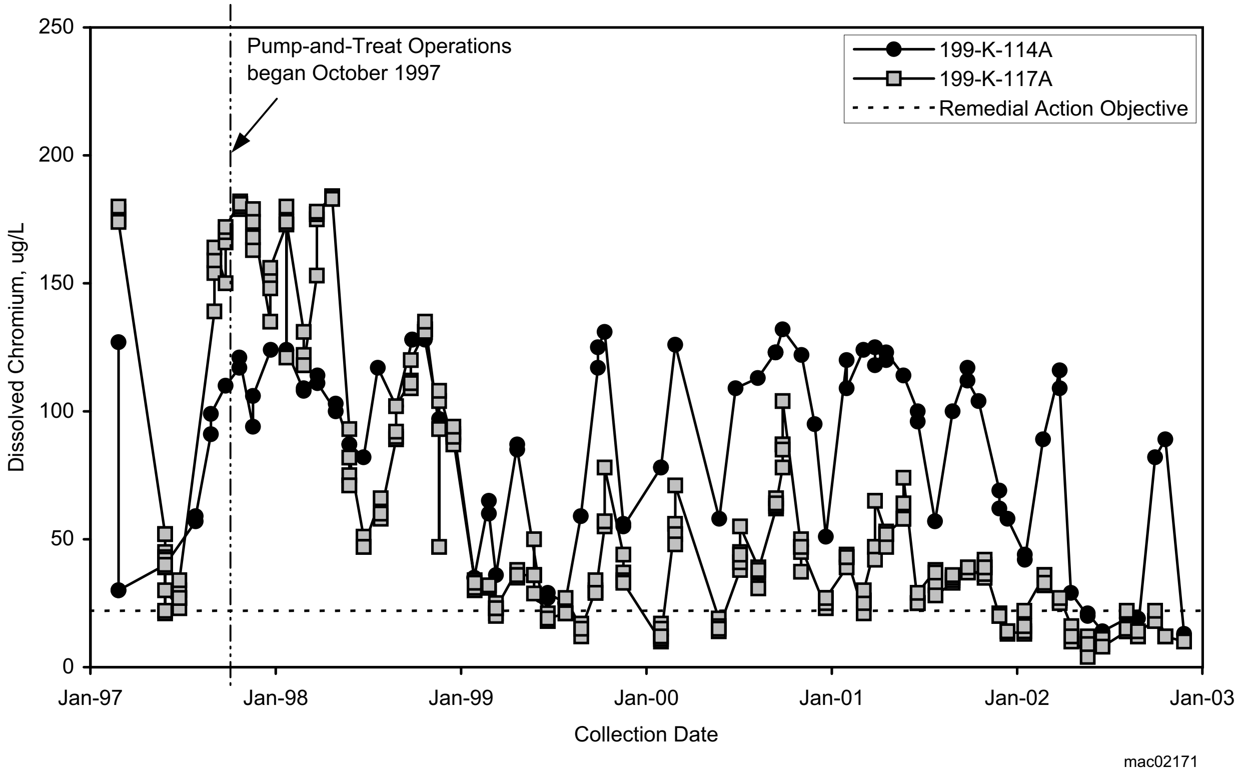

Figure 2.3-26. Dissolved Chromium Concentrations Between Extraction Wells and the Columbia River at the Northeast End of the 116-K-2 Liquid Waste Disposal Trench

2.4 100-N Area

M. J. Hartman

The 100-N Area contains a single reactor that operated from 1963 through 1987. The most significant groundwater contamination is associated with the 116-N-1 and 116-N-3 liquid waste disposal facilities (also known as the 1301-N and 1325-N liquid waste disposal facilities), which are being excavated. Other sources of contamination include the 120-N-1 percolation pond and 120-N-2 surface impoundment (also known as 1324-N/NA facilities) and various spills or leaks of petroleum products. Waste sites and proposed corrective measures are described in DOE/RL-95-111 and DOE/RL-96-39. Facilities and well locations are shown in Figure 2.4-1.

Strontium-90 is the most significant groundwater contaminant in the 100-N Area. It has a relatively low mobility in the aquifer, and the general shape of the plume has not changed in many years.

2.4.1 Groundwater Flow

Groundwater generally flows to the north and northwest beneath most of the 100-N Area, toward the Columbia River (Figure 2.4-2). Estimated flow velocities in March 2002 ranged from 0.04 to 1.3 meters per day (see Appendix A, Table A.2). Movement of a peak in specific conductance at the 116-N-3 facility in 1997 to 1999 indicated a flow velocity within the calculated range, 0.3 meter per day.

River stage in fiscal year 2002 was higher than in the previous 2 years and the water table rose in response. For example, the water level rose in well 199-N-2 in fiscal year 2002 from a historic minimum in fiscal year 2001 (Figure 2.4-3).

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The environmental restoration contractor completed excavation of the 116-N-3 liquid waste disposal facility in fiscal year 2002 and began excavation of the 116-N-1 liquid waste disposal facility (the jagged trench shown above). Also, a pump-and-treat system operated in the 100-N Area to remove strontium-90.

A pump-and-treat system extracts groundwater from wells near the Columbia River. The extraction wells have drawn down the water table, creating a potential for water to flow inland from the river (see Figure 2.4-2).

2.4.2 Strontium-90

Groundwater beneath the 116-N-1 and 116-N-3 liquid waste disposal facilities is contaminated with strontium-90 at levels far above the 1,000-pCi/L U.S. Department of Energy (DOE) derived concentration guide (Figure 2.4-4). Contamination is concentrated in an area between the 116-N-1 facility and the Columbia River where a pump-and treat system is operating (see Section 2.4.9). The contours of Figure 2.4-4 take into account the strontium-90 remaining in the treated water that is injected into wells 199-N-29 and 199-N-104A, near the 116-N-3 facility. The average strontium-90 concentration of the injected water in fiscal year 2002 was 358 pCi/L.

Monitoring Objectives in 100-N Area

Groundwater monitoring is conducted in the 100-N Area:

- triennially to annually to describe the nature and extent of contamination
- semiannually to detect the possible impact of three RCRA sites
- semiannually to monitor trends in variable constituents/wells
- quarterly to monitor potential effects of surface remediation and dust-control water application
- various time intervals to evaluate the performance of a pump-and treat system for strontium-90

Although the general shape of the strontium-90 plume in the 100-N Area has remained relatively constant for more than 10 years, concentrations have increased in many parts of the plume (see Summary of this document or Section 2.5 of PNNL-13404 for comparison maps). During the same period, concentrations decreased in some wells near the 116-N-3 facility and near the extraction wells. Factors that may have contributed to these changes include the following:

(a) Beneath the 116-N-3 facility, water levels dropped after effluent discharge ceased in 1991, leaving much of the strontium-90 above the water table. Therefore, strontium-90 concentrations in groundwater decreased.

(b) After effluent disposal ceased in 1991, groundwater with low specific conductance from effluent recharge was replaced with higher-conductance groundwater from upgradient locations. The calcium in the high-conductance groundwater replaced strontium on the sediment grains, thereby releasing the strontium (including strontium-90) to groundwater. This effect was most notable in wells near the 116-N-3 site, but also was observed near the 116-N-1 facility.

(c) Near the Columbia River and the 116-N-1 facility, high river stage in 1996 and 1997 caused the water table to rise and mobilized strontium-90 that was formerly in the vadose zone. Thus, concentrations in groundwater increased.

(d) Strontium-90 concentrations are highest in the vadose zone and at the top of the aquifer. The extraction wells draw down the water table to a depth where concentrations are lower. Extraction wells also may be inducing flow from the Columbia River into the aquifer, creating a dilution effect.

The strontium-90 plume appears to be limited to the upper few meters of the aquifer. Wells 199-N-69 and 199-N-70 are completed at the bottom of the upper unconfined aquifer, ~4 meters deeper than nearby shallow wells, and have no detectable strontium-90. Well 199-N-80, located near the 116-N-1 facility and completed below a 5-meter-thick clay layer, also has shown undetectable or very low levels (<1 pCi/L) of strontium-90.

Strontium-90 concentrations at 100-N Area vary with changing water-level elevations and ion exchange processes.

In fiscal year 2002, the highest strontium-90 concentration in the 100-N Area was ~18,000 pCi/L in well 199-N-67 in fall 2002 (Figure 2.4-5). This well is adjacent to the 116-N-1 liquid waste disposal facility. Strontium-90 concentrations vary with water level in this well. High water levels mobilize contamination from what is usually the vadose zone.

Near the 116-N-3 facility, strontium-90 trends show the influences of upgradient groundwater chemistry and changing water levels. The peak in strontium-90 concentration in well 199-N-81 in 1997 (Figure 2.4-6) appears to have been related to high-conductance groundwater from the 120-N-1 percolation pond moving through the area and mobilizing strontium that was sorbed to sediment grains. With the influx of the higher-conductance groundwater, more calcium was available for ion exchange with strontium-90 on the sediment grains, thereby releasing the strontium-90 to solution (see Appendix A of WHC-EP-0675). Strontium-90 and specific conductance levels declined between 1997 and 2001, but rose in fiscal year 2002. Strontium-90 concentrations in wells 199-N-27 and 199-N-28, near the 116-N-3 facility, continued to decline in fiscal year 2002.

2.4.3 Cobalt-60

Cobalt-60 was detected unexpectedly at 36.8 pCi/L in well 199-N-67 near the 116-N-1 facility in January 2002 (Figure 2.4-7). This level was confirmed by re-analysis of the sample, but the detection appears to have been an isolated event. Cobalt-60 was present in the effluent discharged to this facility and was commonly detected in groundwater in the past, but levels declined rapidly because of the radionuclide's relatively short half-life (5.3 years). Groundwater samples collected from well 199-N-67 in March, August, and September 2002 contained no detectable cobalt-60. September samples from nearby wells 199-N-2 and 199-N-103A were analyzed for cobalt-60; none was detected.

The recent strontium-90 trend in well 199-N-67 is very different from the cobalt-60 trend (see Figure 2.4-5). In January and March 2002, strontium-90 concentrations were much lower than in recent years. The concentration increased again in August and fell in September 2002.

When the cobalt-60 was detected in well 199-N-67 in January 2002, water levels were low, and the well contained very little water. Water levels rose slightly before subsequent samples were collected. The January sample also had a high turbidity (67 NTU), which may have affected results (the sample was not filtered before analysis). However, strontium-90 was not similarly elevated, and evaluation of historical data does not show a clear relationship between turbidity and cobalt-60 levels. The groundwater project will continue to monitor wells 199-N-67, 199-N-2, and 199-N-103A for strontium-90 and cobalt-60.

2.4.4 Tritium

The tritium plume beneath the 100-N Area continued to shrink in fiscal year 2002 because of migration, dilution, and radioactive decay.

The 116-N-1 and 116-N-3 liquid waste disposal facilities contaminated groundwater with tritium, which forms a plume at levels exceeding the 20,000-pCi/L drinking water standard (Figure 2.4-8). The plume is shrinking, and concentrations are declining in most 100-N Area wells. The general decline is expected to continue because of plume dilution and radioactive decay. The core of the plume (i.e., the highest concentration) was formerly beneath the 116-N-3 facility and has migrated to the northwest. The highest concentrations of tritium currently are detected near the Columbia River (39,300 pCi/L in well 199-N-14). Tritium is present in upgradient wells 199-N-74 and 199-N-52, but at levels below the drinking water standard. The upgradient tritium is believed to have been moved inland by mounding during use of the 116-N-3 facility.

Unlike strontium-90, tritium concentrations are fairly constant with depth in the aquifer. Tritium concentrations in wells 199-N-69 and 199-N-70, completed at the base of the unconfined aquifer, are about the same as in nearby shallow wells. The tritium concentration in well 199-N-69 increased slightly in fiscal year

2002 and now is greater than in the adjacent shallow well 199-N-67. Concentrations in well 199-N-70 are declining at about the same rate as in nearby shallow well 199-N-81. Tritium also is elevated (25,600 pCi/L) in well 199-N-80, monitoring a locally confined aquifer in the Ringold Formation.

2.4.5 Sulfate and Specific Conductance

The 120-N-1 percolation pond added non-hazardous constituents, including sulfate and sodium, to groundwater, creating high specific conductance (>1,000 µS/cm). The plume extends to the north-northwest, presumably discharging to the Columbia River.

The maximum concentration of sulfate in 100-N Area in fiscal year 2002 was 384 mg/L in well 199-N-59, adjacent to the former percolation pond. When high-conductance effluent was being discharged, sulfate concentrations were over 1,500 mg/L. This well was installed when the water table was higher than it is now, and it is shallower than the other wells monitoring the percolation pond. Variations in chemistry with depth may explain why sulfate and specific conductance levels are higher and remaining stable in well 199-N-59, while they are lower (~120 mg/L) and declining in wells 199-N-72 and 199-N-73. The secondary drinking water standard for sulfate is 250 mg/L.

The high-conductance plume is evident in wells near the Columbia River north of the former percolation pond. For example, specific conductance in well 199-N-3 was ~1,100 µS/cm in fiscal year 2002, a decline from levels seen in fiscal year 2001. The decline may be related to increased river stage or to passage of the peak of the plume. Sulfate concentrations in this well averaged ~200 mg/L in fiscal year 2002.

A plume of relatively high-conductance groundwater, which also originated from past discharges to the 120-N-1 percolation pond, is passing beneath the 116-N-3 facility. The plume apparently moved inland when the pond was active and had created a water-table mound 4 meters high. After discharges to the pond ceased, the high-conductance plume began to move in the natural flow direction (north and northwest). The plume apparently passed the location of upgradient well 199-N-74 in the early 1990s (before the well was installed), and is passing through downgradient wells 199-N-81 and 199-N-41. Specific conductance and sulfate increased sharply in well 199-N-81 in September 2002. None of the other wells in this area showed similar trends.

2.4.6 Nitrate

Nitrate concentrations remained above background levels beneath the 100-N Area in fiscal year 2002. Concentrations increased in wells upgradient of the area, and the sources of nitrate contamination are not known.

Nitrate exceeds the 45-mg/L maximum contaminant level in portions of the 100-N Area, but the sources have not been specifically identified (Figure 2.4-9). The nitrate does not appear to originate from an upgradient location because there is no apparent front of the plume moving with the groundwater. The nitrate does not appear to be coming from deeper in the aquifer because deeper wells have lower nitrate concentrations than the adjacent shallow wells. The nitrate could conceivably represent drainage of nitrate-contaminated water from the vadose zone near the 116-N-1 and 116-N-3 facilities, which received nitrate-bearing waste during their use. Historical data from wells near those facilities show elevated nitrate in the mid-1980s. However, this does not explain the elevated nitrate near the reactor building or near the 120-N-1 percolation pond, where the effluent did not contain high levels of nitrate.

The largest area of nitrate contamination at levels above the maximum contaminant level includes well 199-N-59 near the 120-N-1 percolation pond, wells near the reactor building, and wells near the south end of the 116-N-1 facility (see Figure 2.4-9). Concentrations in the latter area dropped sharply in fiscal year 2002 (see well 199-N-67 in Figure 2.4-10). Nitrate concentrations exceeded the maximum contaminant level in September 2002 in well 199-N-32 near the 116-N-3 facility, but the annual average was slightly below the standard.

Nitrate concentrations increased in many wells in the 100-N Area (and other 100 Areas) in the mid-1990s. Concentrations have declined or leveled off in most wells since the late 1990s (see Figure 2.4-10). The reason for these changes is unknown. Nitrate concentrations continued to rise in fiscal year 2002 in well 199-N-52 upgradient of 100-N Area facilities. The concentrations increased from 23 mg/L in 1994 to 36 mg/L in 2002. Levels also are increasing in upgradient well 699-81-58 (18 mg/L in January 2002).

Several wells near an area contaminated with petroleum products have anomalous, low nitrate values. For example, nitrate has been historically below detection limits in well 199-N-18 and has a highly variable trend in well 199-N-16. This anomaly appears to be related to chemically reducing conditions brought on by bacterial breakdown of petroleum products.

2.4.7 Petroleum Products

Concentrations of residual petroleum products from a 1960s leak (DOE/RL-95-111) increased in well 199-N-18 in September 2001 and remained elevated in 2002. Lower levels of contamination were detected in wells 199-N-3 and 199-N-19 (both cross-gradient to 199-N-18) and 199-N-96A (downgradient on the river bank).

Of the affected wells, 199-N-18 is closest to the former leak site and has the highest levels of groundwater contamination (Figure 2.4-11; note logarithmic scale). The well is sampled with a bailer. In 2001 and 2002, groundwater samplers noted a petroleum odor and visible oil on their equipment or in samples. Total petroleum hydrocarbons in the diesel range had the highest concentrations and results decreased between 2001 and 2002. Because of the nature of the contaminant (a light, nonaqueous liquid), it is difficult to determine whether samples are representative of overall groundwater conditions. However, when laboratory results are supported by field observations, it is apparent that contamination was higher in 2001 and 2002 than in the previous 5 years.

Contamination from an old leak of petroleum products was detected in one well in fiscal year 2001 and in three additional wells in 2002.

Samples from well 199-N-3 in March and September 2002 contained lower levels of contamination than well 199-N-18 (Figure 2.4-12; note difference in scale). Well 199-N-3 has had elevated total organic carbon levels, but these have declined since late 2000 (Figure 2.4-13). No oil sheen was noted during sampling this well in 2001 or 2002. Samples from this well in September 2002 were analyzed for oil and grease and for total petroleum hydrocarbons (in the gasoline, diesel, and all ranges). Only oil and grease have been detected in this well, and levels are much lower than in well 199-N-18. Samples also were analyzed for volatile organic compounds. Levels were below detection limits or were so low that they are not considered significant.

Well 199-N-19 is located southwest of well 199-N-18 and has had evidence of petroleum hydrocarbon contamination in the past. The groundwater project sampled this well for petroleum hydrocarbons in March 2002, the first time since 1996. No oil sheen was noted during sampling. Total petroleum hydrocarbons in the diesel and gasoline ranges were undetected in 1996 and 2002; oil and grease was detected at 9.9 mg/L in March 2002 (see Figure 2.4-12).

Well 199-N-96A, on the bank of the Columbia River, had low but detectable levels of oil and grease and total petroleum hydrocarbons in the diesel range for the first time in September 2002 (see Figure 2.4-12). There was no visible oil sheen in the water from this well. Samples also were analyzed for volatile organic compounds. Results showed no significant detections. Total organic carbon levels were 4,300 μg/L in 2001 and increased to 8,300 μg/L in September 2002.

Groundwater chemistry in the petroleum-contaminated area suggests that bacterial degradation of the product is taking place, creating reducing conditions in the aquifer. Chemical reduction may explain anomalous, low nitrate and high iron and manganese concentrations in wells 199-N-16 and 199-N-18.

Groundwater chemistry in the petroleum-contaminated area suggests that bacterial degradation of the product is taking place

In fiscal year 2002, the groundwater project followed up on an earlier observation of an oily smell observed while measuring the water level in a cased borehole in the Hanford Generating Plant, adjacent to the 100-N Area. Numerous wells and boreholes installed in the 1970s for geologic characterization studies are present in the plant area. They were not intended to be monitoring wells, and no groundwater data are available. During a field inspection in spring 2001, one borehole, labeled 699-84-62A, contained only ~0.3 meter of water, with a water level only 5 meters below top of casing – too high to represent the water table. The water seemed to give off an oily smell. The borehole was sampled with a bailer in October 2001. At that time, the water did not have a noticeable organic smell nor any visible organic layer on the water. The water was very dirty and contained mud, fur, feathers, and grass. When samplers attempted to filter the water, it clogged the filter. The water was orange-colored, presumably because of rust, had a specific conductance of 19,000 μS/cm, and a pH of ~8.9. Samples were analyzed for total petroleum hydrocarbons in the diesel range (0.6 mg/L), gasoline range (undetected), and tritium (undetected). There was not enough water for additional analyses.

The sample appears to have represented stagnant water in the casing, which has now largely been removed, and no additional sampling is planned. Other boreholes in the Hanford Generating Plant are much deeper and reach groundwater. A few are potentially useable for groundwater monitoring. Sampling was cancelled in fiscal year 2002 because of higher priorities elsewhere on the Hanford Site.

2.4.8 Chromium

Only one well in the 100-N Area consistently has chromium concentrations above the 100-μg/L maximum contaminant level. Well 199-N-80, which is completed in a thin, confined aquifer in the Ringold Formation, typically has chromium concentrations of ~170 μg/L. The source for chromium in this deep horizon is unknown. Chromium was disposed of in the 116-N-1 facility until the early 1970s, and it was identified as a contaminant of potential concern based on soil data (see Section 2.5 in DOE/RL-96-39). There are no chromium data from wells that monitored the facility in the early 1970s, and chromium was not detected in significant concentrations in wells near the crib in the 1980s. One potential explanation for the elevated chromium involves corrosion of the stainless steel well screen.

2.4.9 Groundwater Remediation at the 100-NR-2 Operable Unit

The pump-and-treat system at the 100-NR-2 Operable Unit, located along the 116-N-1 facility, is part of an interim action that began operating in 1995. The primary objective of the pump-and-treat system is to reduce strontium-90 contaminant flux from the groundwater to the Columbia River (Ecology and EPA 1994; ROD 1996b).

The extraction wells create a hydraulic sink between the 116-N-1 facility and the Columbia River and, thus, reduce or reverse the hydraulic gradient in the groundwater toward the Columbia River. The reduction or reversal of the hydraulic gradient results in less groundwater discharging to the Columbia River through the N Springs area. However, the pump-and-treat system is not capable of controlling the water discharged because of the cyclical river stage and bank storage effects of the Columbia River. A complete description of the progress and effectiveness of the remedial action in calendar year 2001 is presented in DOE/RL-2002-05.

The distribution of strontium-90 is illustrated in Figure 2.4-4. Groundwater is pumped from three extraction wells in the strontium-90 plume: wells 199-N-75, 199-N-103A, and 199-N-106A. An additional well, 199-N-105A, is an alternate extraction well and was used for one month in fiscal year 2002. Strontium-90 concentrations have varied greatly in the extraction wells since pumping began in 1995 but remained fairly level in fiscal year 2002 (Figure 2.4-14). The highest concentrations are detected in the well farthest north, 199-N-106A. Strontium-90 concentrations in the extraction wells may be lower than concentrations at the top of the aquifer in the same locations, because except for well 199-N-75, the extraction wells are screened over virtually the entire aquifer thickness. This may explain why concentrations are relatively low in extraction well 199-N-103A, while they are much higher in nearby monitoring wells 199-N-2 and 199-N-46, which have shorter screens near the top of the aquifer.

Extraction wells between the 116-N-1 facility and the Columbia River have created a hydraulic sink, reducing the amount of strontium-contaminated groundwater entering the river. However, the pump-and-treat system has not removed a significant quantity of strontium-90 mass. Since operations began in 1995, the pump-and-treat system has removed 1.3 curies of strontium-90 while ~12 curies of the estimated inventory have decayed naturally.

During fiscal year 2002, the pump-and-treat system extracted over 120 million liters of groundwater and removed ~0.2 curie of strontium-90. Combined, the extraction wells delivered an average concentration of 1,934 pCi/L to the treatment system during the fiscal year. After treatment, the effluent contained 358 pCi/L strontium-90 and was returned to the aquifer through wells 199-N-29 and 199-N-104A.

The pump-and-treat system has not reduced the concentration of strontium-90 in the aquifer, nor has it removed a significant quantity of strontium-90 mass compared to the estimated existing inventory. The distribution of strontium-90 in the aquifer remained essentially unchanged in recent years.

Since operations began in 1995, the pump-and-treat system has removed 1.3 curies of strontium-90, compared to a total inventory in the aquifer estimated to exceed 75 curies. Assuming a starting inventory of 75 curies in September 1995, ~12 curies of the estimated inventory have decayed during this time. The pump-and-treat system's removal of strontium-90 is insignificant compared to radioactive decay. Current estimates indicate that it will take >300 years before the strontium-90 concentrations reach permissible levels (DOE/RL-95-110) as a result of radioactive decay. For this reason, DOE is investigating and evaluating alternative remediation technologies.

A review of alternative remediation technologies for the 100-N Area concluded that monitored natural attenuation, phytoremediation, and reactive barriers are promising remediation approaches that warrant further study. Phytoremediation involves planting trees or shrubs near the river shoreline to take up strontium-90 from the groundwater through their roots. Leaves and debris from the trees would be collected and disposed elsewhere. The reactive barrier involves injecting a liquid form of the mineral apatite into the aquifer, where it would solidify into a permeable treatment zone. As groundwater flows through the apatite, strontium-90 would be immobilized. Phytoremediation and the reactive barrier could be used together at the 100-N Area to reduce the amount of strontium-90 entering the Columbia River. DOE is evaluating both of these methods to determine their strengths and limitations. DOE also has funded laboratory studies to evaluate the uptake of strontium-90 by aquatic plants and fish, to support site-wide and site-specific risk assessments.

A review of alternative remediation technologies for the 100-N Area concluded that monitored natural attenuation, phytoremediation, and reactive barriers are promising remediation approaches that warrant further study.

2.4.10 RCRA Parameters for 116-N-1 and 116-N-3 (1301-N and 1325-N) Facilities

Monitoring for the *Resource Conservation and Recovery Act* (RCRA) in fiscal year 2002 indicated these liquid waste disposal facilities are not contaminating groundwater with non-radioactive, hazardous constituents. Specific conductance was elevated in some wells, but reflects non-hazardous contaminants from upgradient sources. Appendix A contains more information about these sites.

The 100-N Area RCRA facilities do not appear to have contaminated groundwater with hazardous, non-radioactive constituents.

Downgradient of the 116-N-1 facility, specific conductance of groundwater declined beneath the critical mean value in well 199-N-3 in fiscal year 2002 (Figure 2.4-15). The plume causing the high conductance originated at the 120-N-1 percolation pond (see Section 2.4.5).

Specific conductance in 116-N-3 downgradient wells 199-N-41 and 199-N-81 continued to exceed the critical mean value in 2002 (Figure 2.4-16). This area of high specific conductance also is believed to originate at the 120-N-1 percolation pond. Because the 116-N-3 facility is not the source, no assessment is required.

In March 2002, the average of replicate measurements of field pH (7.25) in well 199-N-3 was below the lower limit of the critical range for pH (7.34 to 8.44; Figure 2.4-17). The critical range for fiscal year 2002 was based on recent data from upgradient wells 199-N-34 and 199-N-57. Because the recent pH data in the upgradient wells showed less variability than earlier periods (Figure 2.4-18), the critical range became narrower. Thus, although pH in well 199-N-3 did not decrease in March 2002, it was below the revised lower limit.

It appears that the lower-than-background pH in well 199-N-3 is caused by the overall distribution pattern of pH in the 100-N Area (Figure 2.4-19). An area of relatively low pH probably is related to the presence of hydrocarbon contamination from an old diesel spill site, located south of well 199-N-3 (see Section 2.4.7). Because the low pH is not related to a release from the RCRA unit, the site remains in detection monitoring.(a)

Total organic carbon concentrations in well 199-N-3 exceeded the critical mean value in the past, but declined below that level in fiscal year 2002 (see Figure 2.4-13). The contamination originated from a nearby petroleum leak site (see Section 2.4.7), not the 116-N-1 facility.

Groundwater at the 116-N-1 and 116-N-3 facilities also is analyzed for other constituents discharged to these facilities during their use. These constituents include cadmium, chromium, and nitrate (see Appendix A). Cadmium and chromium (in filtered samples) were not detected in significant concentrations in downgradient wells. Nitrate was elevated in some of the downgradient wells, as discussed in Section 2.4.6, but the sources are unclear.

2.4.11 RCRA Parameters for 120-N-1 and 120-N-2 (1324-N/NA) Facilities

RCRA monitoring in fiscal year 2002 indicated these facilities have not contaminated groundwater with hazardous constituents. Since monitoring began in 1988, specific conductance has been elevated at this site (see wells 199-N-59 and 199-N-72 in Figure 2.4-15) primarily because of non-dangerous constituents that were present in the waste, such as sodium and sulfate. No additional assessment

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(a) Letter 02-GWVZ-0029 from J. G. Morse (U.S. Department of Energy, Richland Operations Office) to J. Hedges (Washington State Department of Ecology), "Notification of Exceedance of Critical Range for pH in 1301-N Facility," dated July 8, 2002.

is required. Total organic carbon, total organic halides, and pH were all below the critical mean value in downgradient wells. Appendix A contains more information about this site.

2.4.12 Waste Site Remediation

The environmental restoration contractor completed excavating the 116-N-3 liquid waste disposal facility in fiscal year 2002. The excavation reached a depth of ~4.6 meters. The contractor applied water as necessary to control dust, but held application of water to a minimum to reduce the potential for mobilizing contaminants from the vadose zone to groundwater.

Excavation of the 116-N-1 facility began in fiscal year 2002. The excavation focused on removal of the trench cover panels and the contaminated soil beneath. In fiscal year 2003, the contaminated soil will be removed from beneath the former crib.

Quarterly groundwater monitoring in wells 199-N-67, 199-N-81, 199-N-105A, and 199-N-103A for strontium-90 and gamma-emitting radionuclides did not indicate increased mobilization due to dust-control water. Section 2.4.3 discusses a single detection of cobalt-60 in well 199-N-67, apparently an isolated event.

2.4.13 Monitoring at River Shoreline

Water quality near the Columbia River in the 100-N Area is evaluated by sampling wells near the river (199-N-46, 199-N-92A, 199-N-96A, and 199-N-99A) and riverbank seepage. The sampling points are located on the shoreline downgradient of the 116-N-1 facility (see Figure 2.4-1). Table 2.4-1 lists constituents of interest for the 100-N Area for fiscal year 2002. The closest aquifer sampling tubes to the 100-N Area are located upstream (between 100-K and 100-N Areas). Aquifer tubes were not installed in the 100-N Area because of the availability of near-river wells and the presence of concrete rubble along the shoreline.

In fiscal year 2002, strontium-90 and tritium concentrations continued to exceed drinking water standards in wells near the Columbia River shore in the 100-N Area.

2.4.13.1 Near-River Wells

Strontium-90 concentrations in samples from near-river wells are illustrated with the contaminant plume in Figure 2.4-4. In fiscal year 2002, concentrations ranged from undetected in well 199-N-92A (north of the main plume) to 4,810 pCi/L in well 199-N-46, within the plume. Well 199-N-46 frequently detects even higher strontium-90 concentrations, but the September 2001 sample was diluted with river water, as indicated by its relatively low specific conductance.

The highest tritium concentration in fiscal year 2001 in a near-river well was 21,500 pCi/L in well 199-N-92A, a typical value for this well. These concentrations fit the overall distribution of tritium illustrated in Figure 2.4-8.

2.4.13.2 Riverbank Seepage

The Sitewide Environmental Surveillance Project collected a sample from one seep along the 100-N Area shoreline in October 2001 and September 2002 (see Table 2.4-1). The samples contained low levels of gross beta, no detectable strontium-90, and ~7,000 pCi/L tritium. Low strontium-90 and gross beta levels are typical for this seep because it is located downstream of the main strontium-90 plume. The seep usually contains higher tritium concentrations and elevated nitrate. Levels in October 2001 and September 2002 were lower because of dilution effects from the Columbia River, as indicated by relatively low specific conductance. Another seep located in the heart of the strontium-90 plume has not produced any water in recent years.

The Near-Facility Environmental Monitoring Program, which is mandated primarily by DOE orders, monitors 13 "seep wells" along the 100-N Area shoreline (NS-1 through -13 in Figure 2.4-1). These structures are metal casings installed in the gravel of the shoreline, designed to enable sampling of seep water. Data from samples collected in October 2001 are listed in PNNL-13910, Appendix 2, and results for tritium and strontium-90 are included in Table 2.4-1. Concentrations were uniformly lower in October 2001 than in October 2000 (tritium was below detection limits). The samples may have been dominated by water from bank storage; no specific conductance data are available to check this possibility. Water from four seep wells exceeded the drinking water standard for strontium-90 in fiscal year 2002. No seep wells exceeded the DOE derived concentration guide.

Table 2.4-1. Shoreline Monitoring Data for the 100-N Area, Fiscal Year 2002

Location Name	Sample From(a)	Sample Date(b)	Specific Conductance (µS/cm)(c)	Chromium (µg/L)	Strontium-90 (pCi/L)	Gross Beta (pCi/L)	Tritium (pCi/L)	Sulfate (mg/L)	Nitrate (mg/L)
199-N-46	Well	09/23/02	234		4,810		681		
199-N-92A	Well	09/06/01	254	5.0	0.975 U	5.0	29,700	32.5	16.8
		09/23/02		7.7	0.69	2.9	21,500	40	16.0
199-N-96A	Well	09/10/01	1,091	4.8 U	3.3	11.4	3,370	96.9	8.3
		12/13/01	1,019	4.6					
		09/23/02	634	2.6	6.5	16.5	1,980	96.0	43.4
199-N-99A	Well	09/06/01	241	4.8 U	1,700	3,440	16,700	16.6	11.4
		09/23/02		2.7 U(d)	1,790(d)	3,450	4,225(d)	16(d)	27(d)
25-D	Tube	11/13/01	289	18(e)					
26-D	Tube	11/13/01	371	36(e)					
SN-093 (NS8-13)	Seep	10/25/01	240		0 U	5.5	6,550	28.2	8.9
		09/16/02	241		0 U	4.8	7,140	36.1	12.8
Y301	Seep well	10/01			4.3		1 U		
Y302	Seep well	10/01			19		1U		
Y303	Seep well	10/01			45		96 U		
Y305	Seep well	10/01			9.6		59 U		NA
Y306	Seep well	10/01			3.3		50 U		NA
Y307	Seep well	10/01			3.4		97 U		NA
Y309	Seep well	10/01			2.5		190 U		NA
Y310	Seep well	10/01			2.8		88 U		NA
Y311	Seep well	10/01			34		53 U		NA
Y312	Seep well	10/01			6.0		1 U		NA
BN-098-SHR	River	09/05/02			0 U		25	8.6	0.25

U = Below detection limit.

(a) Well = monitoring well; Seep = riverbank seepage; Seep well = metal casing in shoreline gravel; monitors seep water; River = nearshore Columbia River water; Tube = aquifer sampling tube located near the low-river shoreline.

(b) Data from September 2001 (fiscal year 2001) included to provide comparison for October 2001 (fiscal year 2002) seep data.

(c) Specific conductance provides an indication of the amount of river water in the sample; uncontaminated groundwater is typically in the range of 350 to 450 µS/cm and river water in the range of 120 to 150 µS/cm.

(d) Average of multiple measurements.

(e) Tube located between 100-K and 100-N Areas. Source of chromium believed to be 100-K Area.

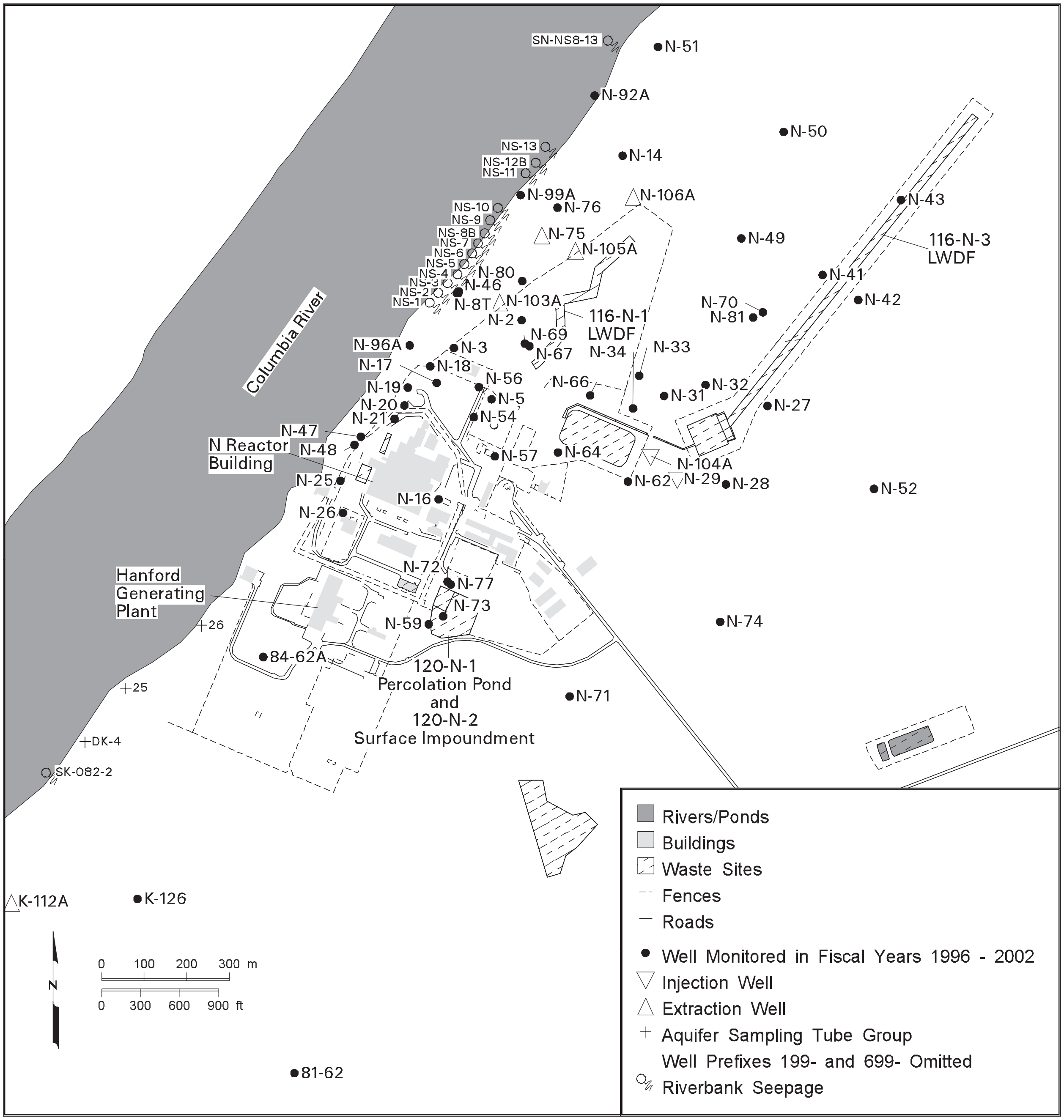

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Figure 2.4-1. Groundwater Monitoring Wells in the 100-N Area

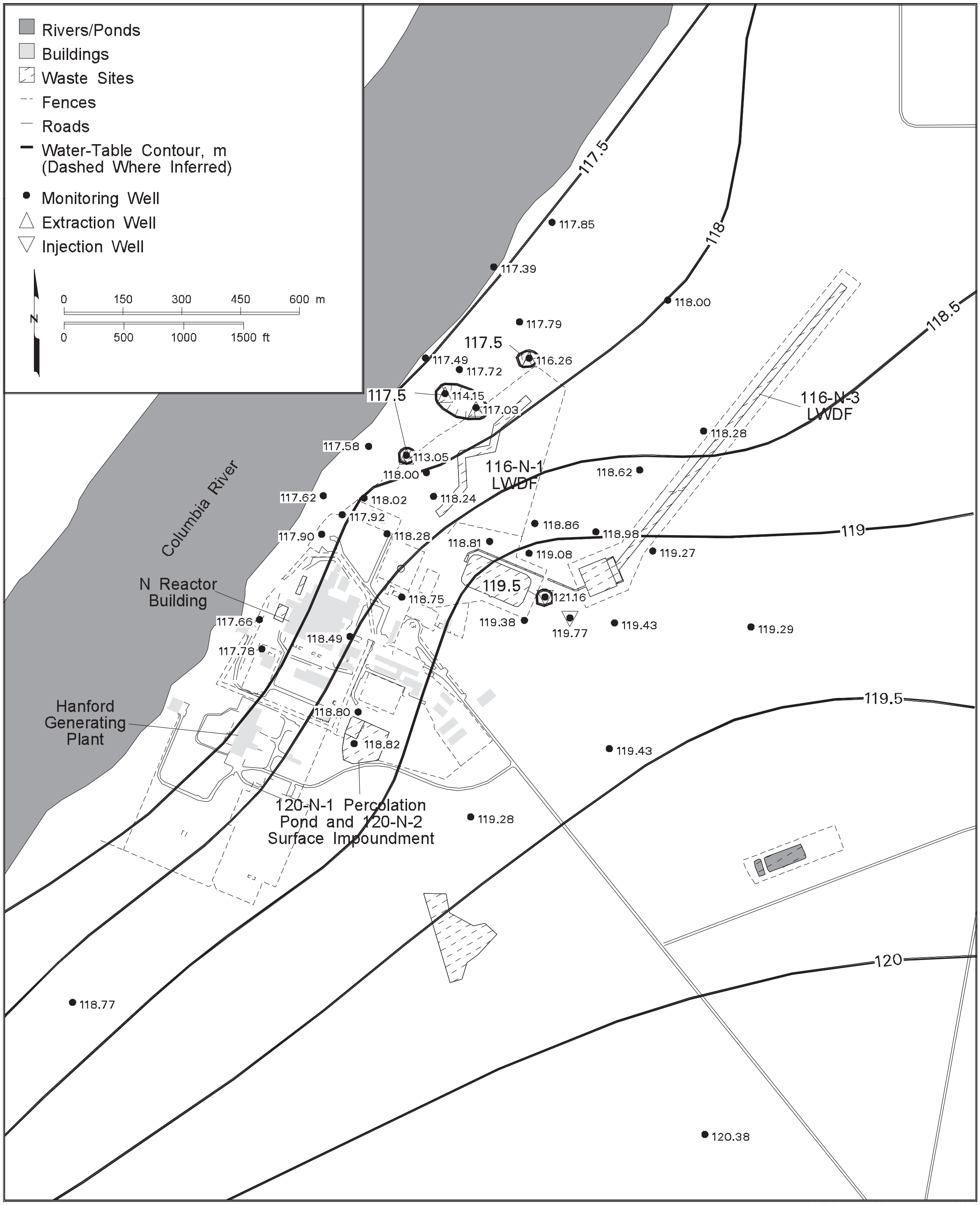

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Figure 2.4-2. Water Table Beneath 100-N Area, March 2002

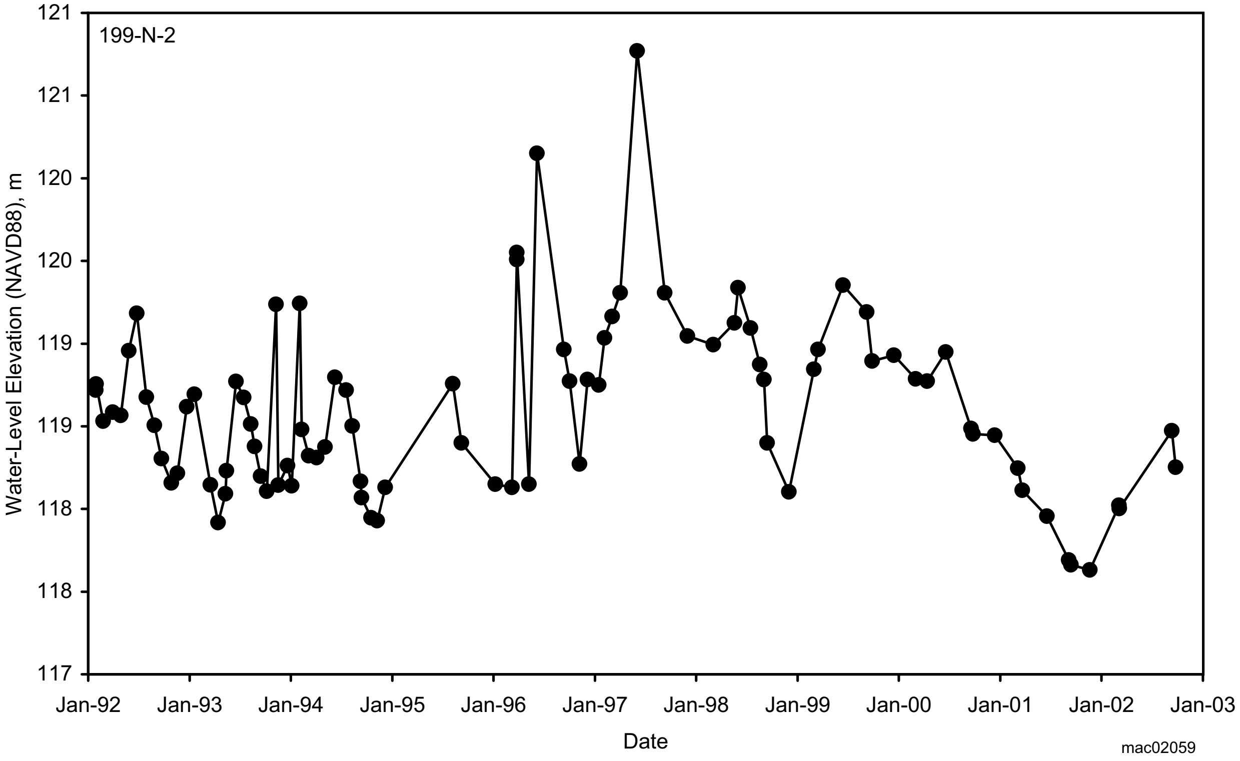

Figure 2.4-3. Water Level Between 116-N-1 Facility and the Columbia River

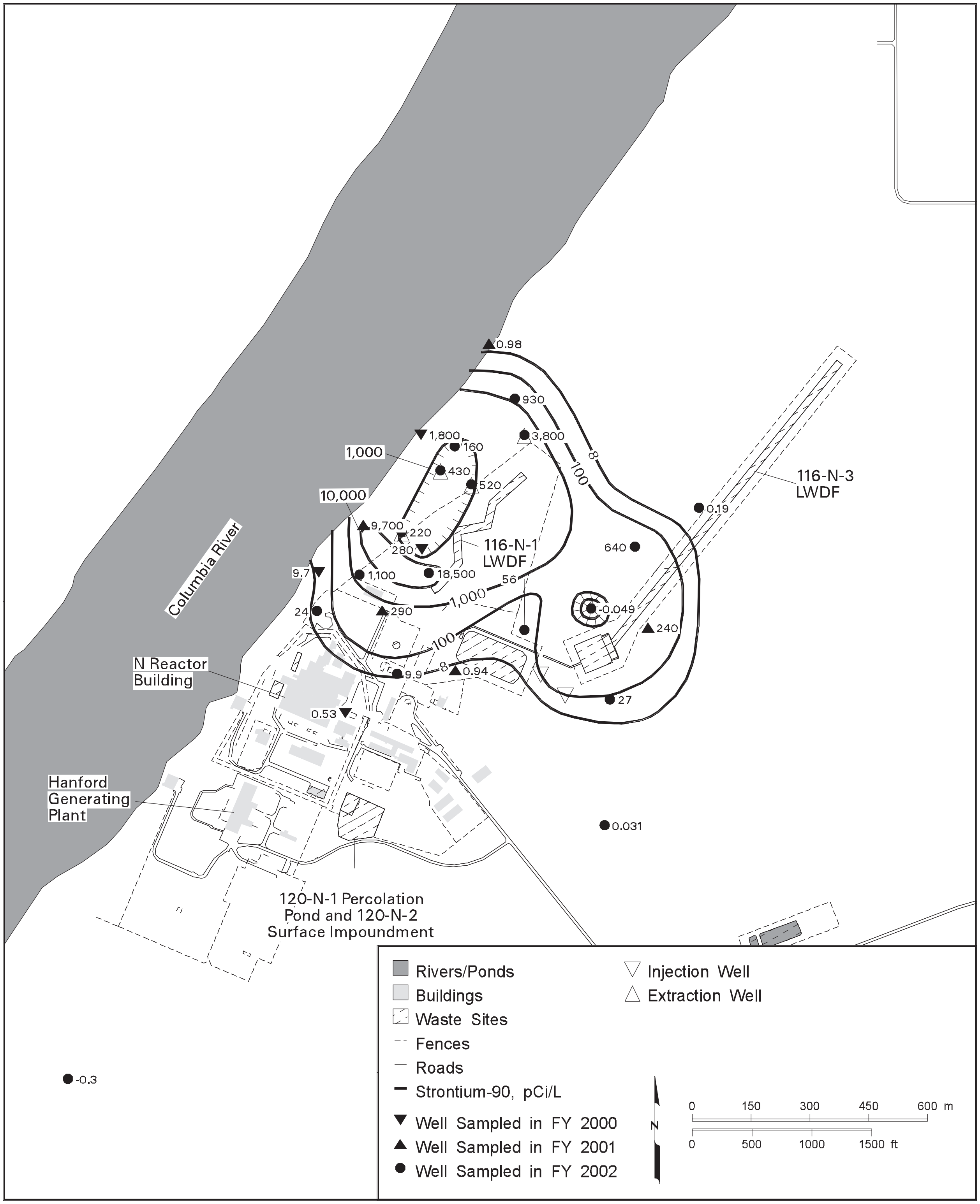

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Figure 2.4-4. Average Strontium-90 Concentrations in the 100-N Area, Top of Unconfined Aquifer

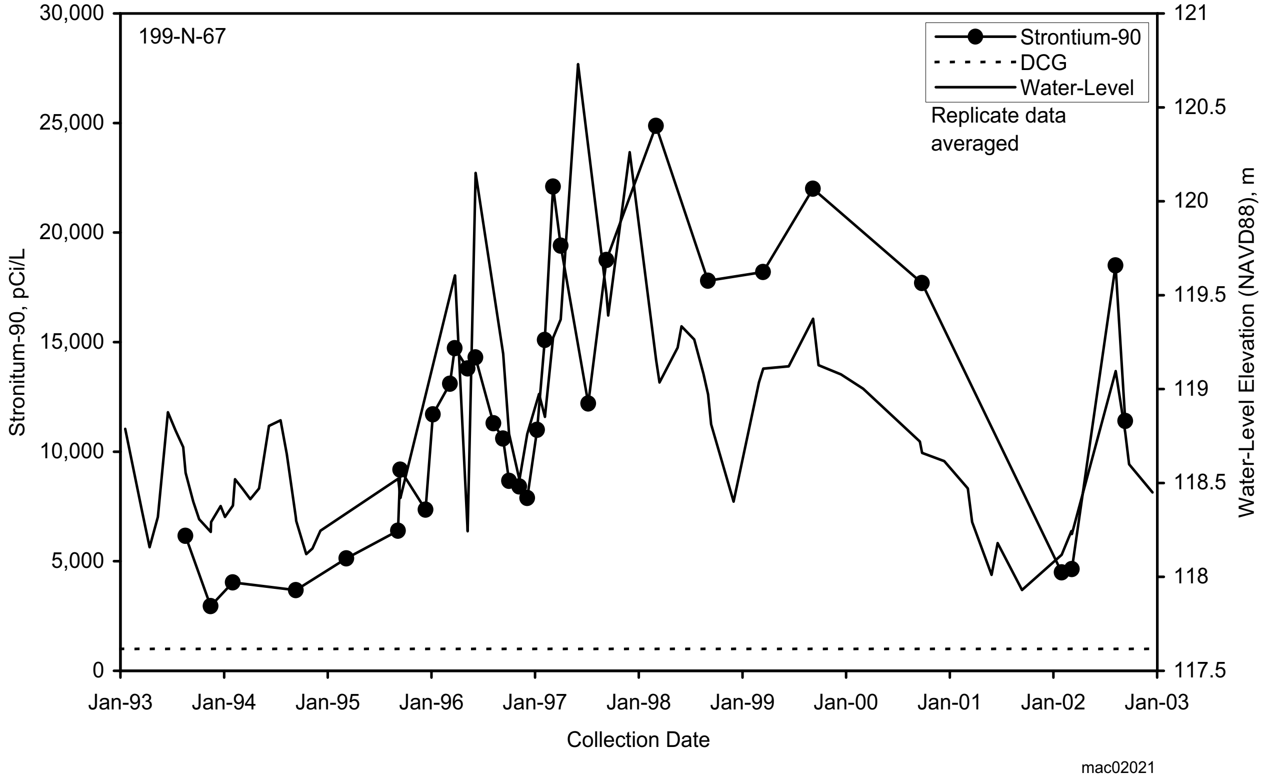

Figure 2.4-5. Strontium-90 Concentrations Near the 116-N-1 Facility

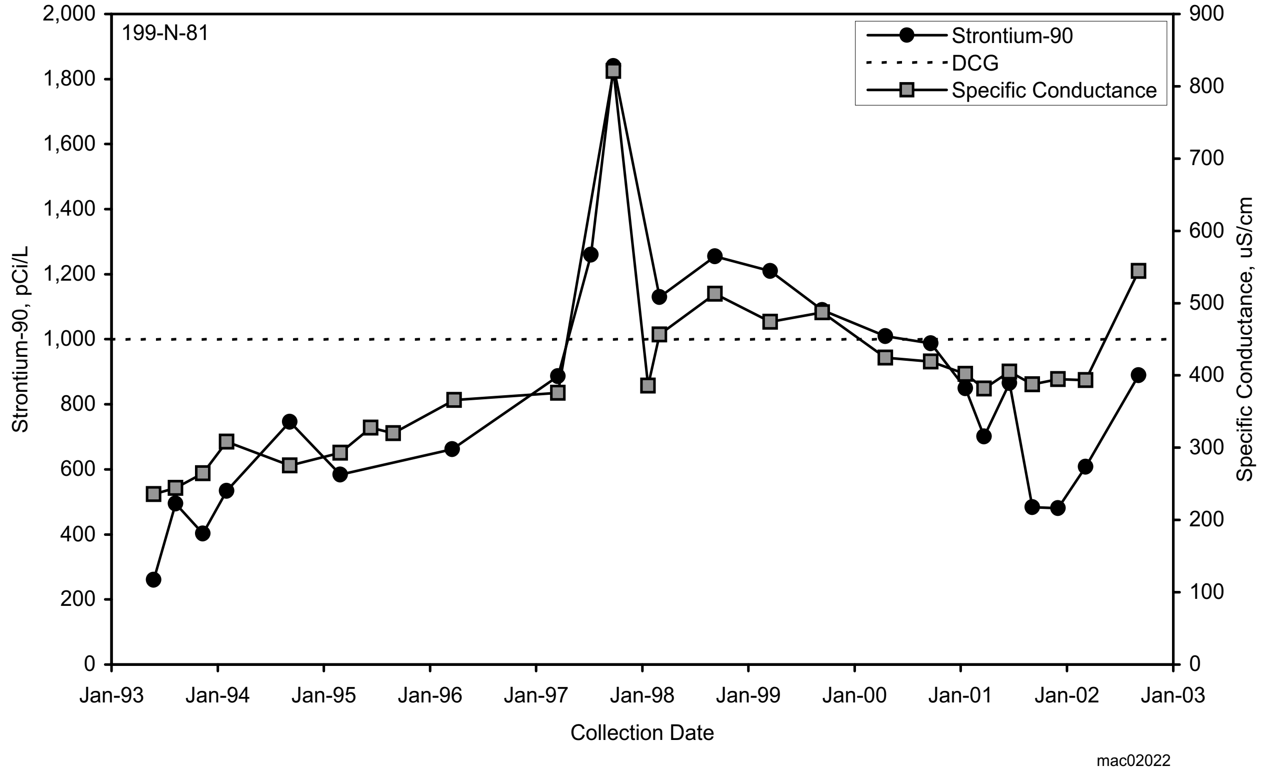

Figure 2.4-6. Strontium-90 Concentrations Near the 116-N-3 Facility

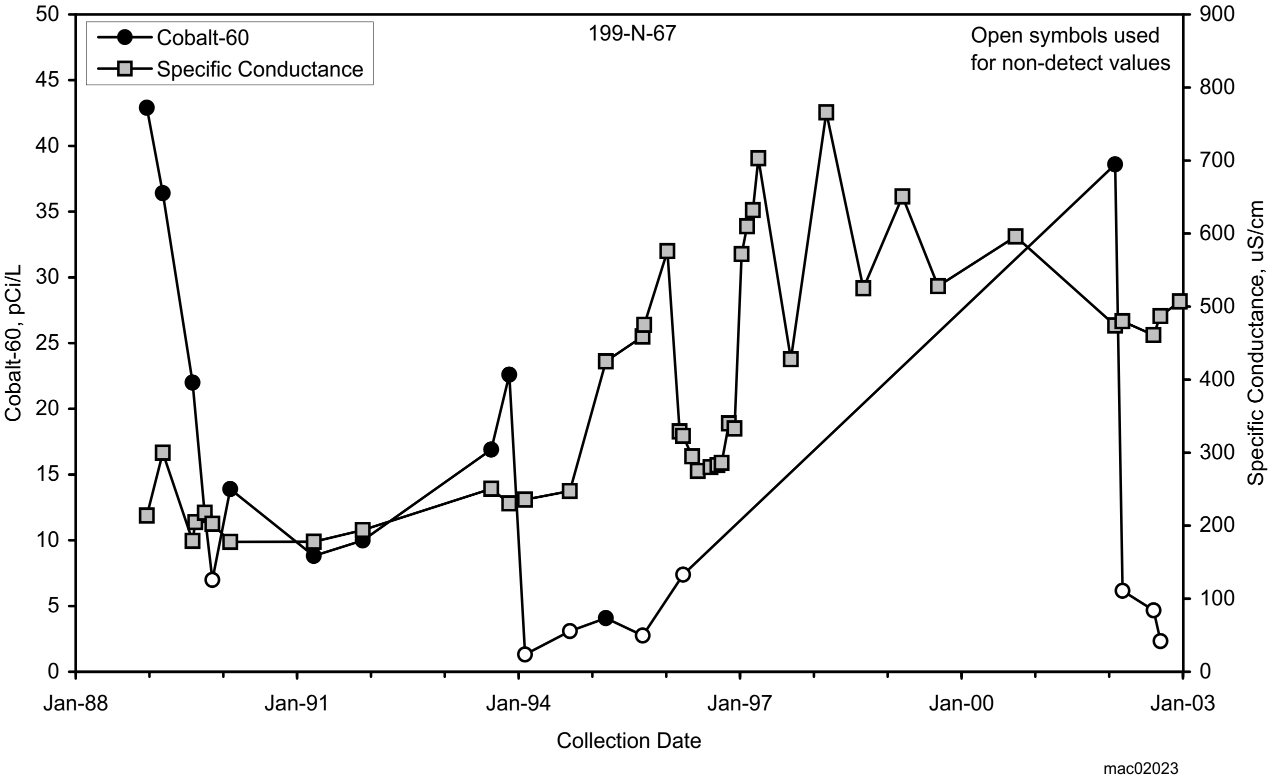

Figure 2.4-7. Cobalt-60 Concentrations Near the 116-N-1 Facility

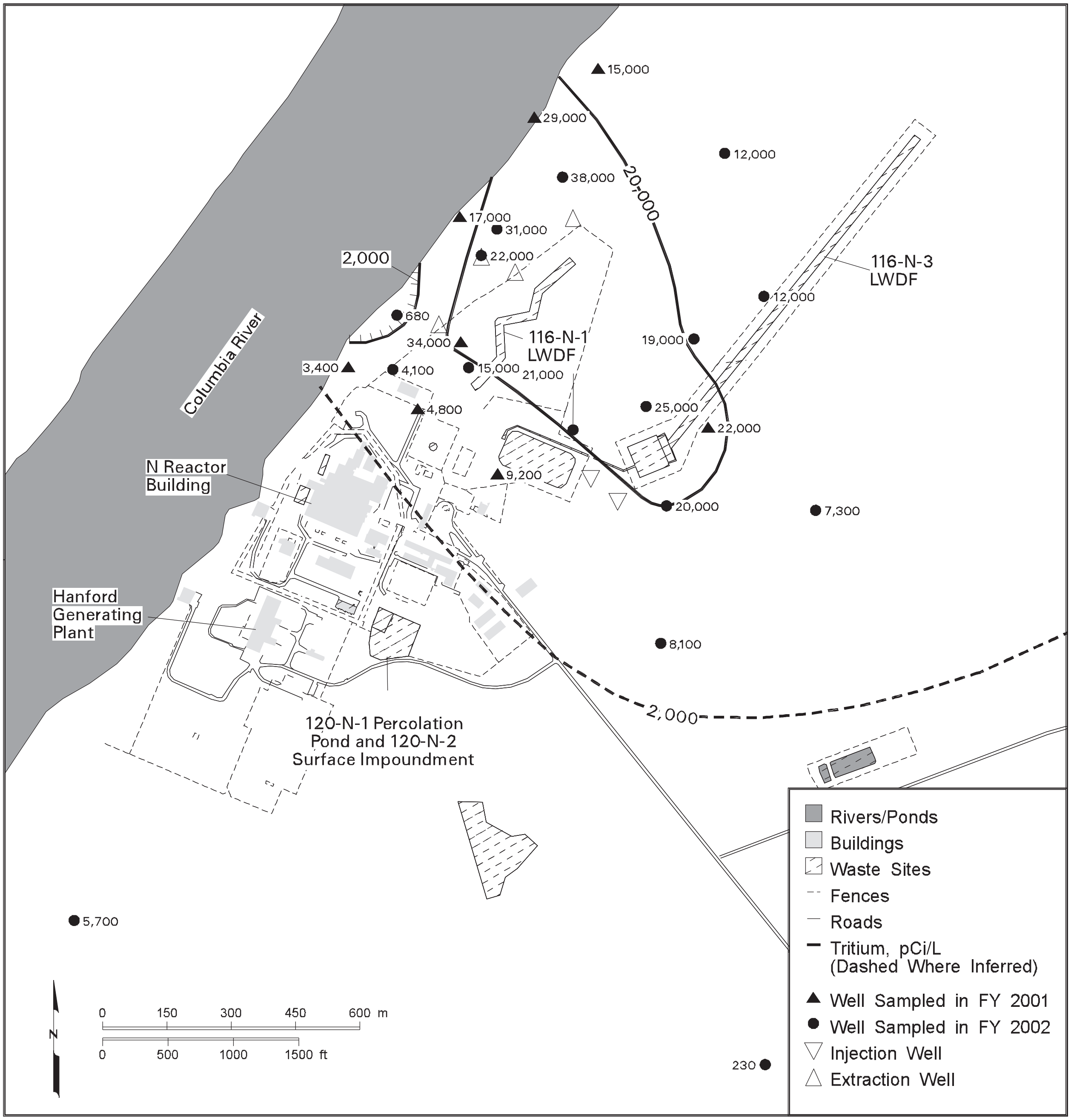

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Figure 2.4-8. Average Tritium Concentrations in the 100-N Area, Top of the Unconfined Aquifer

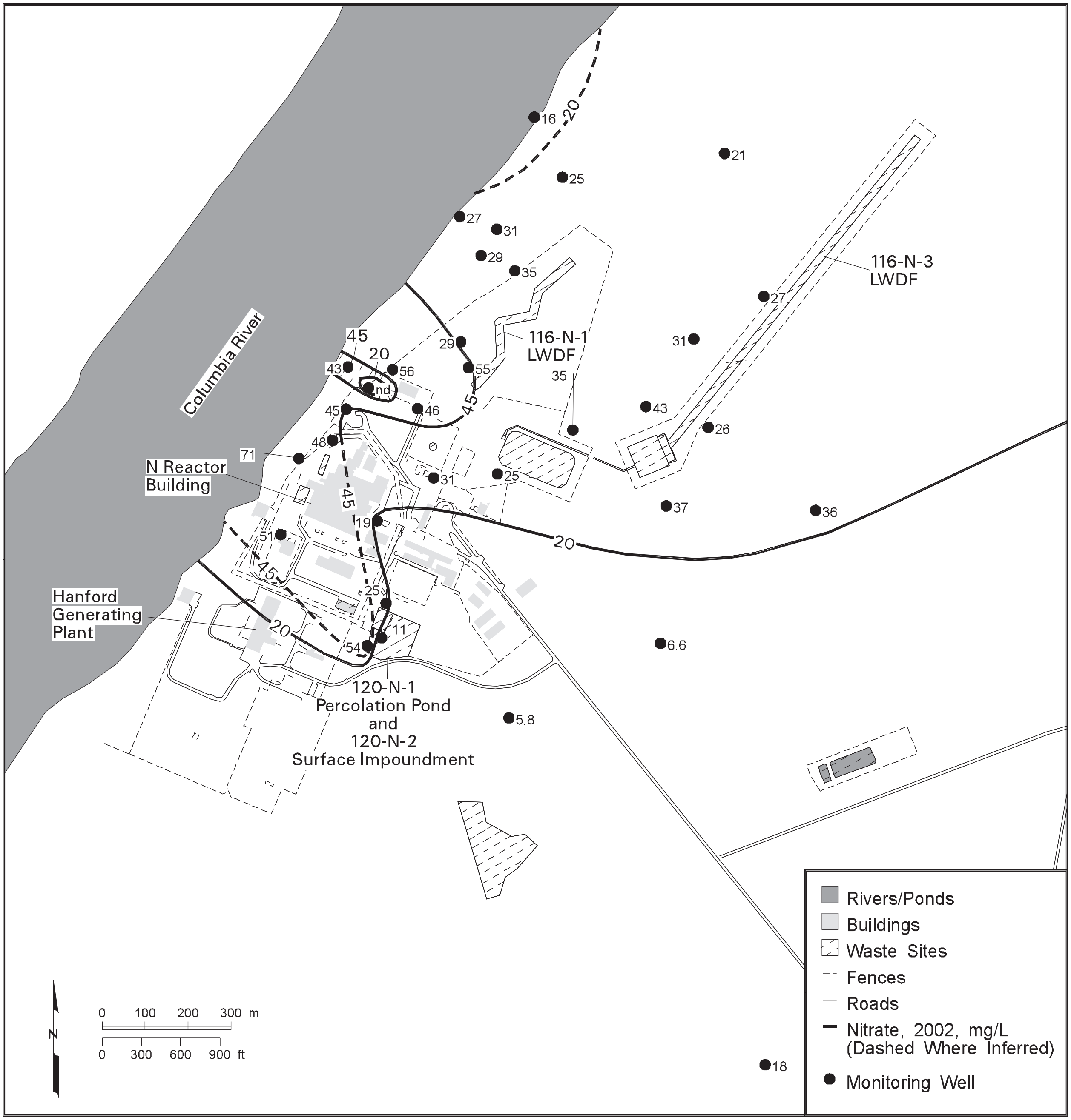

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Figure 2.4-9. Average Nitrate Concentrations in the 100-N Area, Top of Unconfined Aquifer

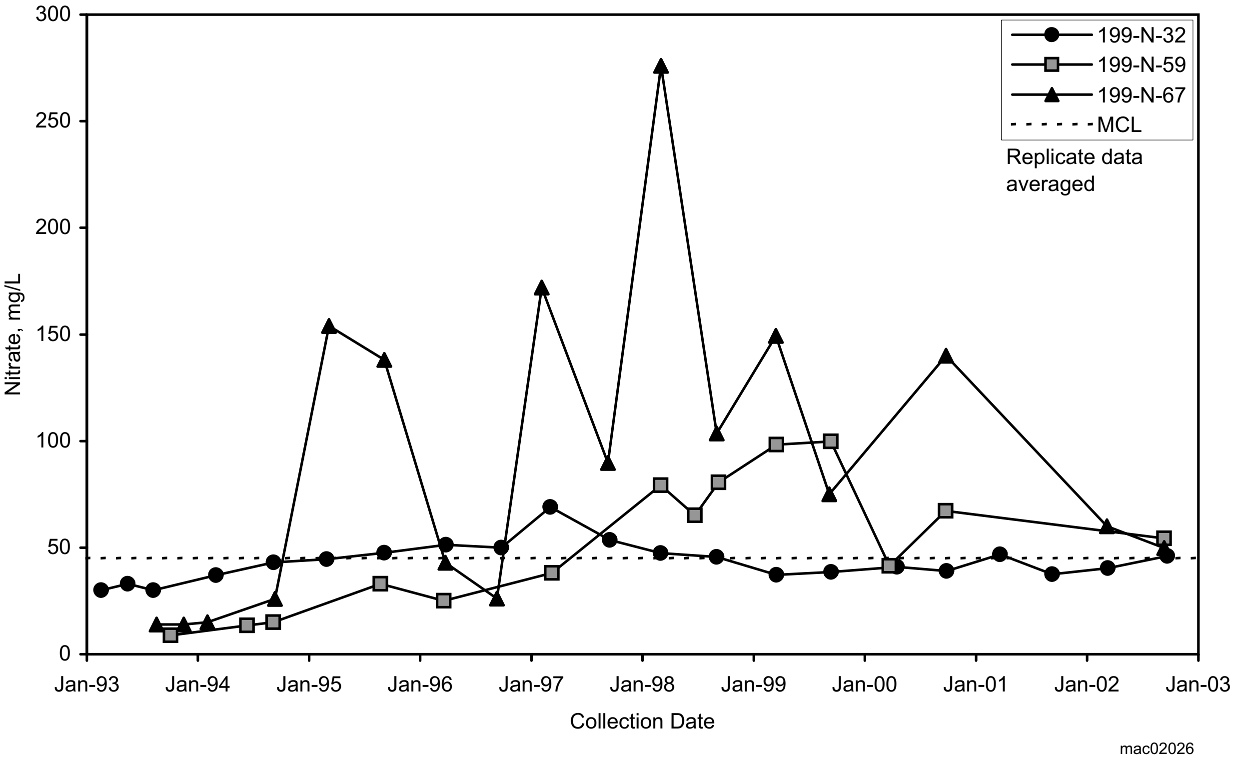

Figure 2.4-10. Nitrate Concentrations in 100-N Area Wells

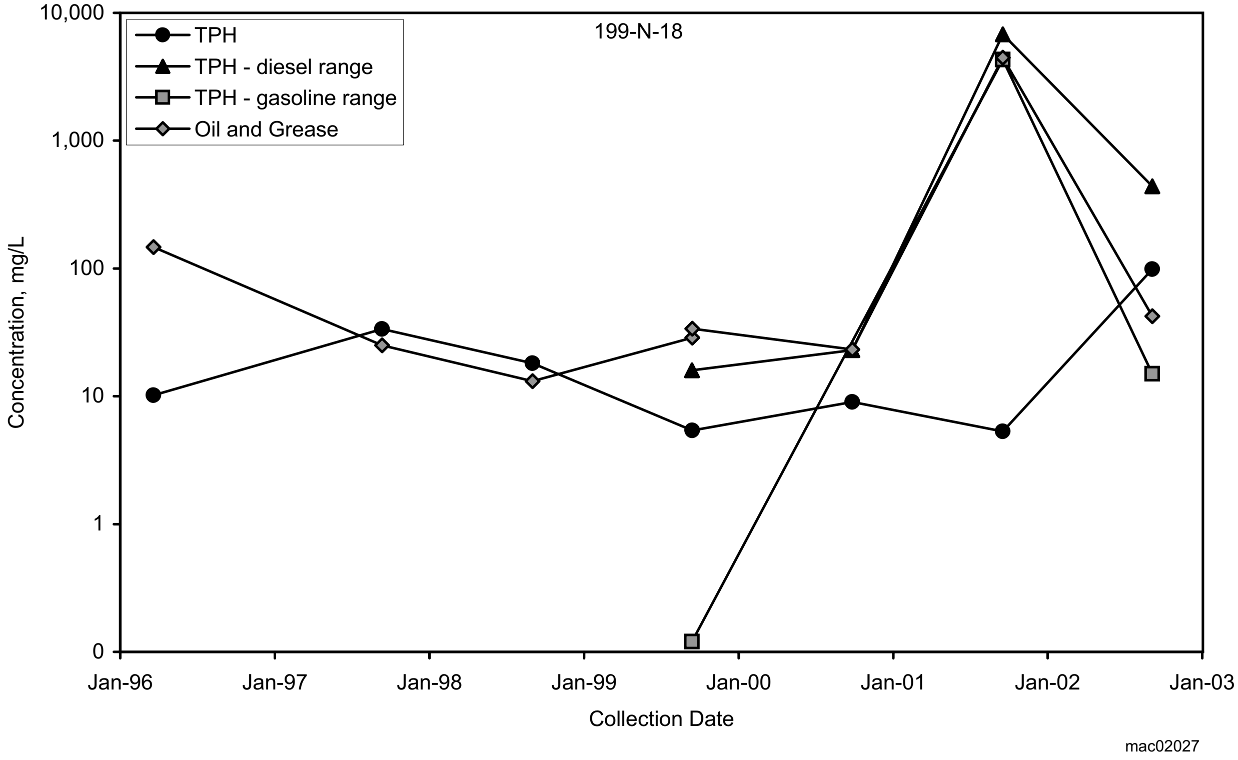

Figure 2.4-11. Petroleum Hydrocarbons Near Former Petroleum Leak Site

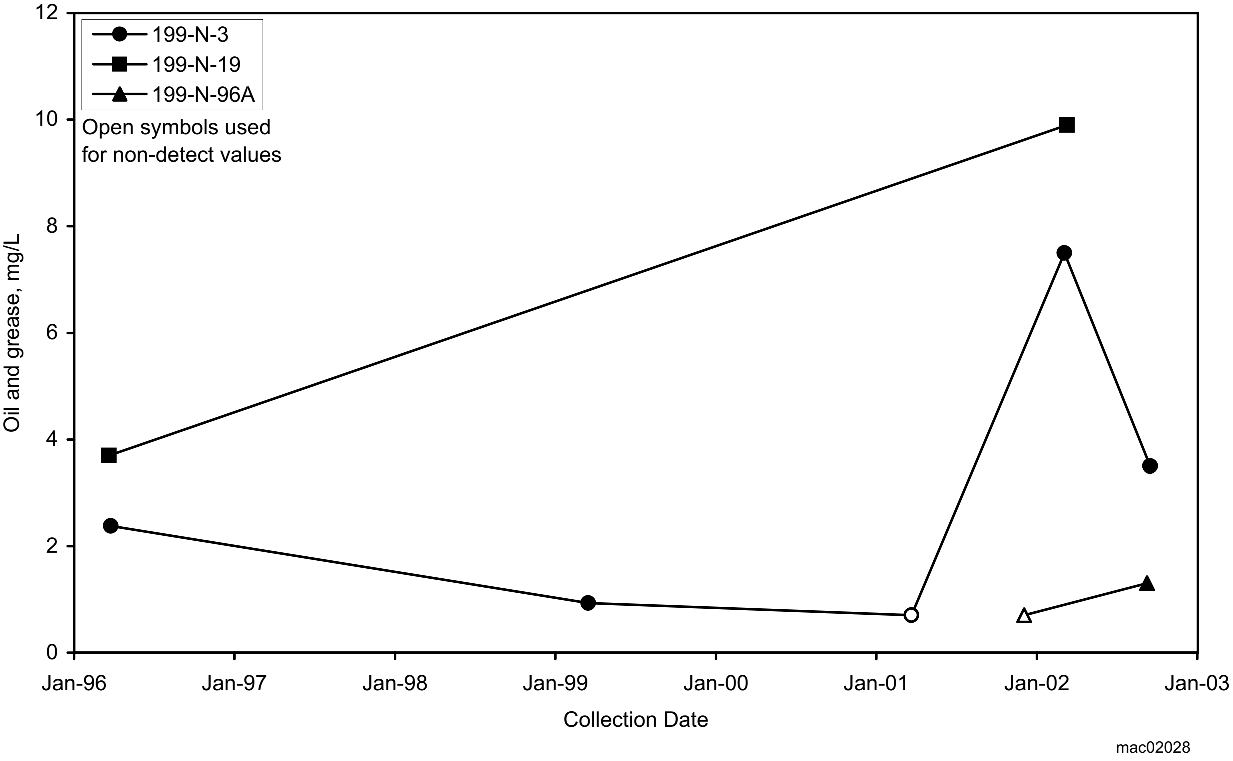

Figure 2.4-12. Oil and Grease in Wells Near Former Petroleum Leak Site

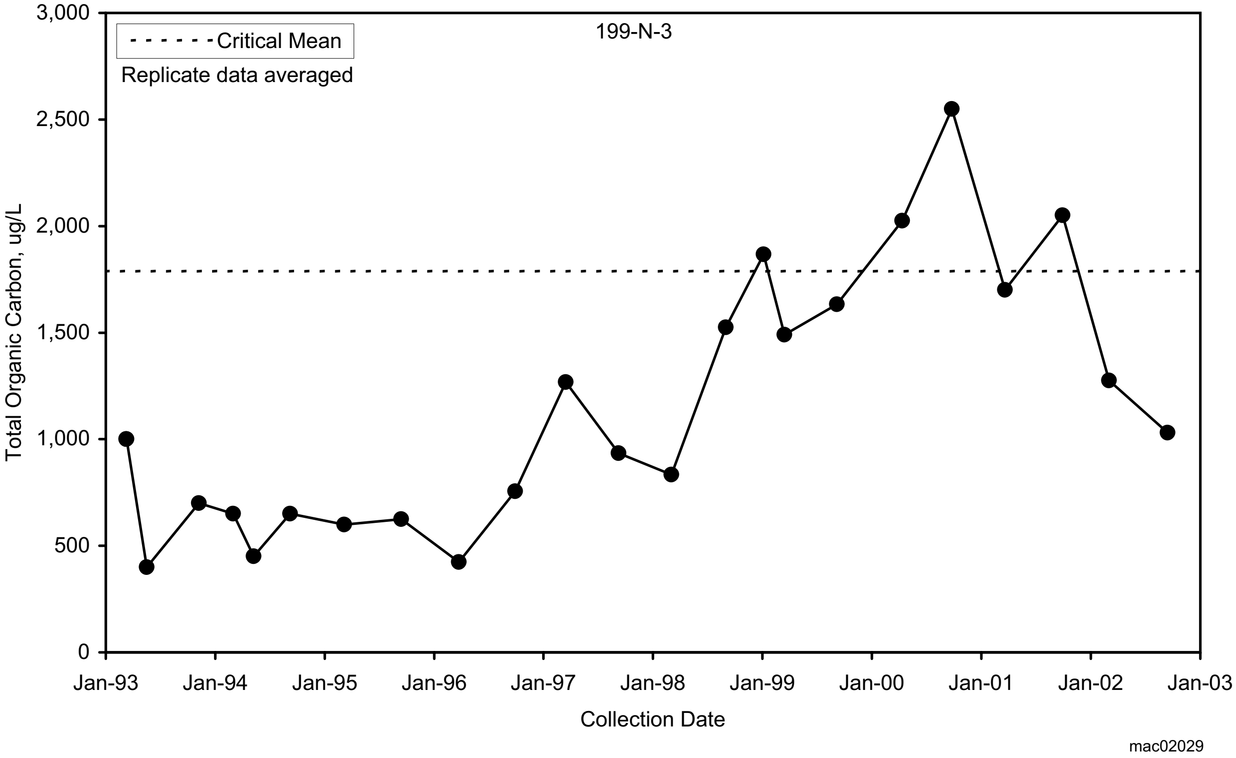

Figure 2.4-13. Total Organic Carbon Near the 116-N-1 Facility

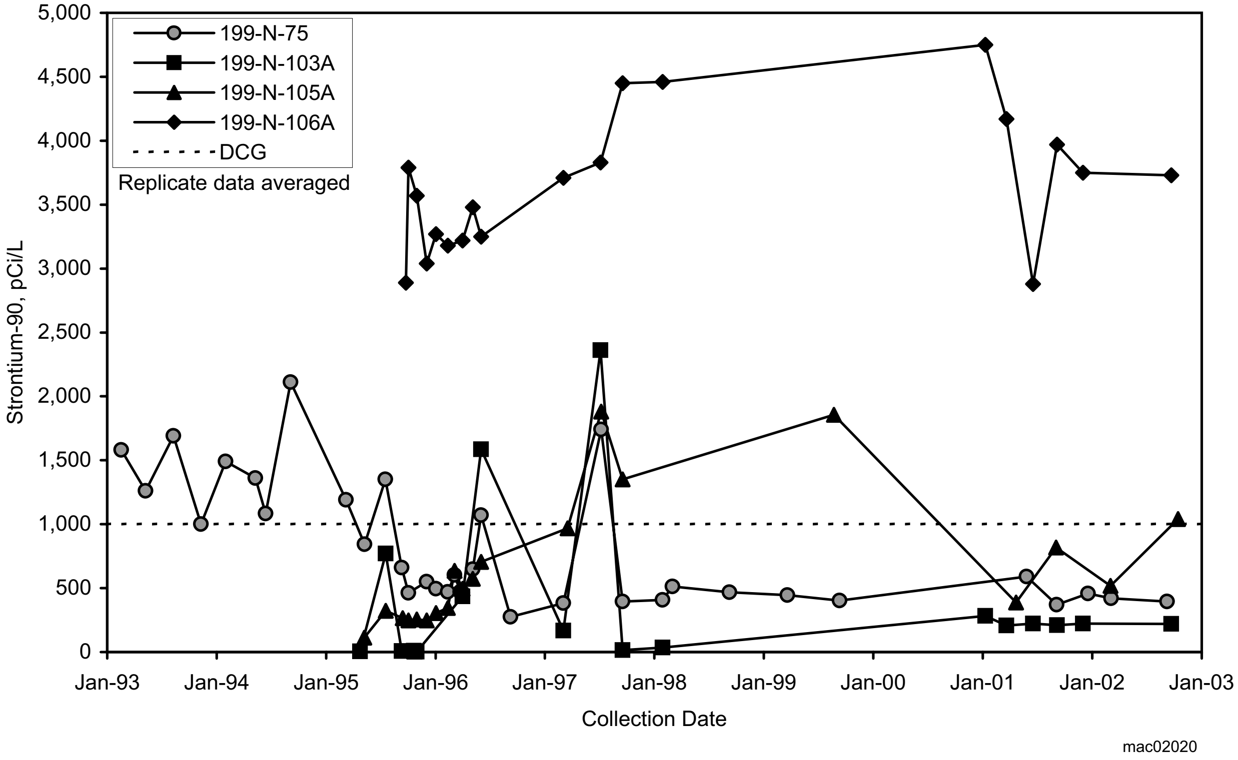

Figure 2.4-14. Strontium-90 Concentrations in 100-N Area Extraction Wells

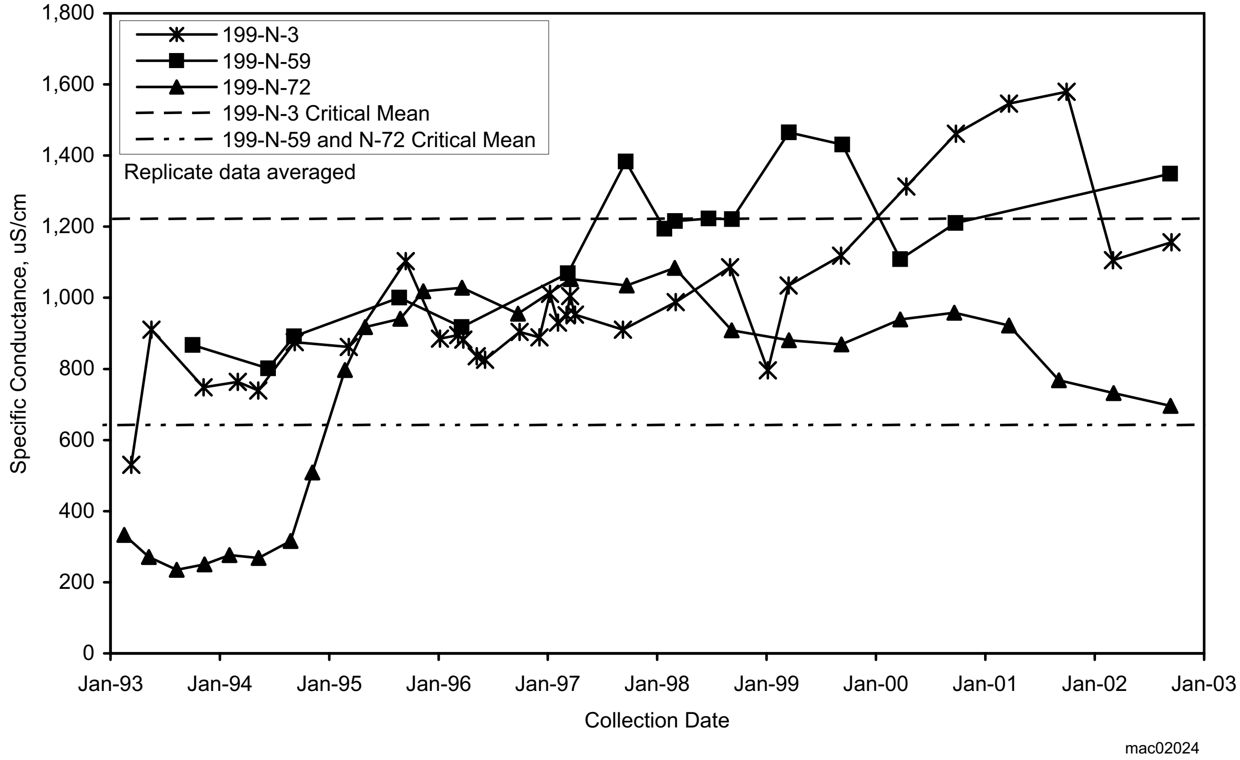

Figure 2.4-15. Specific Conductance in Wells Affected by Past Discharges to 120-N-1 Percolation Pond

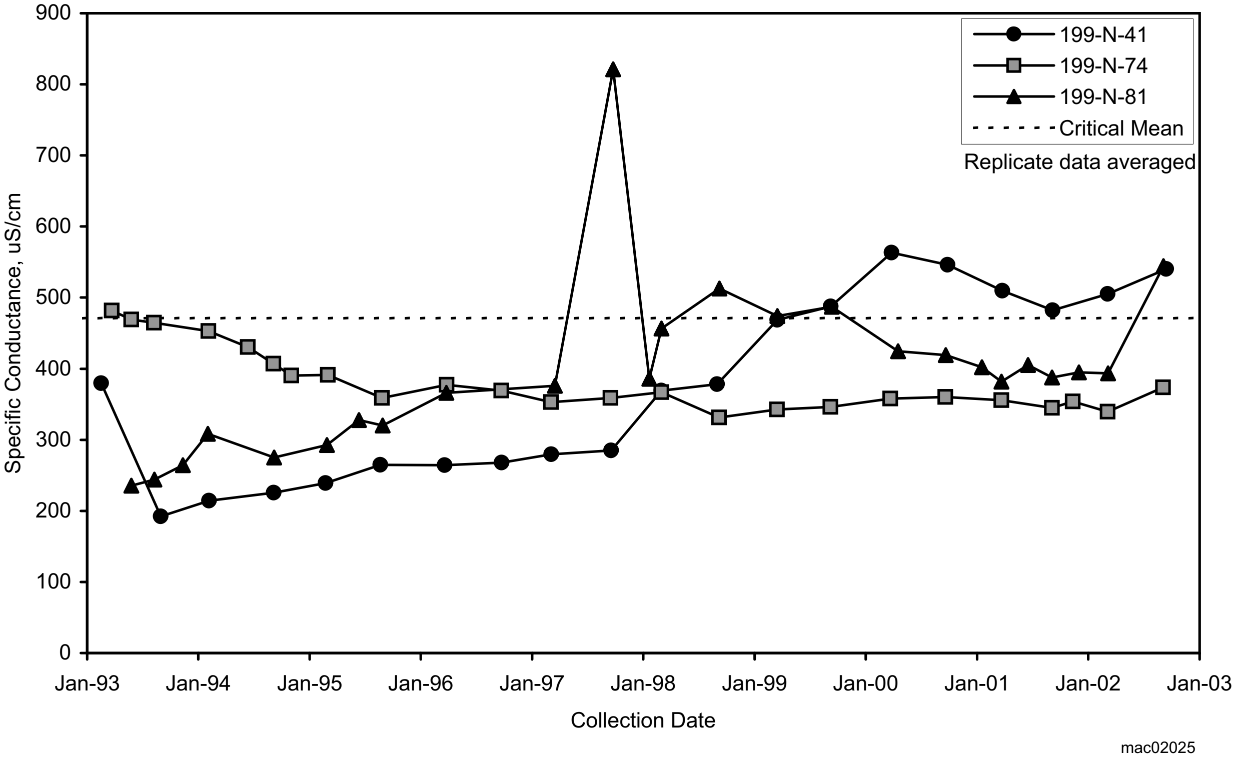

Figure 2.4-16. Specific Conductance in Wells Near the 116-N-3 Facility

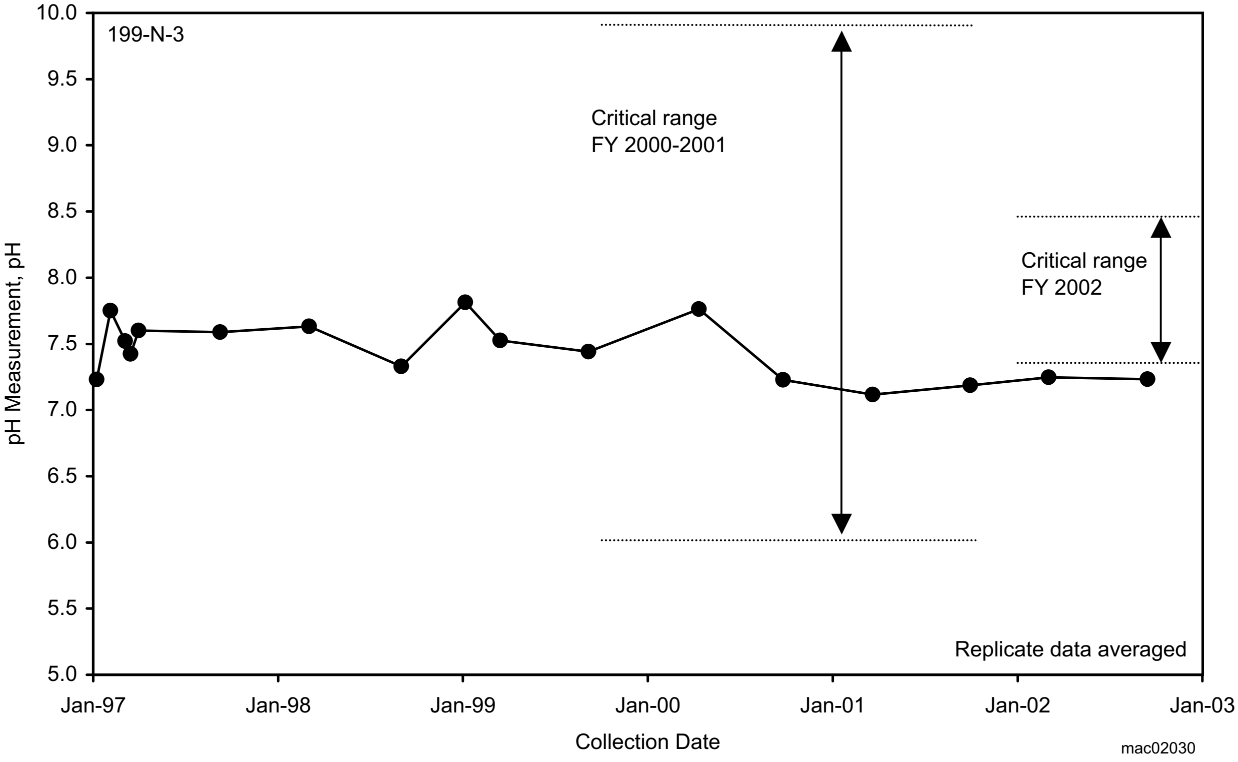

Figure 2.4-17. Average pH Downgradient of the 116-N-1 Facility

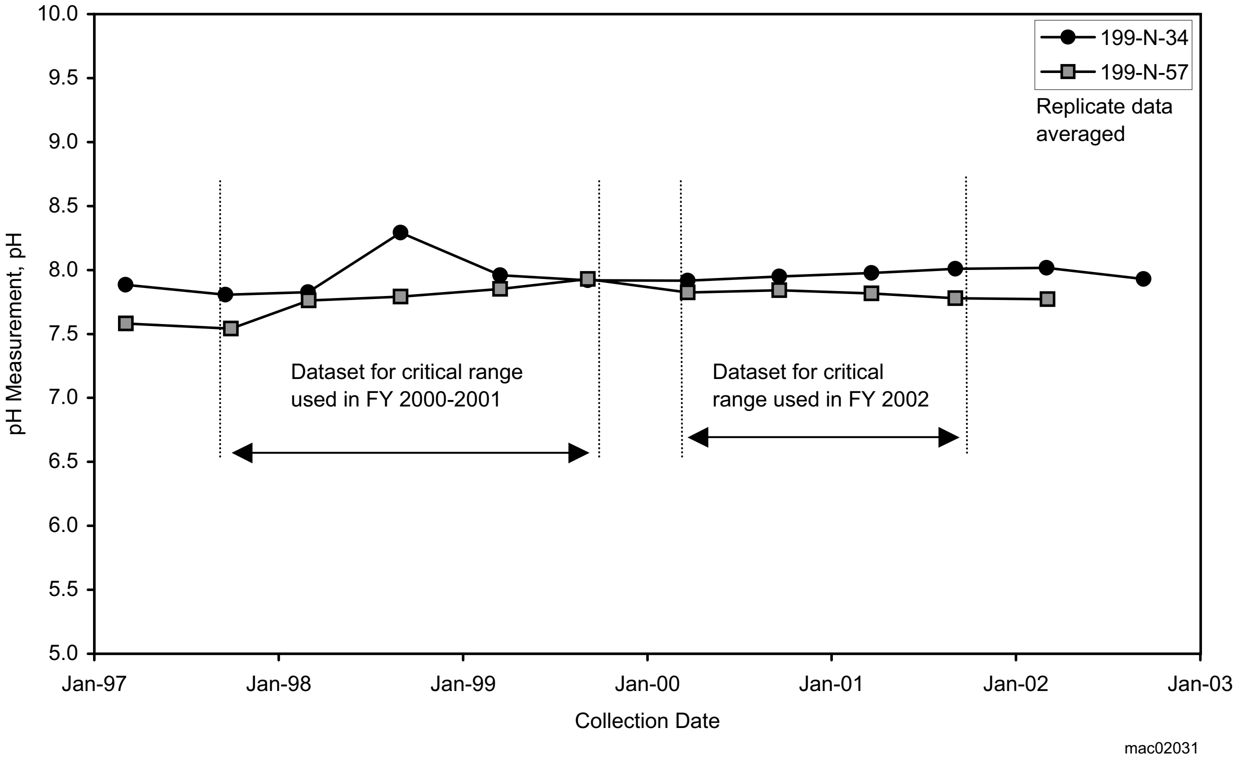

Figure 2.4-18. Average pH in Wells Upgradient of the 116-N-1 Facility

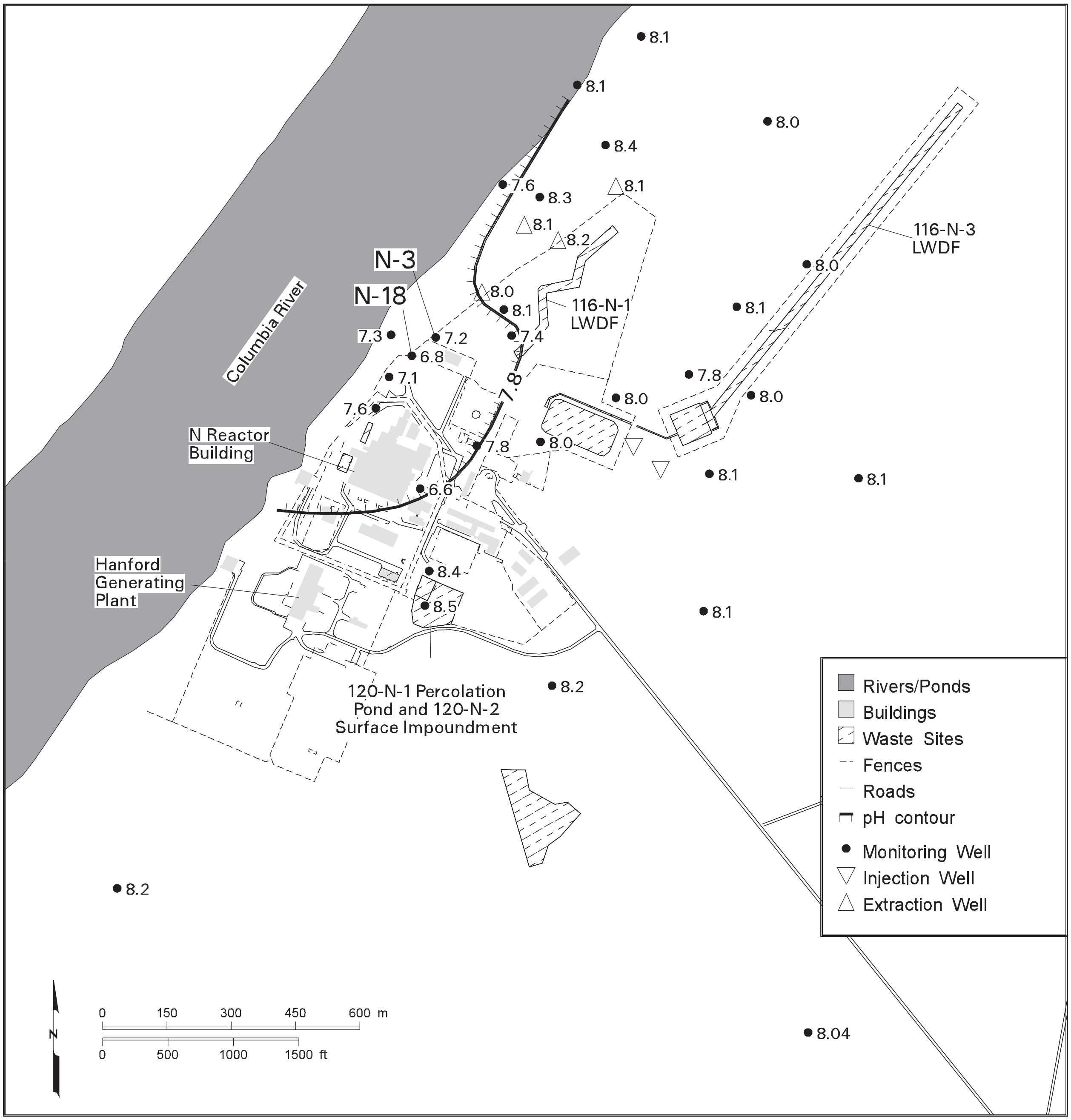

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Figure 2.4-19. Average pH in the 100-N Area, Top of Unconfined Aquifer (September 2001 and March 2002)

2.5 100-D Area

M. J. Hartman and R. O. Mahood

The 100-D Area contains two former plutonium production reactors. D Reactor operated between 1944 and 1967 and DR Reactor between 1950 and 1964. Descriptions of operations and associated waste sites for the 100-D Area are presented in WHC-SD-EN-TI-181. Locations of former waste sites and monitoring wells are shown in Figures 2.5-1 and 2.5-2. Many of the waste sites have been excavated to remove contaminated sediment and backfilled with clean material.

Chromium-contaminated groundwater at the 100-D Area flows into the Columbia River where it is a potential threat to some aquatic wildlife. The chromium-contaminated groundwater is believed to well up through the adjacent riverbed gravel used by salmon for spawning habitat. Two interim remedial actions operate to reduce the amount of chromium entering the Columbia River at 100-D Area. A pump-and-treat system is active in the north 100-D Area near the former retention basins, and an in situ reduction oxidation (redox) manipulation site (see Figure 2.5-2) is being expanded in the southwest 100-D Area.

Hexavalent chromium is the contaminant of greatest concern in the 100-D Area. Two remediation systems help reduce the amount of chromium entering the Columbia River: a pump-and-treat system in the north 100-D Area and in situ remediation in the southwest 100-D Area.

2.5.1 Groundwater Flow

Groundwater flows toward the north and northwest in the west part of the 100-D Area, and to the north-northeast in the east (Figure 2.5-3). In June 2002 when river stage was high, the water-table gradient reversed, sloping to the east or southeast away from the Columbia River across the entire 100-D Area.


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Groundwater remediation continues at the 100-D Area, shown above. During fiscal year 2002, a pump-and-treat system and in situ redox manipulation operated to remove or reduce hexavalent chromium in groundwater. The redox barrier was expanded in fiscal year 2002.

In the central and north 100-D Area (from D Reactor building to the retention basins), the average flow direction is primarily to the north. Groundwater extraction from wells in the north 100-D Area has created a local depression in the water table, inducing radial flow toward these wells.

Monitoring Objectives in 100-D Area

Groundwater monitoring is conducted in the 100-D Area:

- triennially to annually to describe the nature and extent of contamination
- semiannually to monitor trends in variable constituents/wells
- quarterly to characterize chromium and sulfate distribution
- quarterly to evaluate the performance of in situ remediation of chromium
- various time intervals to evaluate the performance of a pump-and treat system for chromium

2.5.2 Chromium

In 100-D Area groundwater, chromium is distributed in two plumes that appear to be merging: a north plume with sources near the former D Reactor and a southwest plume with a source near the former 183-DR water treatment facility (Figure 2.5-4). In previous years, there was an area of low or undetected chromium concentrations between the plumes. This is believed to be a result of former leakage of clean water from the 182-D reservoir, which created an area of dilution and perhaps a groundwater mound. The 182-D reservoir has been in use almost continually since 1947 to store raw process water pumped from the Columbia River. In 1995, it was drained, repaired, and refilled. In the past few years, changes in the distribution of chromium and other constituents (nitrate, sulfate, specific conductance) suggest that a lower rate of leakage after the repairs is allowing the north and southwest plumes to move into the central 100-D Area.

2.5.2.1 North Chromium Plume

Cribs and trenches near the D Reactor building were the primary sources for a chromium plume that extends toward the Columbia River (see Figure 2.5-4). The former retention basins and disposal trenches in the north also were contaminant sources. Chromium concentrations in most wells near the reactor building continued to decrease in fiscal year 2002. Average chromium concentrations on the north side of the former retention basins ranged from 120 to 200 µg/L in fiscal year 2002. Higher average concentrations were measured in wells 199-D5-13 (760 µg/L), 199-D8-5 (520 µg/L), and in a new extraction well 199-D8-72 (390 µg/L).

Chromium concentrations increased sharply in wells 199-D5-41 and 199-D5-20 in fiscal year 2002 (Figure 2.5-5), probably as a result of movement of the north chromium plume. The direction of groundwater flow estimated from water-table maps is toward the north or north-northwest in this region, yet the plume has been observed to move successively toward the west (Figure 2.5-6). The chromium trend in wells 199-D5-13, 199-D5-20, and 199-D5-41 are consistent with movement of this plume, showing a time lag with distance from the source (see Figure 2.5-5). It appears less likely that the chromium increases in wells 199-D5-20 and 199-D5-41 primarily relate to movement of the south chromium plume. The chromium increases in wells 199-D5-20 and 199-D5-41 are concurrent with increases in wells in the south plume, not lagged in time as would be expected if the plume were moving north.

A pump-and-treat system in the north 100-D Area removes chromium-contaminated groundwater to prevent it from reaching the Columbia River. Groundwater remediation is discussed in Section 2.5.6.

2.5.2.2 Southwest Chromium Plume

The long axis of the chromium plume in the southwest 100-D Area is oriented perpendicular to the Columbia River (see Figure 2.5-4). Concentrations are higher in this plume than in the north plume. Researchers have been unable to identify the source of the southwest plume with certainty. It may have been the former 183-DR water treatment facility, where sodium dichromate was added to the water as a corrosion inhibitor. Another possible source is a former transfer station where chromate stock solutions were unloaded from railcars and piped to the water treatment facilities. The transfer station was located north of the 183-DR facility. Vadose zone characterization in these areas failed to locate areas of high chromium contamination in the vadose zone (PNNL-13486; PNNL-13107). Section 2.5.6.2 contains additional details about this plume and associated groundwater remediation.

During characterization work to define the source of the plume, one borehole was completed as a monitoring well (199-D2-8). The initial groundwater sample from the well in August 2000 contained 1,490 µg/L hexavalent chromium (value is not in the Hanford Environmental Information System [HEIS] database). Subsequent samples had much lower concentrations of chromium (<200 µg/L). In fiscal year 2002, the well was sampled several times during a slightly extended purge to investigate the possibility that the concentration would vary with time as a result of chemical changes related to well materials. Concentrations remained stable, indicating that chromium levels are representative.

The distribution of chromium in the 100-D Area has changed over the past few years. The high-concentration portions of the plumes have moved toward the central 100-D Area.

In recent years, the southwest chromium plume appears to have expanded toward the north (see Figure 2.5-6). Concentrations increased in wells in the central 100-D Area and decreased or remained essentially unchanged in south wells. Concentrations in well 199-D5-39 were highly variable in fiscal year 2002, but continued to be highest of any wells in the plume (Figure 2.5-7). The concentration decreased by ~60% from August 2001 to August 2002, but increased ~61% in early October 2002. The apparent northward movement of the plume may be related to the decrease in artificial recharge from the water reservoir, as discussed in Section 2.5.2.

The presence of chromium in well 699-87-55, located south of the 100-D Area, is puzzling (see Figure 2.5-4). Contamination may have moved south from the 100-D Area in the 1960s and 1970s when a prominent groundwater mound was present beneath the retention basins. Chromium levels in the unconfined aquifer beneath the 100-N Area are low.

2.5.3 Nitrate and Nitrite

Nitrate is widely distributed in the 100-D Area. There are two apparently separate plumes with concentrations exceeding the 45-mg/L maximum contaminant level. The two plumes coincide generally with the chromium plumes. The maximum concentration in fiscal year 2002 was 90 mg/L in well 199-D8-6 in the north 100-D Area. Levels are declining overall.

Like chromium, nitrate concentrations are low within and downgradient of the redox remediation site as a result of chemical reduction. Nitrite concentrations are elevated in dithionite injection wells and occasionally downgradient of the injection wells.

2.5.4 Tritium

Tritium is above background levels in some 100-D Area wells, but concentrations were below the drinking water standard in fiscal years 2001 and 2002. The highest concentrations are in wells near the former reactors (Figure 2.5-8). Tritium in the southwest 100-D Area may have migrated from the 100-N Area; levels declined in fiscal year 2002.

2.5.5 Strontium-90

Strontium-90 is detected in few wells in the 100-D Area. Until its decommissioning in 1999, well 199-D5-12 near D Reactor consistently had elevated strontium-90 (~30 pCi/L). The contamination presumably was related to past disposal of radionuclide-bearing effluent from the D Reactor fuel storage basin to cribs located nearby. The contamination is not widespread; nearby well 199-D5-15 detected a low level of strontium-90 in fiscal year 2002 (1.5 pCi/L) and no strontium-90 was detected in wells 199-D5-14 or 199-D5-16.

In the north 100-D Area, strontium-90 concentrations are above background levels in several wells near the pump-and-treat system. Concentrations in fiscal year 2002 ranged from below detection limits in well 199-D8-55 to 13 pCi/L in well 199-D8-68. There is no clear increasing or decreasing trend.

2.5.6 Groundwater Remediation at the 100-HR-3 (D) Operable Unit

Two interim actions for groundwater remediation are underway in the 100-D Area to reduce the amount of hexavalent chromium entering the Columbia River: (1) a pump-and-treat system in the north 100-D Area, and (2) an in situ treatment system in the southwest 100-D Area. Objectives of the interim remedial actions are discussed in Appendix A and summarized in Table 2.1-2.

2.5.6.1 Pump-and-Treat System

A pump-and-treat system operates in the 100-D Area as part of an interim action for the 100-HR-3 Operable Unit, primarily to protect aquatic receptors in the river bottom by reducing the discharge of chromium to the Columbia River (ROD 1996b). The system is located north of the former 116-D-7 and 116-DR-9 retention basins and began operating in July 1997. Groundwater is pumped from extraction wells 199-D8-53, 199-D8-54A, 199-D8-68, and 199-D8-72, then is piped to the 100-H Area, where it is treated and injected into the aquifer.

During fiscal year 2002, the pump-and-treat system removed ~23 kilograms of chromium from 100-D Area groundwater. Two additional extraction wells were put into use during the year to intercept more of the plume. The system will continue operating until a final remedy is determined or until the concentration of hexavalent chromium is below 22 µg/L and appears stable.

The pump-and-treat system made progress toward achieving the remedial action goals in 100-D Area during fiscal year 2002. Groundwater that flows beneath the most significant waste sites in this area (retention basins, trenches, and cribs) is prevented from reaching the Columbia River. Two additional extraction wells were put into service in May 2002 to capture more of the plume: well 199-D8-68 is a former compliance well that was converted to an extraction well, and well 199-D8-72 is a newly installed extraction well. DOE/RL-2002-05 provides a complete description of the progress and effectiveness of the remedial action in calendar year 2001.

Although designed primarily to prevent or reduce the amount of contaminated groundwater discharging into the Columbia River, the pump-and-treat system also is reducing overall contamination in the operable unit by the process of contaminant mass removal. During fiscal year 2002, the pump-and-treat system extracted ~150 million liters of groundwater from the 100-D Area, removing ~23 kilograms of hexavalent chromium. The withdrawn water was sent to the 100-H Area, where it was treated and injected into the aquifer. A total of ~120 kilograms of hexavalent chromium has been removed from the plume targeted for interim action since startup of the pump-and-treat system in July 1997. This is in addition to the ~30 kilograms removed earlier by the pilot test conducted between August 1992 and August 1994 (DOE/RL-95-83). An estimate for the total amount of chromium in the plume suggests a mass of 590 kilograms (DOE/RL-94-95). This estimate was prepared before the discovery of chromium in the southwest 100-D Area. Uncertainty in this estimate is associated primarily with the sparse distribution of monitoring wells and the lack of data on the vertical distribution of chromium in the aquifer. The value should be viewed as an order-of-magnitude estimate.

In fiscal year 2002, as in most years, chromium concentrations varied seasonally, as shown for compliance monitoring wells in Figure 2.5-9. In fiscal year 2002, the lowest concentrations were measured in summer months when river stage was high, diluting contaminant concentrations in these near-river wells. Chromium concentrations rebounded in late summer and early fall 2002.

Chromium concentrations in the extraction wells also fluctuate with river stage (Figure 2.5-10). Chromium concentrations were lower during fiscal year 2002 than in fiscal year 2001 when there was a drought and no significant dilution effect from high river levels.

Chromium concentrations in extraction wells were lower during fiscal year 2002 than in fiscal year 2001 when there was a drought and no significant dilution effect from high river levels.

Because the concentration of chromium shows a cyclical pattern, an overall trend in concentration is difficult to identify. The concentration has declined below 22 μg/L in some extraction and compliance wells several times since 1996, during summers when the river stage was high. However, the concentration of chromium rebounded above the action level each fall as river stage declined. Because of the recurring elevated concentration of chromium in the compliance wells, the annual summary report (DOE/RL-2002-05) recommended continued operation of the pump-and-treat system. Contaminant data indicate that many years of pumping may be required before the remedial action objectives have been entirely satisfied. Planning is currently underway to evaluate methods of improving the performance of the pump-and-treat system and reducing the amount of time needed to achieve the remedial action objectives.

2.5.6.2 In Situ Redox Manipulation

The amended record of decision for the 100-HR-3 Operable Unit includes use of the in situ redox manipulation technique for interim remediation of groundwater (ROD 1999b). The technique was tested in the 100-D Area in 1997 through 1999 and expanded in fiscal years 2000 through 2002. The redox system creates a permeable reactive barrier in the aquifer by reducing the ferric iron to ferrous iron on the surfaces of sediment grains and within the minerals of the sediment. This reduction was accomplished by injecting a chemical-reducing agent, sodium dithionite, into closely spaced wells. After the aquifer sediment was reduced, reagent and reaction products were pumped out of the wells. The reducing conditions remain in the aquifer because of the change in iron chemistry. Chromium is not easily re-oxidized under ambient environmental conditions and will, thus, remain immobile.

Fluor Hanford, Inc. continued to expand the permeable reactive barrier in fiscal year 2002 (Table 2.5-1). Crews installed and treated new injection wells, extending the total length of the barrier to 590 meters (the barrier will continue to be lengthened to 643 meters in 2003). Treatment was completed in fiscal year 2002 for nine wells which began treatment in fiscal year 2001. Seventeen wells were treated for the first time in fiscal year 2002, and six wells were treated for a second time. A total of 61 injection/extraction wells have been treated since 1997. The remaining wells identified for the interim remedial action are planned for treatment during fiscal year 2003. Results of remediation in fiscal year 2002 will be reported in more detail in the fiscal year 2002 summary report for the in situ redox manipulation operations.

The redox manipulation technique has decreased the concentration of chromium in groundwater in a portion of the southwest 100-D Area. In fiscal year 2002, the effect was observed in downgradient compliance wells and perhaps in sampling tubes along the river shore.

The chromium map of Figure 2.5-11 illustrates which wells were injected in fiscal year 2002 and in previous years and shows the distribution of chromium in late fiscal year 2002. The withdrawn solution was discharged to a lined evaporation pond east of the site. Chromium concentrations are low along the line of active injection wells, and the effect extends farther downgradient of the center of the barrier, where initial injections occurred.

The redox manipulation technique creates a permeable barrier in the aquifer. Sodium dithionite was injected into additional wells in fiscal year 2002 to extend the length of the treatment zone. As groundwater flows through this zone, the hexavalent chromium is converted to the trivalent form, which is virtually immobile in groundwater.

Wells within the initial reactive barrier (e.g., well 199-D4-7 in Figure 2.5-11) showed sharp declines in chromium concentration after injections in 1997 and 1998 (the early data for this well are not in the HEIS database). There was an increase in chromium in well 199-D4-7 and some of the other wells in the barrier in September 2000 and concentrations fluctuated in fiscal year 2001. The chromium concentration also increased in well 199-D4-35 in June 2001, persisting with some fluctuation through June 2002 (operational data in a project database; not in HEIS). The increases may have been caused by changes in flow direction, variations in groundwater velocity, heterogeneity of the distribution of reduced sediment within the aquifer, or the effects of air rotary drilling nearby. Fluor Hanford, Inc. implemented a mitigation plan to evaluate potential causes of the increased chromium in these wells and to identify potential responses if the observed conditions are found to decrease the longevity of the barrier. Fluor Hanford, Inc. injected treatment chemicals into some of the wells in the center of the barrier a second time in August and September 2002 (see Table 2.5-1). Chromium concentrations in those wells subsequently dropped to below or near the remedial action objective of 20 µg/L. In September 2002, elevated chromium concentrations (>200 µg/L; operational data) were reported in wells 199-D4-26 and 199-D4-37, also in the redox barrier.

Chromium trends in compliance wells downgradient of the barrier were mixed in 2002 (see Figure 2.5-11). Concentrations declined in southwest wells 199-D4-85 and 199-D5-86 and remained stable in well 199-D4-84. This section of the barrier was injected in fiscal year 2002, so the effects are unlikely to be due to remediation. The declines probably were related to a higher river stage in fiscal year 2002 than in 2001. Chromium concentrations were relatively stable in central wells 199-D4-23 and 199-D4-38. Concentrations declined in north wells 199-D4-39 and 199-D4-83 as a result of remediation effects. The latter wells also experienced increases in sulfate concentration due to movement of chemical treatment solution from the redox treatment zone. Chromium levels dropped in aquifer sampling tubes downgradient of the redox site (see Section 2.5.7).

Other effects of the redox technique observed in wells within the treatment zone include decreases in dissolved oxygen and nitrate, and increases in aluminum, arsenic, gross beta, iron, manganese, nitrite, and sulfate. In late fiscal year 2002, some of these changes also had affected upgradient well 199-D4-22. Aluminum, iron, manganese, nitrite, and sulfate also have been elevated in one or more sample from compliance wells 199-D4-23, 199-D4-38, and 199-D4-39. Samples from the downgradient compliance wells have not been analyzed for arsenic. The increases in metals are due to increased solubility in the reducing aquifer conditions. Increased sulfate is a result of incomplete recovery of the reaction products following the reduction treatment. Elevated gross beta activity (up to 401 pCi/L) is due to potassium-40 naturally present in the injected solution.

Three characterization boreholes were drilled in fiscal year 2002 to investigate the cause of elevated chromium in some wells near the center of the barrier. The boreholes were drilled near well 199-D4-7. Sediment samples were collected at various depths within the aquifer, and laboratory tests analyzed the mass of reduced iron and its vertical variability. Results were compared to a similar study conducted in 1999 to determine if the barrier life was shorter than originally estimated.[a]

(a) Unpublished report provided to Fluor Hanford, Inc. 2002. *Interim Report: Geochemical and Physical Property Analysis of Sediment Core Samples Collected from the 100D Area In Situ Redox Site*. J. E. Szecsody, B. J. DeVary, M. D. Williams, V. R. Vermeul, and J. S. Fruchter, Pacific Northwest National Laboratory, Richland, Washington.

The study concluded that on average, the mass of reduced iron in 2002 was essentially the same as that observed in 1999. However, vertical variability in redox capacity was observed in 2002, with a more oxygen-rich zone at about 26.8 to 27.4 meters below the surface in two of the boreholes. These data indicate the possibility of higher permeability channels that re-oxidized after initial treatment, either due to natural groundwater flow or by enhanced aeration during air rotary drilling of nearby areas. This information will be used to help assess barrier performance and determine the most likely cause of the observed barrier degradation.

2.5.7 Monitoring at River Shoreline

Groundwater near the Columbia River is sampled annually in the late fall via aquifer sampling tubes and riverbank seeps. The sampling tubes are polyethylene tubes that were installed in the aquifer at locations near the low water shoreline. Seeps are natural areas of groundwater discharge above the water line. Table 2.5-2 lists constituents of interest for the 100-D Area for fiscal year 2002.

Chromium concentrations decreased significantly in two of the aquifer tubes downgradient of the redox barrier, but most results continued to exceed the 10-µg/L water quality standard for protecting aquatic organisms. The following tubes showed significant chromium declines between fiscal years 2001 and 2002:

- tube DD-42-3: 276 µg/L in November 2000; 74 µg/L in November 2001
- tube Redox-3: 479 µg/L in November 2000; 119 µg/L in November 2001

Levels of hexavalent chromium in aquifer tubes downgradient of the redox remediation system declined sharply in fiscal year 2002. The change may indicate that remediation effects have reached the shoreline. Levels remained above the 10-µg/L aquatic standard.

The relatively low specific conductance in tube DD-42-3 (220 µS/cm) indicates dilution with river water, which may explain the decrease in chromium (specific conductance was higher in November 2000). The high specific conductance (708 µS/cm) and sulfate (215 mg/L) in tube Redox-3 seems to indicate influence from remediation at the redox site. Sulfate is present in 100-D Area groundwater in concentrations up to ~140 mg/L; higher concentrations probably indicate residual chemicals from injections at the redox site. Chromium ranged from 6 to 50 µg/L in aquifer tubes not associated with the redox site.

Chromium concentrations and specific conductance vary with depth in aquifer tubes (see Table 2.5-2). In all cases, the shallower tubes have much lower specific conductance and chromium than deeper tubes because of dilution with river water. For example, the chromium concentration in shallow tube DD-42-2 was 2 µg/L; in mid-depth tube DD-42-3 it was 74 µg/L; and in deepest tube DD-42-4 it was 430 µg/L.

Tritium was analyzed in samples from four aquifer tubes. The two highest concentrations, 17,000 and 29,400 pCi/L, were in tubes in the south 100-D Area. The source of tritium is believed to be the 100-N Area to the south.

One riverbank seep site (SD-098-1, located on the edge of the southwest chromium plume) was sampled in October 2001 and data were published in PNNL-13910, APP. 1. The chromium concentration was 24 µg/L, about the same as the previous year. Concentrations of tritium, nitrate, and gross beta from the seep were below drinking water standards.

Table 2.5-1. Redox Site Injection/Extraction Wells

Well Treated	Injection Start Date	Well Treated	Injection State Date
199-D3-03	Planned FY 2003	199-D4-50	09/14/01
199-D3-04	Planned FY 2003	199-D4-51	07/19/01
199-D4-2	Not treated	199-D4-52	09/11/01
199-D4-7	09/29/97, 08/27/02	199-D4-53	08/09/01
199-D4-9	07/13/98, 09/12/02	199-D4-54	09/05/01
199-D4-10	05/19/98, 09/04/02	199-D4-55	07/12/01
199-D4-11	07/13/98, 09/10/02	199-D4-56	07/31/01
199-D4-12	05/04/98, 08/29/02	199-D4-57	08/23/01
199-D4-21	09/28/99	199-D4-58	09/18/01
199-D4-24	09/07/01	199-D4-59	07/17/01
199-D4-25	07/24/01	199-D4-60	08/29/01
199-D4-26	08/31/00	199-D4-61	09/20/01
199-D4-27	08/17/00	199-D4-62	08/21/01
199-D4-28	08/08/00	199-D4-63	06/20/02
199-D4-29	09/21/00	199-D4-64	03/27/02
199-D4-30	08/22/00	199-D4-65	06/17/02
199-D4-31	08/01/00	199-D4-66	04/11/02
199-D4-32	10/31/00	199-D4-67	06/13/02
199-D4-33	09/19/00	199-D4-68	04/04/02
199-D4-34	08/29/00	199-D4-69	06/11/02
199-D4-35	08/10/00, 08/22/02	199-D4-70	04/02/02
199-D4-36	09/12/00	199-D4-71	06/06/02
199-D4-37	04/10/01	199-D4-72	04/09/02
199-D4-40	09/19/00	199-D4-73	05/30/02
199-D4-41	08/29/00	199-D4-74	05/14/02
199-D4-42	08/10/00	199-D4-75	05/23/02
199-D4-43	09/12/00	199-D4-76	05/16/02
199-D4-44	04/10/01	199-D4-77	05/28/02
199-D4-45	08/10/00	199-D4-78	05/21/02
199-D4-46	09/12/00	199-D4-79	06/04/02
199-D4-47	04/10/01	199-D4-80	Planned for FY 2003
199-D4-48	04/10/01	199-D4-81	Planned for FY 2003
199-D4-49	08/07/01	199-D4-82	Planned for FY 2003

FY = Fiscal year.

Table 2.5-2. Shoreline Monitoring Data for the 100-D Area, Fiscal Year 2002

Location Name	Sample From(a)	Sample Date	Specific Conductance (µS/cm)(b)	Chromium (µg/L)(c)	Gross Beta (pCi/L)	Nitrate (mg/L)	Sulfate (mg/L)	Tritium (pCi/L)
DD-12-3	Tube	11/19/01	150	6				
DD-12-4	Tube	11/19/01	255	40				1,680
DD-17-2	Tube	11/19/01	179	29				
DD-17-3	Tube	11/19/01	250	75				1,700
DD-39-2	Tube	11/14/01	331	36				
DD-39-3	Tube	11/14/01	922	191				
DD-41-1	Tube	11/14/01	144	0 U				
DD-41-3	Tube	11/14/01	435	335			82	
DD-42-2	Tube	11/15/01	137	2				
DD-42-3	Tube	11/15/01	220	74				
DD-42-4	Tube	11/15/01	437	430			72	
DD-43-2	Tube	11/15/01	201	50				
DD-43-3	Tube	11/15/01	520	324			82	
DD-44-4	Tube	11/14/01	534	229			102	29,400
DD-50-3	Tube	11/15/01	298	49			38	17,000
Redox-2 (166-D-2)	Tube	11/19/01	434	82			88	
Redox-3 (166-D-3)	Tube	11/15/01	708	119			215	
RsD-102-ISRM	River	11/28/01	135	6 U		0.40	9.5	
SD-098-1	Seep	10/25/01	224	24	3.5	7.5	22	9,420

U = Below detection limit.

(a) Tube = aquifer sampling tube near shoreline; Seep = riverbank seepage.

(b) Specific conductance provides an indication of the amount of river water in the sample; uncontaminated groundwater is typically in the range of 350 to 450 µS/cm and river water in the range of 120 to 150 µS/cm.

(c) Chromium includes hexavalent chromium and total chromium for filtered samples.

Data sources: Hanford Environmental Information System and various project records.

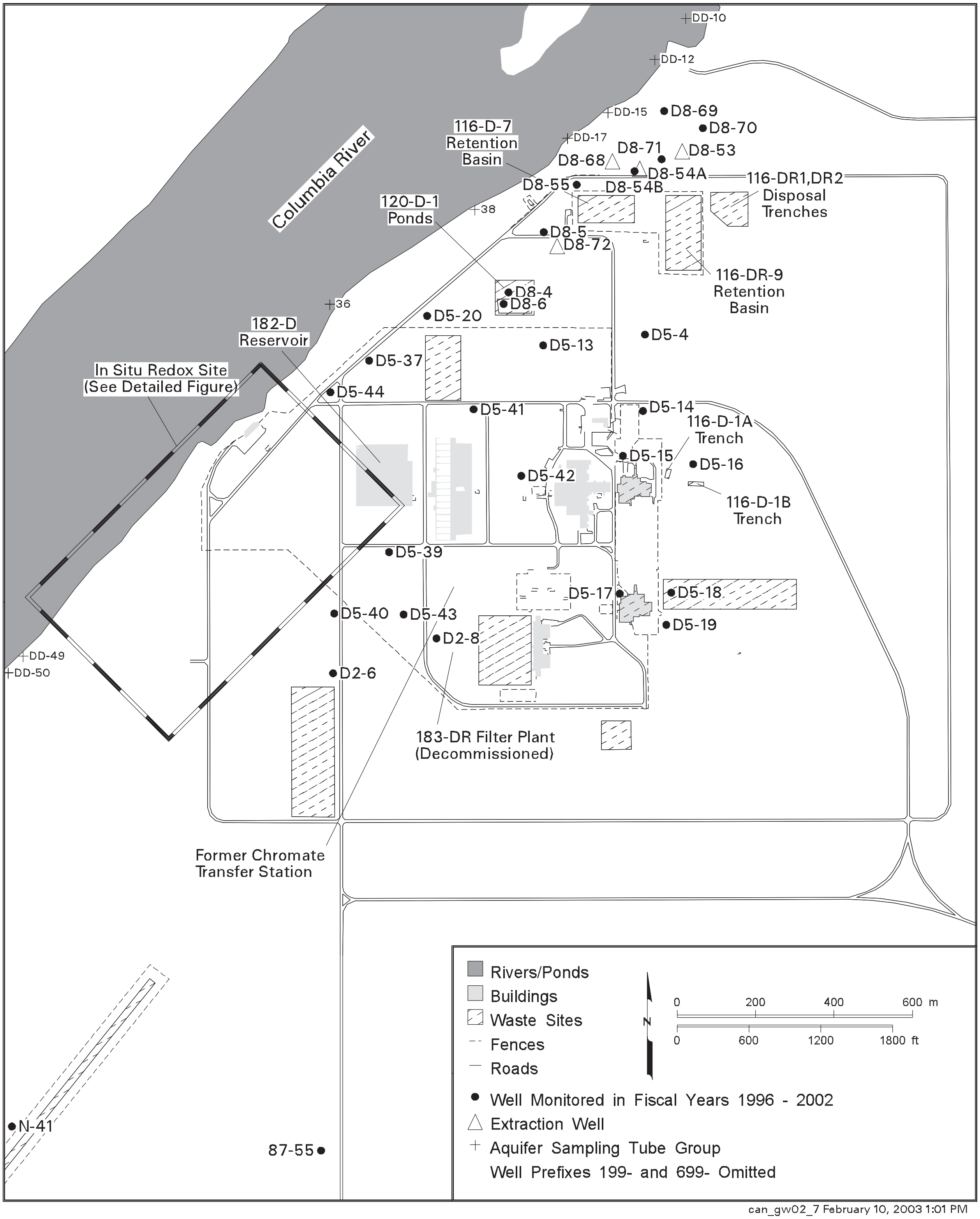

Figure 2.5-1. Groundwater Monitoring Wells in the 100-D Area

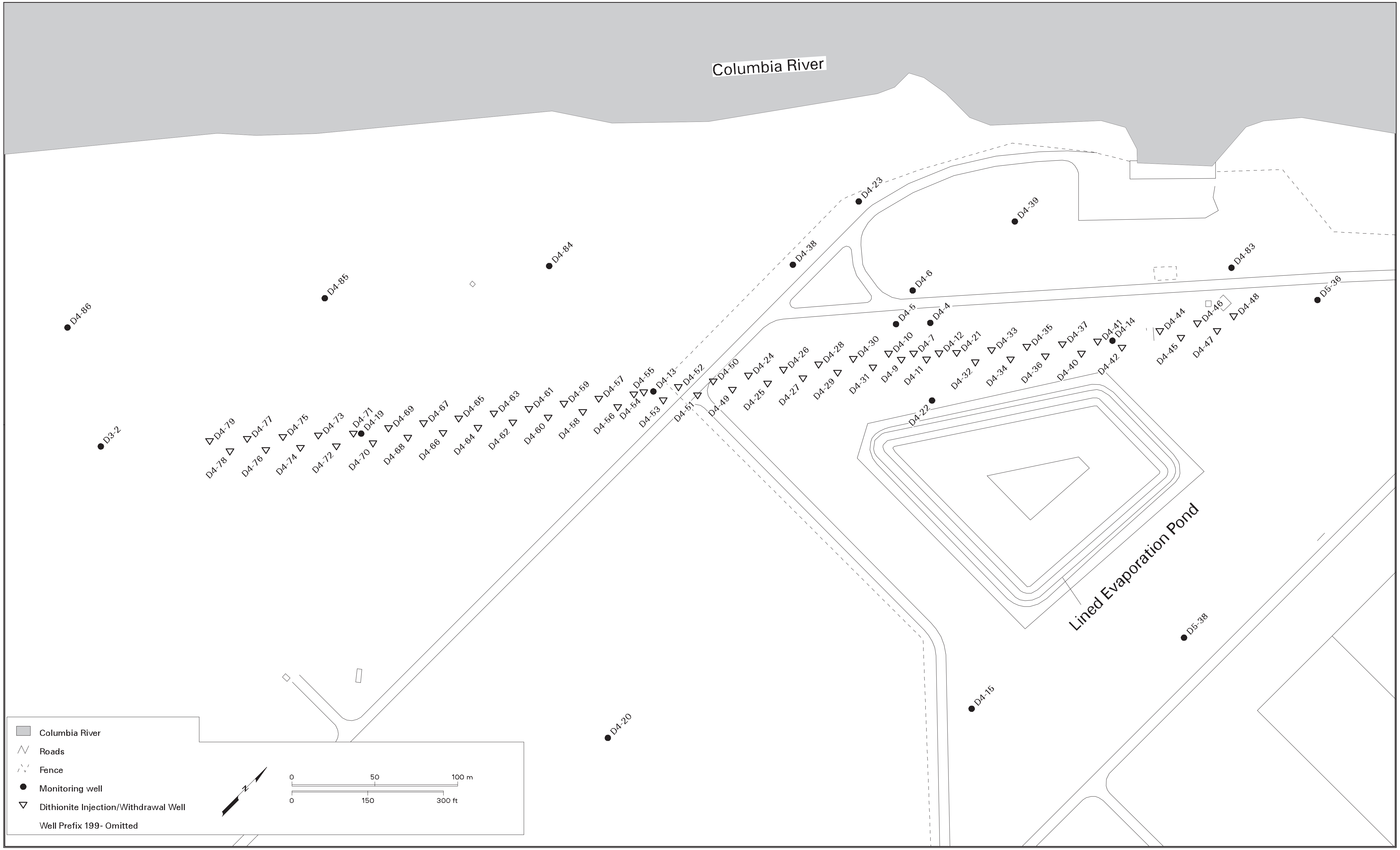

Figure 2.5-2. Injection/Withdrawal Wells and Groundwater Monitoring Wells Near the Redox Site in 100-D Area

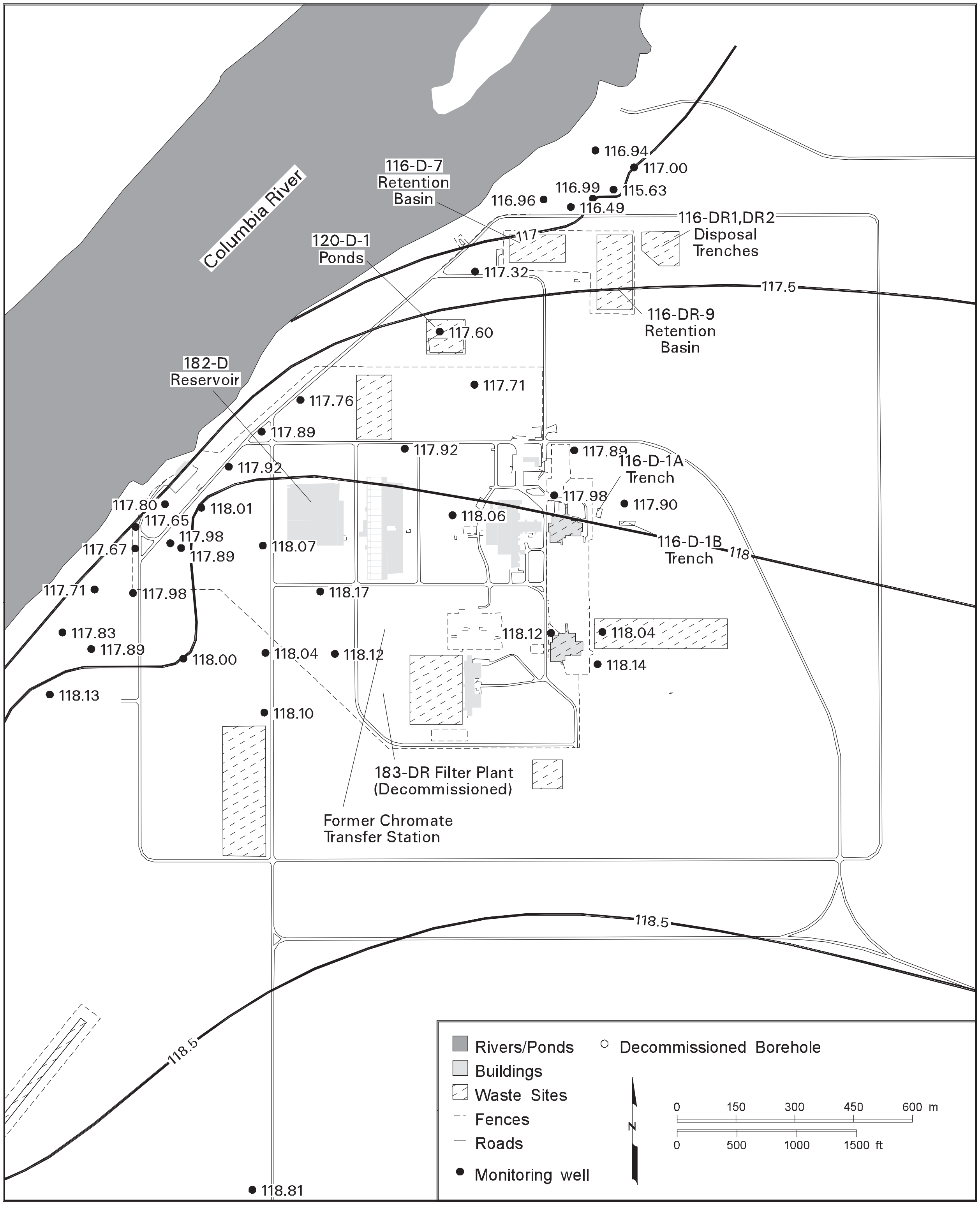

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Figure 2.5-3. 100-D Area Water-Table Map, March 2002

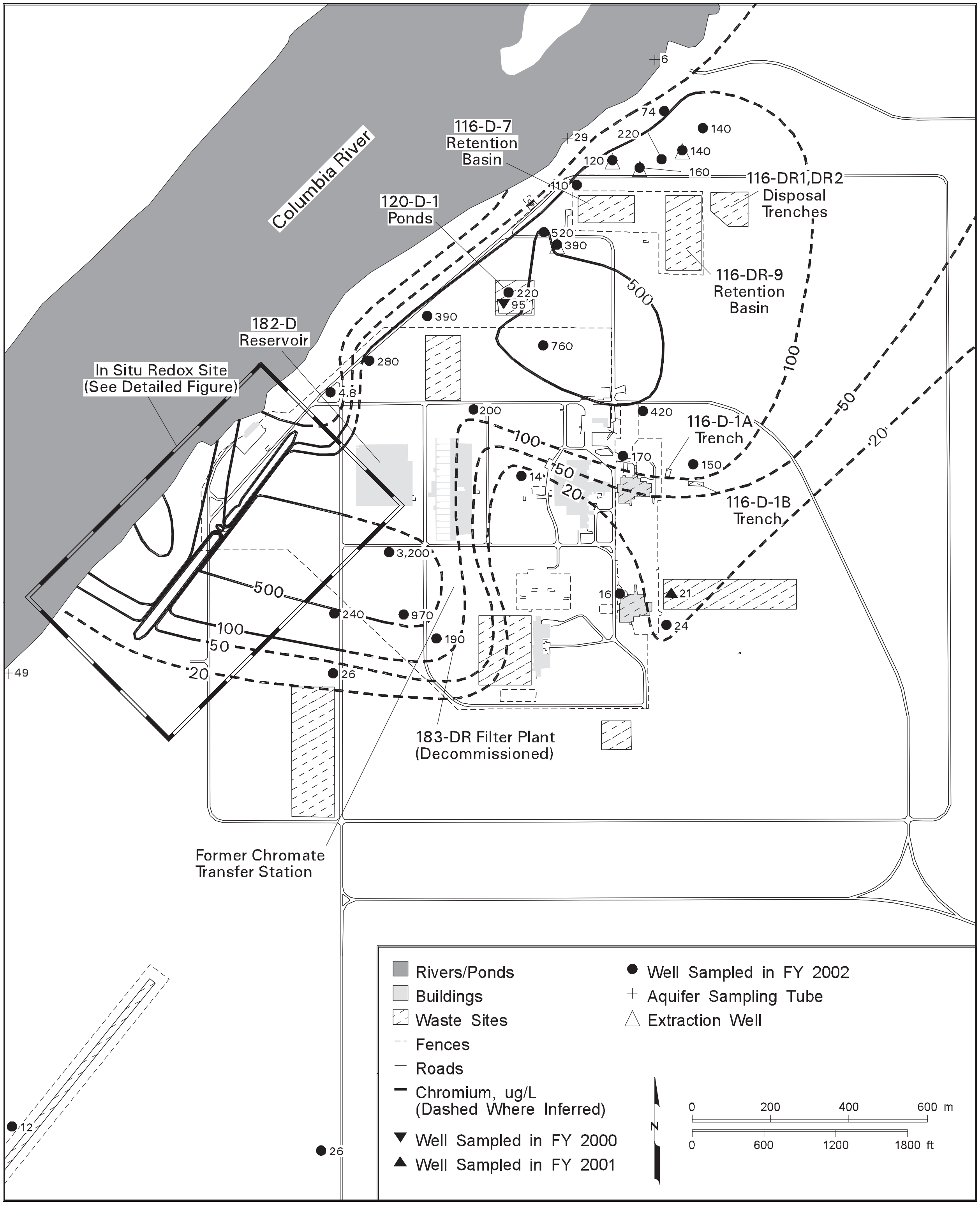

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Figure 2.5-4. Average Dissolved Chromium Concentrations in the 100-D Area, Top of Unconfined Aquifer

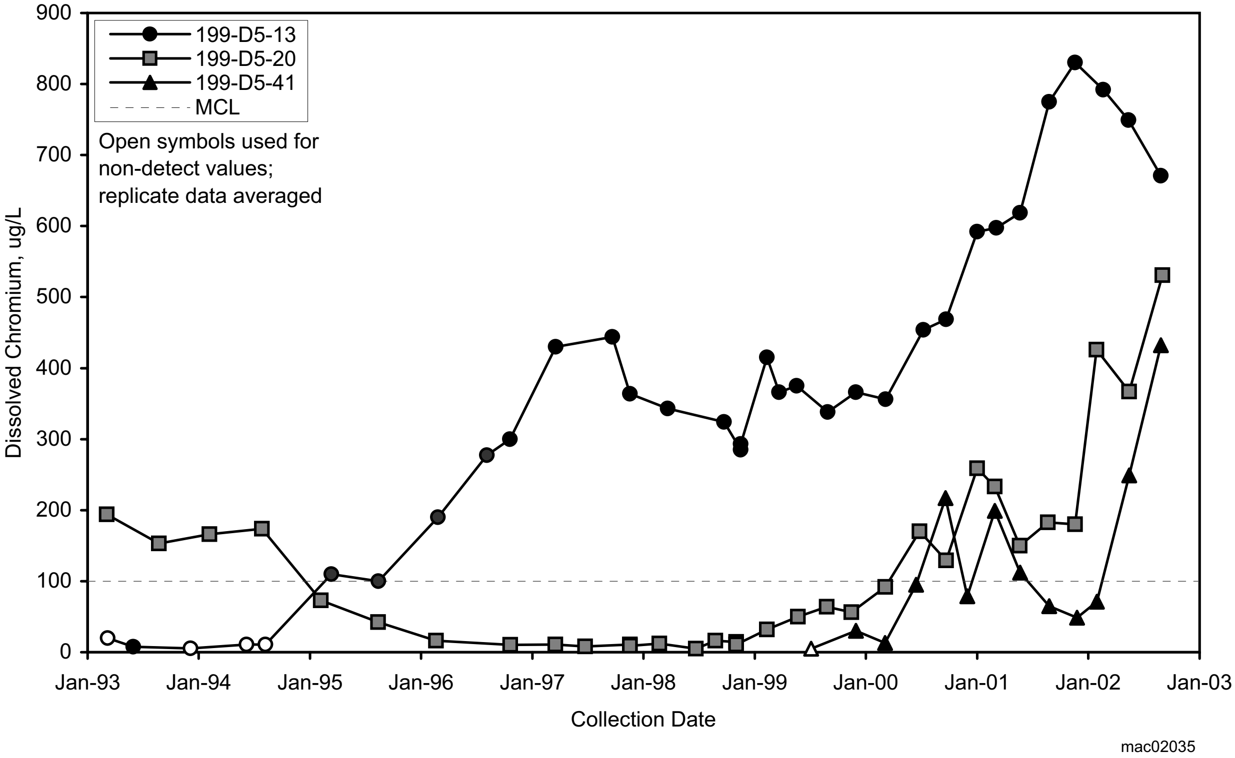

Figure 2.5-5. Dissolved Chromium Concentrations in Wells in the Central 100-D Area

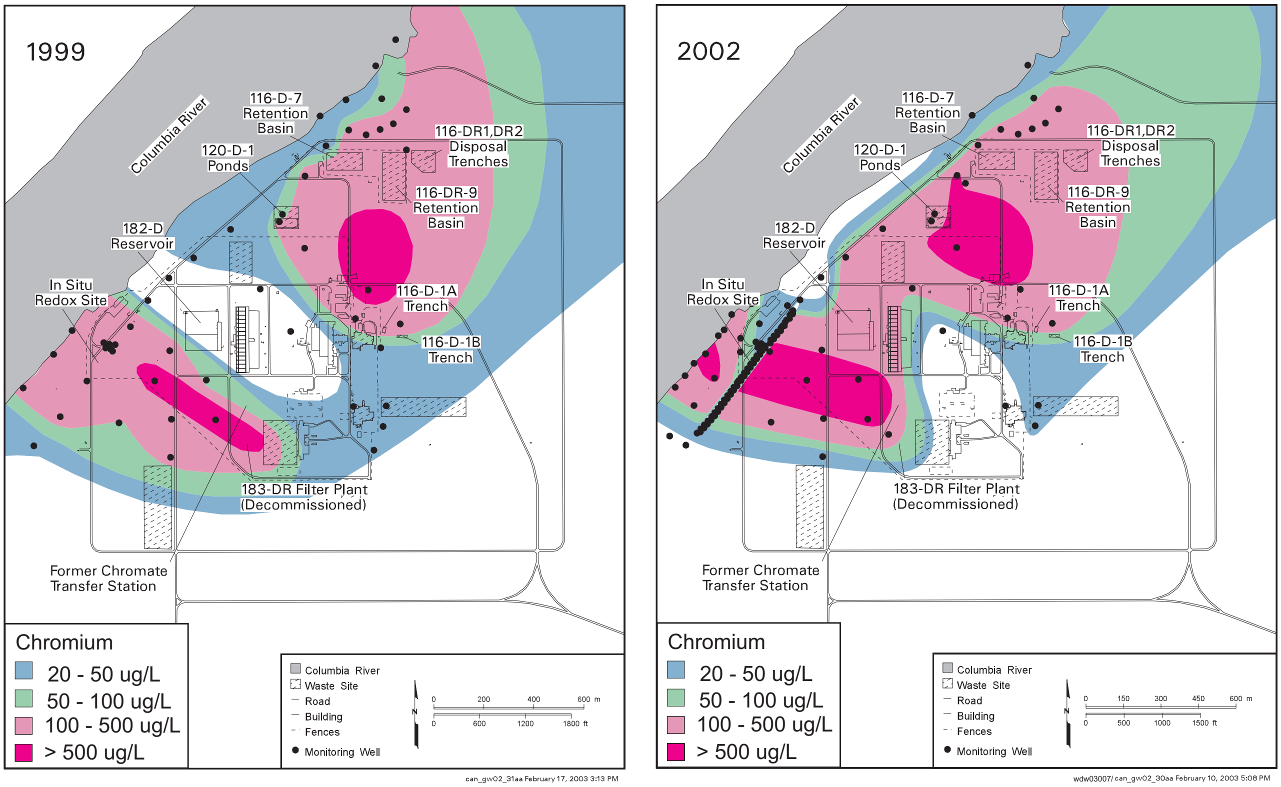

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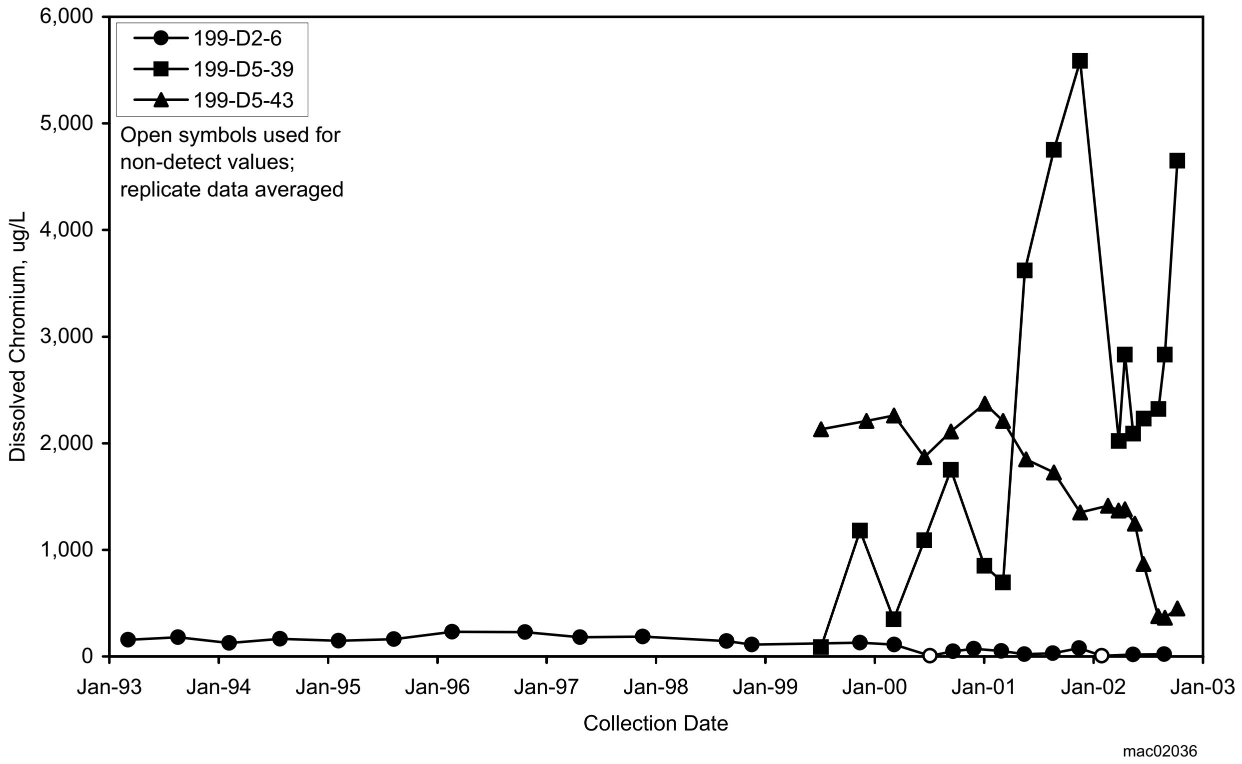
Figure 2.5-6. Comparison of Chromium Plumes in 100-D Area, Fiscal Years 1999 and 2002



Open symbols used for non-detect values; replicate data averaged

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Figure 2.5-7. Dissolved Chromium Concentrations in Wells in South 100-D Area

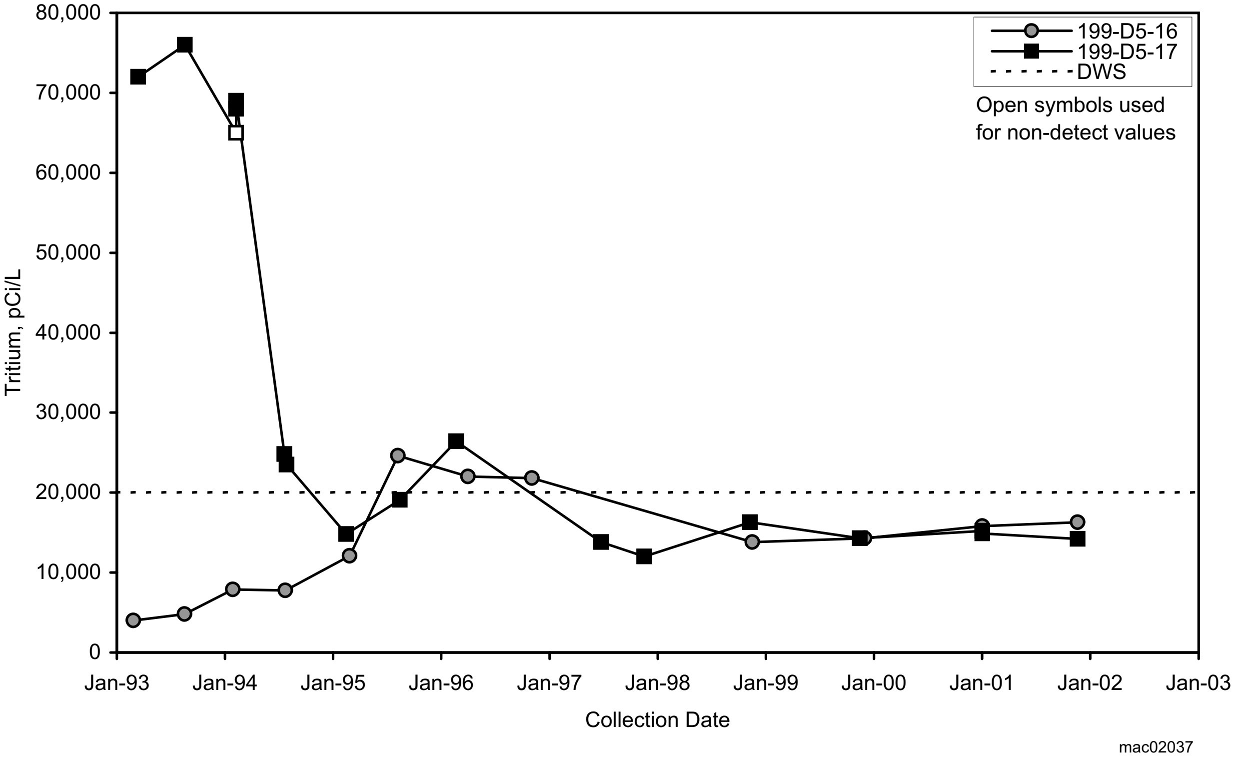

Figure 2.5-8. Tritium Concentrations in Wells Near D and DR Reactor Buildings

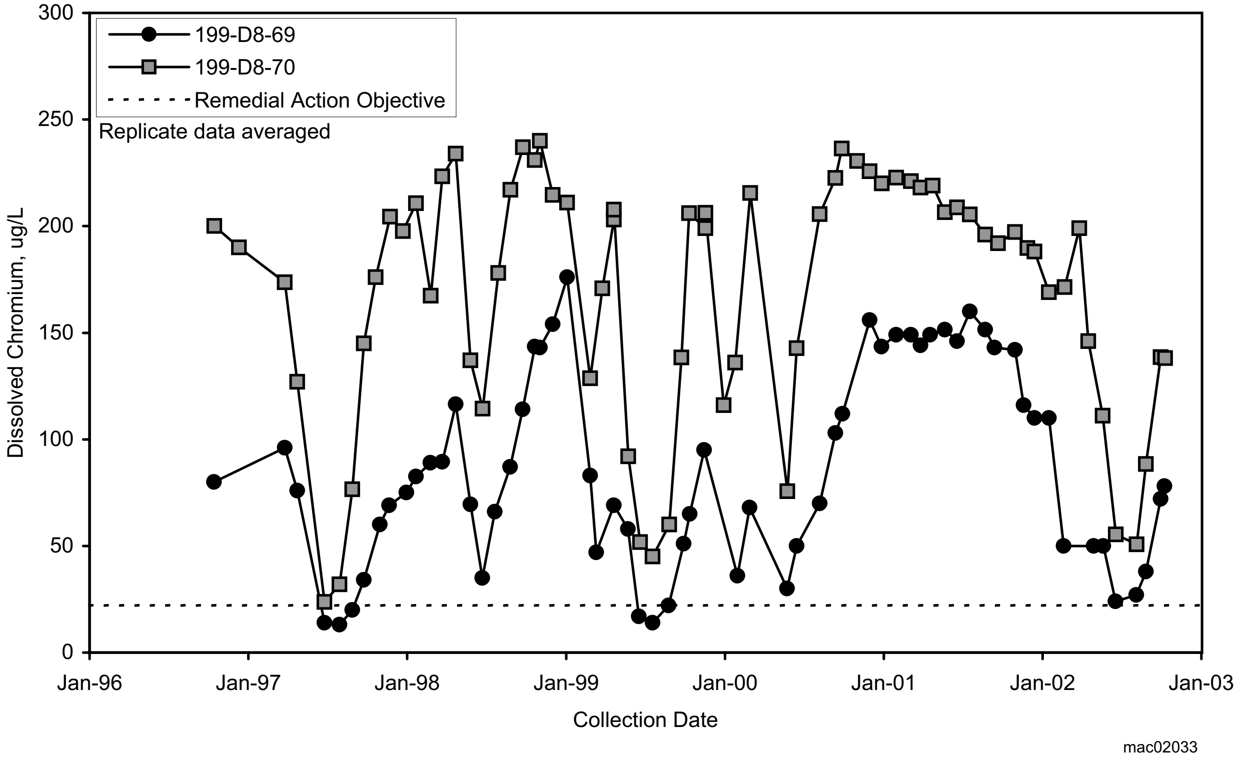

Figure 2.5-9. Dissolved Chromium Concentrations in Compliance Wells for the 100-HR-3 Pump-and-Treat System at 100-D Area

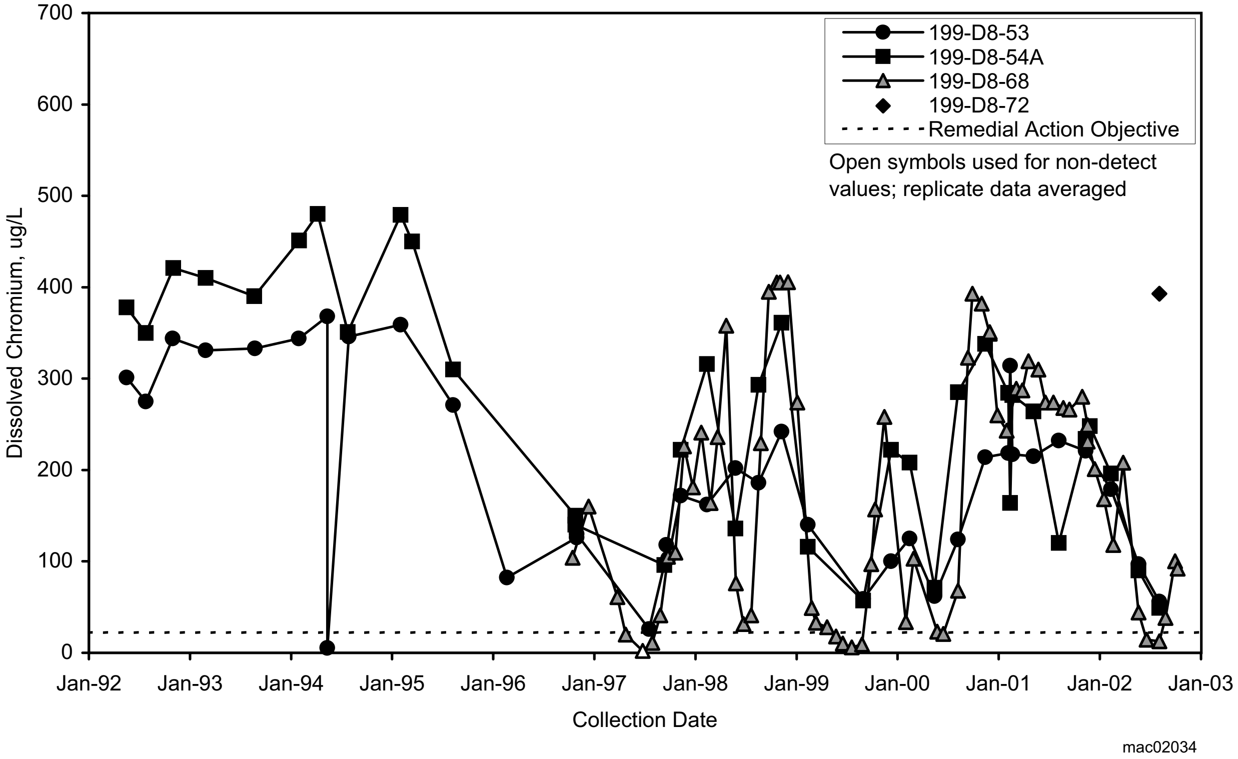

Figure 2.5-10. Dissolved Chromium Concentrations in Extraction Wells for the 100-HR-3 Pump-and-Treat System at 100-D Area

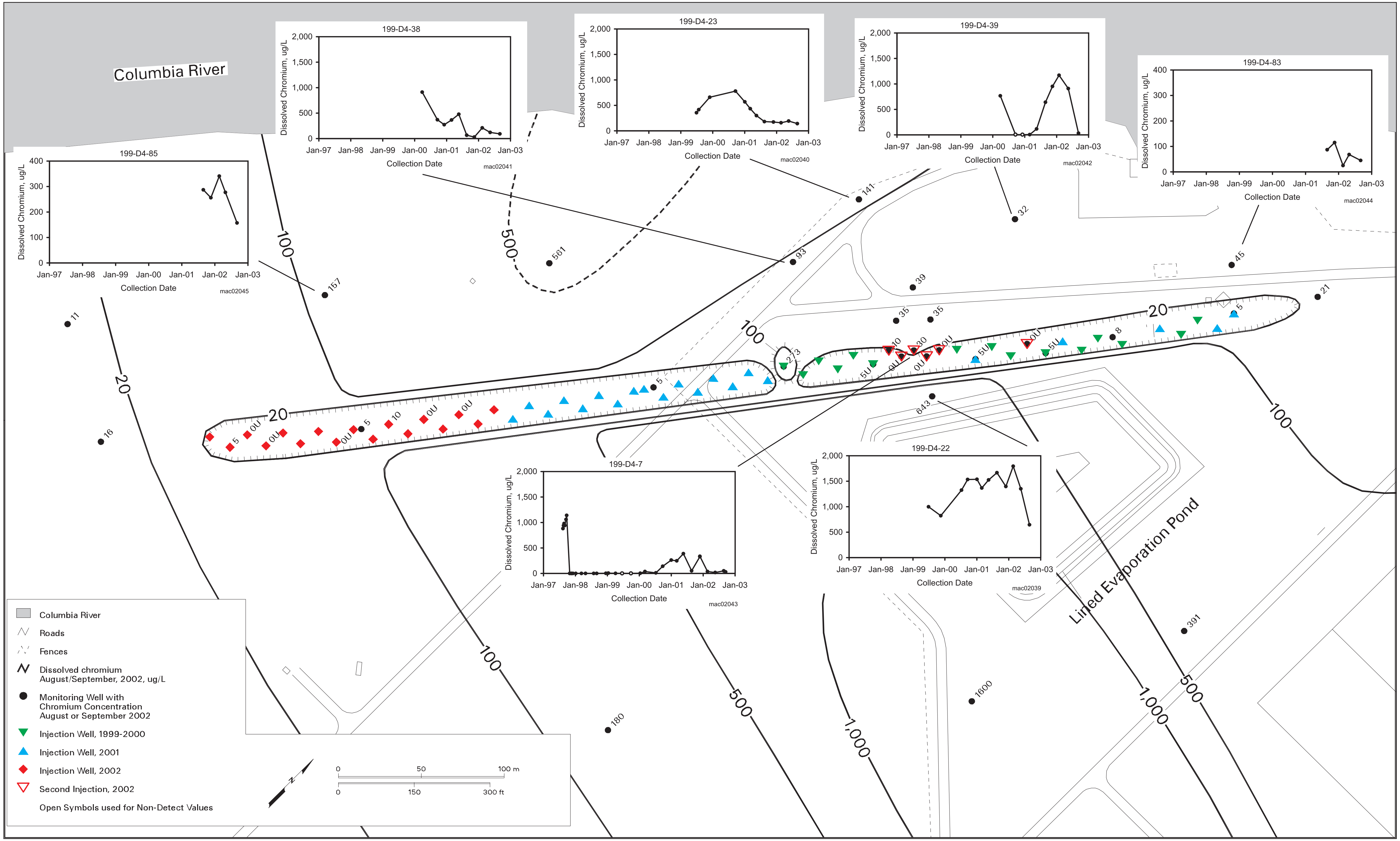

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Figure 2.5-11. Dissolved Chromium Concentrations Near the Redox Site, 100-D Area, August-September 2002

2.6 100-H Area

M. J. Hartman

The H Reactor operated between 1949 and 1965 using a single-pass cooling system. Groundwater contaminants include chromium, nitrate, strontium-90, technetium-99, and uranium. Sources of groundwater contamination include the 116-H-7 retention basins and 116-H-1 disposal trench in the east part of the area and the 116-H-6 (183-H) evaporation basins, which stored fuel fabrication effluent between 1973 and 1985. All of these waste sites have been excavated to remove contaminated sediment, backfilled, and revegetated. A comprehensive description of 100-H Area operations and waste sites is presented in the technical baseline report for the 100-HR-3 Operable Unit (BHI-00127). Facilities and monitoring wells referred to in the text are shown on Figure 2.6-1.

The presence of chromium in 100-H Area groundwater is a concern because the adjacent riverbed is used by salmon for spawning. Additional groundwater contaminants of interest are nitrate, strontium-90, technetium-99, and uranium.

2.6.1 Groundwater Flow

Groundwater movement beneath the 100-H Area is generally southwest to northeast, toward the Columbia River (Figure 2.6-2). Flow through the sandy/gravelly sediment near the water table is relatively rapid and estimated to be within 0.3 to 2 meters per day (DOE/RL-93-43). Groundwater flows generally toward the northeast across the entire horn of the Columbia River north of Gable Mountain, so groundwater approaching the shoreline upstream of 100-H Area and along the area may contain contaminants that originated in the 100-D and 100-N Areas.

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A pump-and-treat system to remove hexavalent chromium operates in the 100-H Area, shown above. Also, contaminated soil was removed from waste sites.

Monitoring Objectives in 100-H Area

Groundwater monitoring is conducted in the 100-H Area:

- annually to describe the nature and extent of contamination in support of environmental restoration decisions
- annually to monitor conditions beneath the former 116-H-6 evaporation basins, a RCRA site
- semiannually to monitor trends in variable constituents/wells
- various time intervals to evaluate the performance of a pump-and-treat system for chromium

Daily and seasonal river stage fluctuations create corresponding changes in the elevation of the water table, which causes changes in flow direction and may also influence water quality monitoring results. During periods of high river levels (e.g., summer 2002), river water infiltrates the banks along the 100-H Area shoreline, causing variable flow directions and mixing between groundwater and river water. The extraction and injection of groundwater associated with the interim remedial action to address chromium contamination also influences the movement of groundwater in the vicinity of the associated wells.

2.6.2 Chromium

Chromium contamination in 100-H Area groundwater originated from multiple sources within the 100-H Area and from upgradient sources in the 100-D Area (Figure 2.6-3). In recent years, the number of wells exceeding the 100-µg/L maximum contaminant level has declined and in fiscal year 2002, no wells monitoring the top of the aquifer within the 100-H Area exceeded that level. Concentrations in most wells continued to exceed the more stringent standard for protection of freshwater aquatic organisms (10 µg/L). The chromium plume in this area is adjacent to gravelly riverbed areas that are heavily used by salmon for spawning (Dauble and Watson 1997). Chromium trends in wells associated with a pump-and-treat system are discussed in Section 2.6.7.

Well 199-H4-12C, located downgradient of the 116-H-6 evaporation basins and completed in a confined unit, has elevated chromium concentrations, with an average of 143 µg/L in fiscal year 2002. One potential explanation for the elevated chromium involves corrosion of the stainless steel well screen. The well is located downgradient of the 116-H-6 evaporation basins but no other contaminants from the basins are present in the well.

West of the 100-H Area (upgradient), chromium in wells 699-96-43 and 699-97-43 is believed to have originated across the horn of the Hanford Site in the 100-D Area. Concentrations have declined since the early 1990s but have been increasing since 1998 in well 699-97-43, and exceeded the maximum contaminant level in fiscal years 2001 and 2002 (Figure 2.6-4). These concentrations were higher than in wells in the 100-H Area. Chromium levels are elevated in aquifer sampling tubes north of the 100-H Area (see Figure 2.6-3). This contamination also is believed to have an upgradient source. The lack of monitoring points in this area prevents an assessment of the amount of chromium entering the Columbia River north of 100-H Area.

Chromium concentrations have decreased in 100-H Area groundwater in recent years, and in fiscal year 2002 all values were below the maximum contaminant level. Concentrations exceeded the more stringent aquatic standard (10 µg/L) beneath most of the 100-H Area.

2.6.3 Strontium-90

The primary source for strontium-90 contamination in the 100-H Area is past disposal of contaminated reactor coolant to the former 116-H-7 retention basin, 116-H-1 liquid waste disposal trench, and the 116-H-5 sludge burial trench, which have been excavated and backfilled. The strontium-90 plume is located east and southeast of the retention basin (see Figure 2.6-8 in PNNL-13788), and has changed very little in the past 10 years. Concentrations are somewhat variable, but there are no clear increasing or decreasing trends. The maximum concentration in fiscal year 2002 was 38 pCi/L in well 199-H4-63.

2.6.4 Tritium

Tritium concentrations in the 100-H Area remained below the 20,000-pCi/L drinking water standard in fiscal year 2002. The highest values detected during fiscal year 2002 were 6,400 pCi/L in wells 199-H4-49 and 199-H5-1 (south 100-H Area) and 6,470 pCi/L in well 699-97-43 (upgradient of 100-H Area). Concentration trends are variable.

2.6.5 Nitrate

During fiscal year 2002, only a few wells in the 100-H Area exceeded the 45-mg/L maximum contaminant level for nitrate. The highest concentrations were measured in groundwater affected by effluent that leaked from the 116-H-6 evaporation basins, which were a source of nitrate (e.g., 87 mg/L in well 199-H4-3). Trends in these wells are variable but appear to be declining overall.

Several wells in the south 100-H Area showed increases in nitrate in the mid-to-late 1990s and formerly exceeded the maximum contaminant level. Concentrations declined below that level in fiscal year 2002.

2.6.6 Technetium-99 and Uranium

The 116-H-6 evaporation basins were a source of technetium-99 and uranium contamination. As with chromium and nitrate, concentrations of these radionuclides have declined in recent years. In fiscal year 2002, neither exceeded their drinking water standard in any wells. The maximum technetium-99 concentration was 243 pCi/L in well 199-H4-3. The maximum uranium concentration was 23 µg/L in well 199-H4-4.

Technetium-99, tritium, and uranium did not exceed their drinking water standard in fiscal year 2002 at 100-H Area. Strontium-90 exceeded its standard in a small, stable plume.

These two contaminants are mobile in groundwater. Near the Columbia River, their concentrations vary with changes in elevation of the water table, which responds to fluctuations in river stage (Figure 2.6-5). Typically, low water levels are associated with higher contaminant concentrations.

The technetium-99 concentration increased to 120 pCi/L in extraction well 199-H4-7 in fiscal year 2002 from undetected in 2001. Co-contaminants chromium and nitrate also increased. A much higher peak of technetium-99, chromium, nitrate, and uranium was observed in 1997, causing the temporary cessation of use of the well for chromium remediation (the technetium-99 binds to resins in the treatment system and complicates disposal options for the resin). Fluor Hanford, Inc. will continue to sample this well semiannually to monitor the technetium-99 trend.

2.6.7 Groundwater Remediation at the 100-HR-3 (H) Operable Unit

A pump-and-treat system began operating in the 100-H Area during July 1997 as an interim remedial action for chromium contamination in groundwater. The primary purpose for this system is to prevent or reduce the movement of hexavalent chromium from the aquifer to the river, thereby protecting aquatic receptors (ROD 1996a). The extraction network currently includes three wells located within ~50 meters of the river shore, and three additional wells located farther inland. A report is prepared annually that describes the performance of the system for the preceding calendar year (e.g., DOE/RL-2002-05).

The pump-and-treat system in the 100-H Area is reducing the amount of chromium that reaches the Columbia River, where it could potentially harm aquatic organisms. Since 1997, 34 kilograms of chromium have been removed from groundwater.

The pump-and-treat system made progress toward achieving its goals during fiscal year 2002. Although designed primarily to prevent or reduce the amount of contaminated groundwater discharging into the Columbia River, the pump-and-treat system also reduces overall contamination in the aquifer by removing contaminant mass. During fiscal year 2002, the pump-and-treat system extracted over 148 million liters of 100-H Area groundwater and removed ~4.7 kilograms of hexavalent chromium from near the river.

The average concentration of hexavalent chromium in the extracted groundwater was 31 µg/L. After treatment, the average effluent concentration was 6.5 µg/L. The treatment system in 100-H Area receives groundwater from both 100-D and 100-H Areas. The treated effluent was injected back into the aquifer at an upgradient location southwest of the H Reactor.

The pump-and-treat system has removed ~34 kilograms of hexavalent chromium from 100-H Area groundwater since July 1997, which appears to represent a significant fraction of the amount likely to be in the aquifer. The amount of chromium in the plume targeted for interim remedial action was estimated to be ~42 kilograms for 1992 conditions (WHC-SA-1674-VA). Estimates of the mass of chromium in the plume are subject to uncertainty because of (a) lack of data on the vertical distribution of contamination in the aquifer; (b) uncertainty in the rate at which chromium enters from the vadose zone; and (c) difficulty in evaluating the amount of chromium flowing into the area from upgradient sources.

Chromium concentrations in most of the extraction and compliance wells remained above the interim remedial action objective of 22 µg/L during fiscal year 2002. The pump-and-treat system will continue to operate in 2003.

Figure 2.6-6 shows chromium concentrations in extracted groundwater from wells nearest the Columbia River. Since 1998, average concentrations and seasonal peaks have declined in wells 199-H4-11 and 199-H4-12A. In well 199-H4-15A, concentrations have ranged from ~30 to ~90 µg/L since 1996 and decreased in fiscal year 2002.

Chromium concentrations in extraction wells located farther inland are shown in Figure 2.6-7. Increasing concentrations in fiscal year 2002 interrupted the overall declining trend in these wells. This may represent inflow of chromium contamination from upgradient sources.

Chromium concentrations are monitored to evaluate the progress of the interim action in compliance wells 199-H4-4 and 199-H4-63. The long-term trend in well 199-H4-4 (Figure 2.6-8) shows a dramatic decline between 1985 and 1990. Concentrations increased somewhat in 1998 and 1999, perhaps because of delayed effects of high water levels in 1996-1997 mobilizing chromium from the vadose zone. Contaminant concentrations in the compliance wells vary inversely with water levels (Figure 2.6-9). Seasonal peak concentrations, generally observed in the fall when water levels are low, have declined since 1998. Chromium rebounded in both compliance wells in September 2002 when water levels dropped.

The concentration in inland extraction well 199-H3-2A has been below the 22-µg/L action level since 1998. Concentrations in near-river extraction well 199-H4-12A and compliance well 199-H4-4 declined below the 22-µg/L action level during summer 2002 when river stage was high, but were above the action level during the rest of the year. Because chromium concentrations continue to exceed the action level in the compliance wells, operation of the pump-and-treat system is continuing into fiscal year 2003. Contaminant monitoring results indicate that several years of pumping may be required before the concentration levels required by remedial action are achieved.

2.6.8 RCRA Monitoring at the 116-H-6 (183-H) Evaporation Basins

Groundwater near the former evaporation basins is monitored to meet *Resource Conservation and Recovery Act* (RCRA) final status corrective action requirements [WAC 173-303-645(11)]. Hazardous waste was removed from the treatment facility during the late 1980s, followed by decontamination and demolition of the structure, which was completed in 1995 (DOE/RL-97-48). Contaminated soil was then removed, though fluoride and nitrate remained elevated in the remaining soil, thus requiring post-closure groundwater monitoring.

Groundwater movement in the vicinity of the basins has been influenced by the interim remedial action under the *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA) that focuses on chromium contamination. While pumping operations are in progress, RCRA monitoring tracks the trends of five contaminants associated with leakage from the basins: chromium, fluoride, nitrate, technetium-99, and uranium (PNNL-11573). Concentrations of all of these constituents except fluoride are elevated and declining in groundwater downgradient of the basins (see Sections 2.6.2, 2.6.5, and 2.6.6). See Appendix A for supporting information about this RCRA site.

2.6.9 Monitoring at River Shoreline

Groundwater samples are collected annually from aquifer sampling tubes located near the low river stage shoreline and from riverbank seepage sites during the period of low river stage that occurs during the fall. The tubes are sampled annually to support Environmental Restoration Project objectives. Riverbank seepage is monitored by the Surface Environmental Surveillance Project. Table 2.6-1 lists the analytical results for key constituents in samples collected during fiscal year 2002 from aquifer sampling tubes and riverbank seepage.

Samples from aquifer sampling tubes were collected during November 2001 and analyzed for hexavalent chromium. Chromium concentrations in sampling tubes ranged from 20 to 46 µg/L generally agreed with concentrations in wells (see Figure 2.6-3). Specific conductance of the samples was relatively high indicating little dilution with river water.

Three riverbank seepage sites were sampled in November 2001 along the 100-H Area shoreline. Only two specific conductance values were recorded. They were relatively low, indicating much dilution with river water. Chromium concentrations exceeded the 10-µg/L standard for protection of aquatic organisms in one of the seeps in fiscal year 2002. Chromium concentrations ranged from 5.6 to 20 µg/L (see Table 2.6-1).

Chromium exceeded its aquatic standard in most shoreline samples from the 100-H Area during fiscal year 2002.

Strontium-90 was analyzed at two seeps. It was undetected in a seep upstream of 100-H Area and 3.8 pCi/L in a seep near the former retention basin, where a contaminant plume is present in groundwater. Gross beta was analyzed in all three seep samples and ranged from undetected to 14.5 pCi/L in a seep in the strontium-90 plume. Tritium and nitrate concentrations in seeps were below drinking water standards.

Table 2.6-1. Shoreline Monitoring Data for the 100-H Area, Fiscal Year 2002

Location Name	Sample From(a)	Sample Date	Specific Conductance (µS/cm)(b)	Chromium (µg/L)(c)	Gross Beta (pCi/L)	Nitrate (mg/L)	Strontium-90 (pCi/L)	Tritium (pCi/L)
44-M	Tube	11/05/01	308	40				
46-D	Tube	11/05/01	316	20				
48-S	Tube	11/06/01	499	25				
49-M	Tube	11/06/01	525	37				
50-M	Tube	11/06/01	542	46				
51-M	Tube	11/26/01	548	46				
SH-145-1	Seep	10/31/01		22				
		11/01/01	211	20(d)	1.7 U	6.6	0.06 U	1,245(d)
SH-152-2	Seep	10/31/01		10				
		11/01/01		10(d)	12.3	5.5	3.8	350(d)
SH-153-1	Seep	11/01/01	162	5.6(d)	14.5	2.5		205

U = Below detection limit.

(a) Tube = aquifer sampling tube located near the low-river shoreline; Seep = natural riverbank seepage site.

(b) Specific conductance provides an indication of the amount of river water in the sample; uncontaminated groundwater is typically in the range of 350 to 450 µS/cm and river water in the range of 120 to 150 µS/cm.

(c) Chromium includes hexavalent chromium and total chromium for filtered samples.

(d) Average of multiple measurements.

Data sources: Hanford Environmental Information System and various project records.

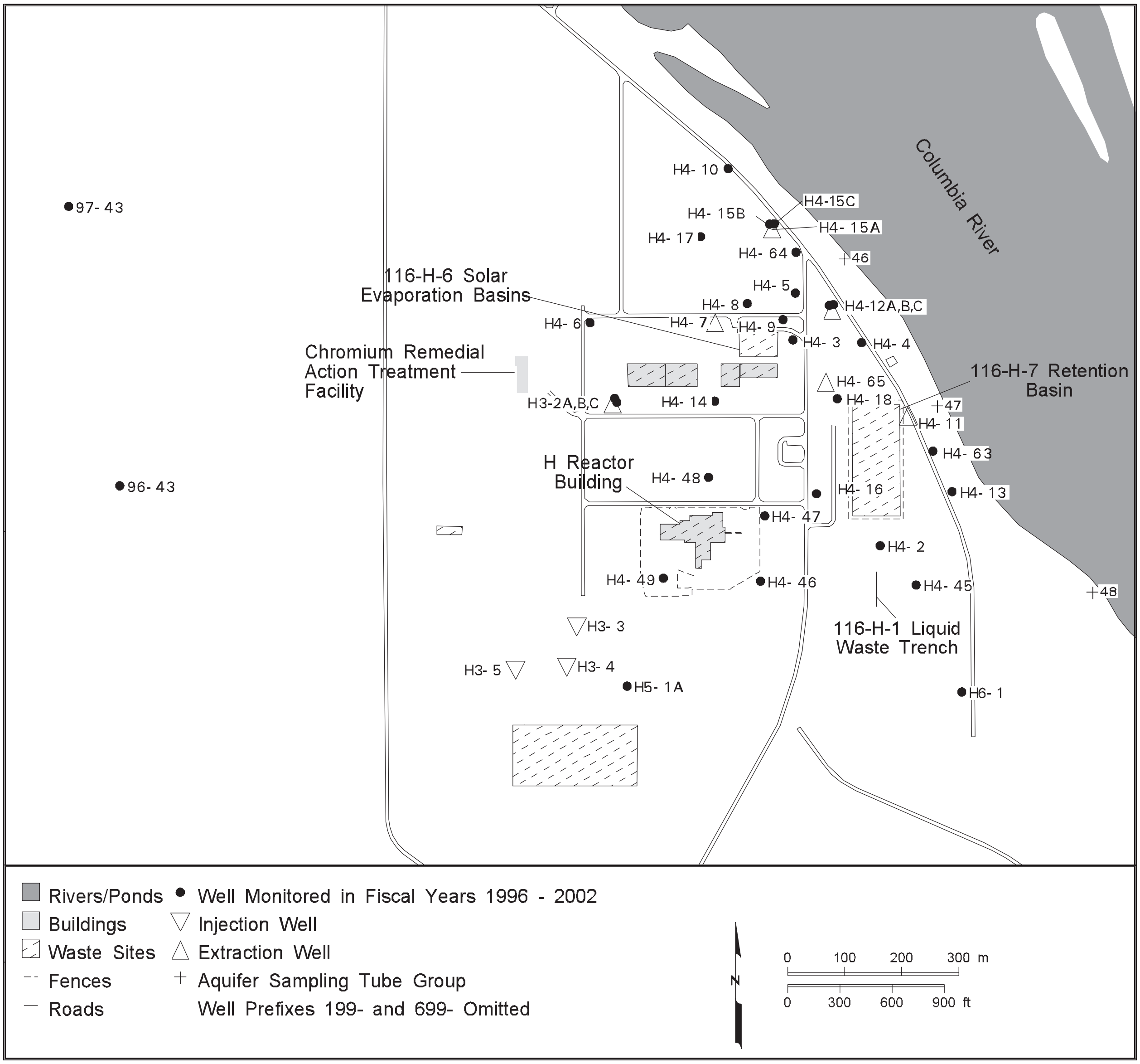

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Figure 2.6-1. Groundwater Monitoring Wells in the 100-H Area

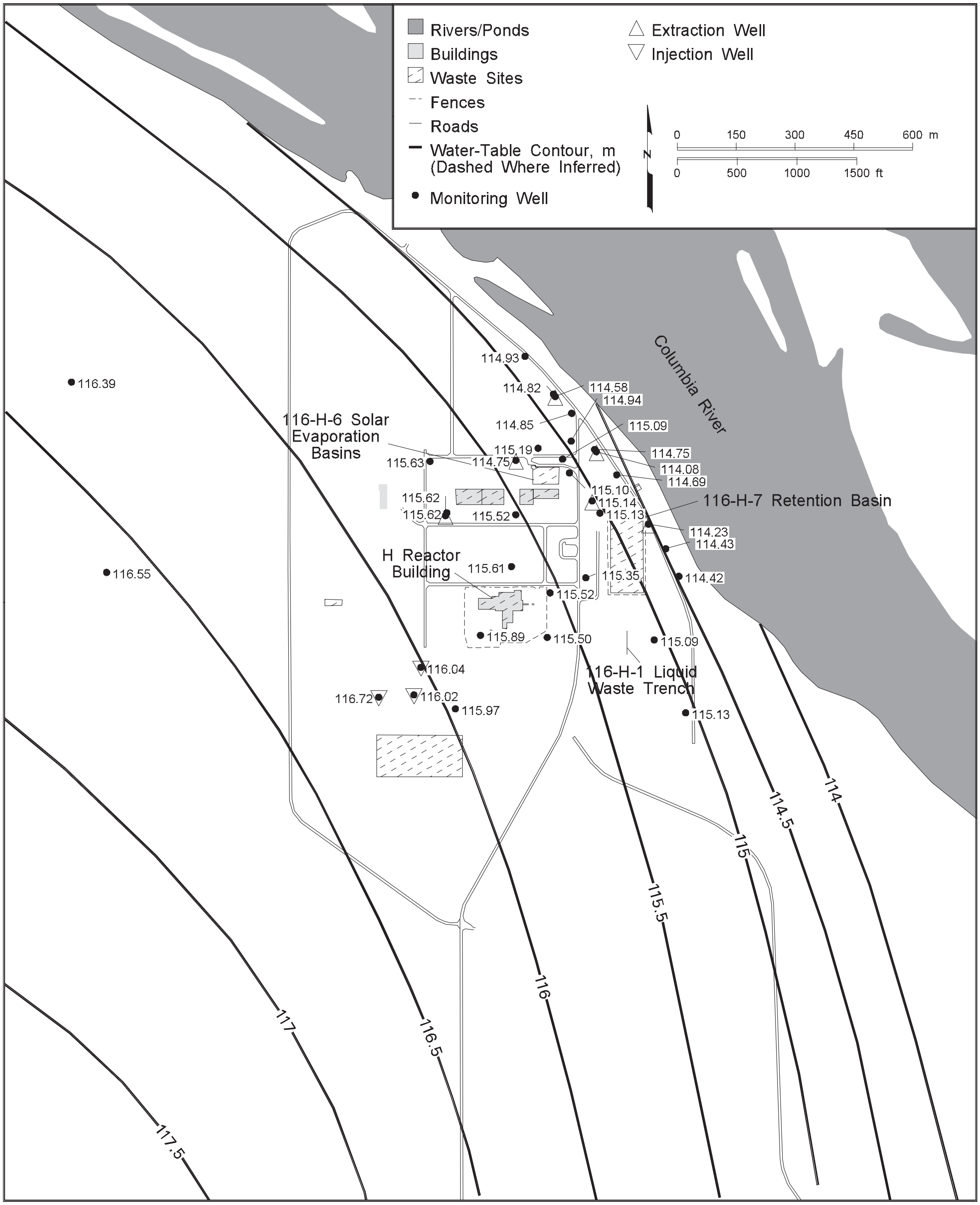

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Figure 2.6-2. Water Table Beneath 100-H Area, March 2002

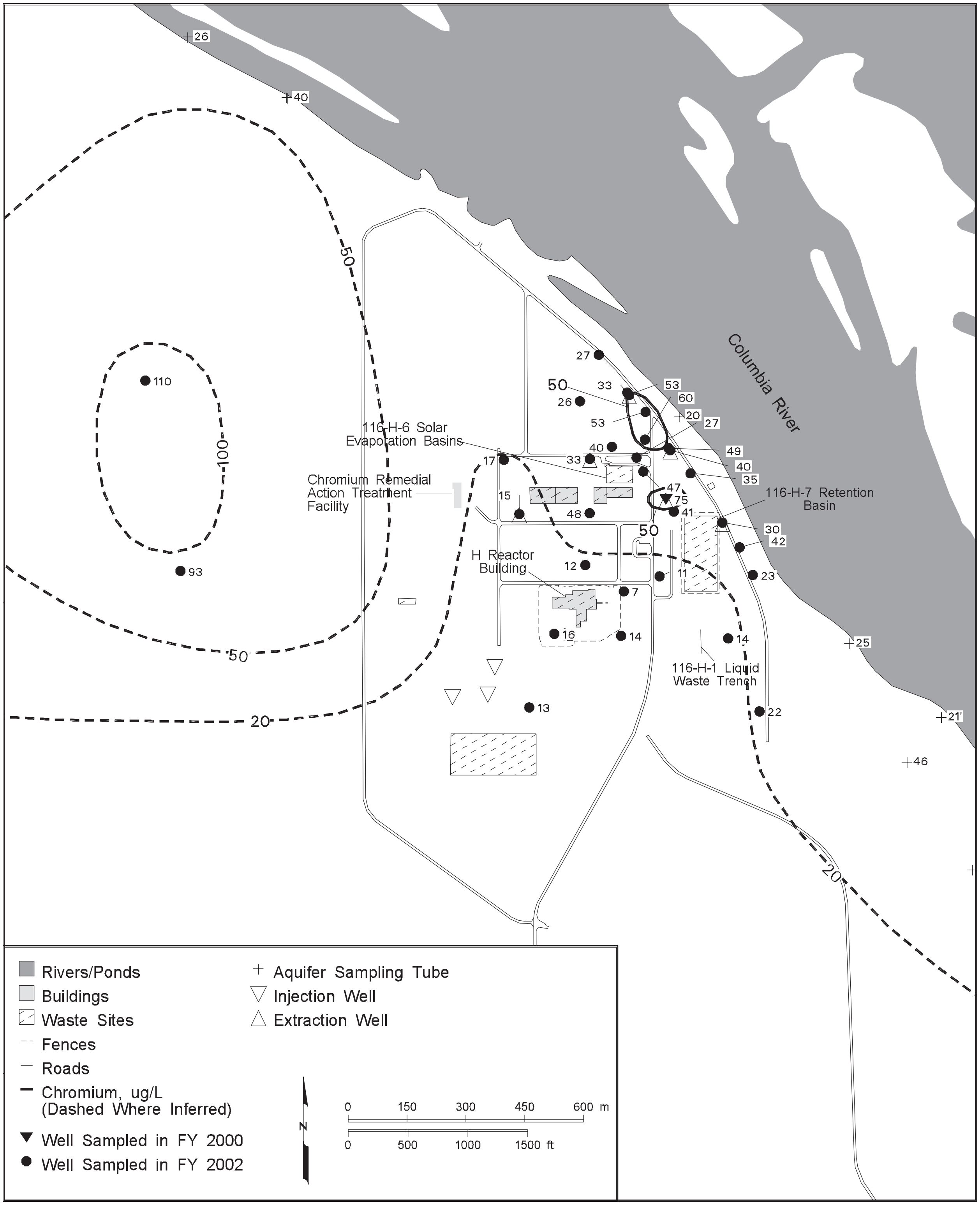

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Figure 2.6-3. Average Chromium Concentrations in the 100-H Area, Top of Unconfined Aquifer

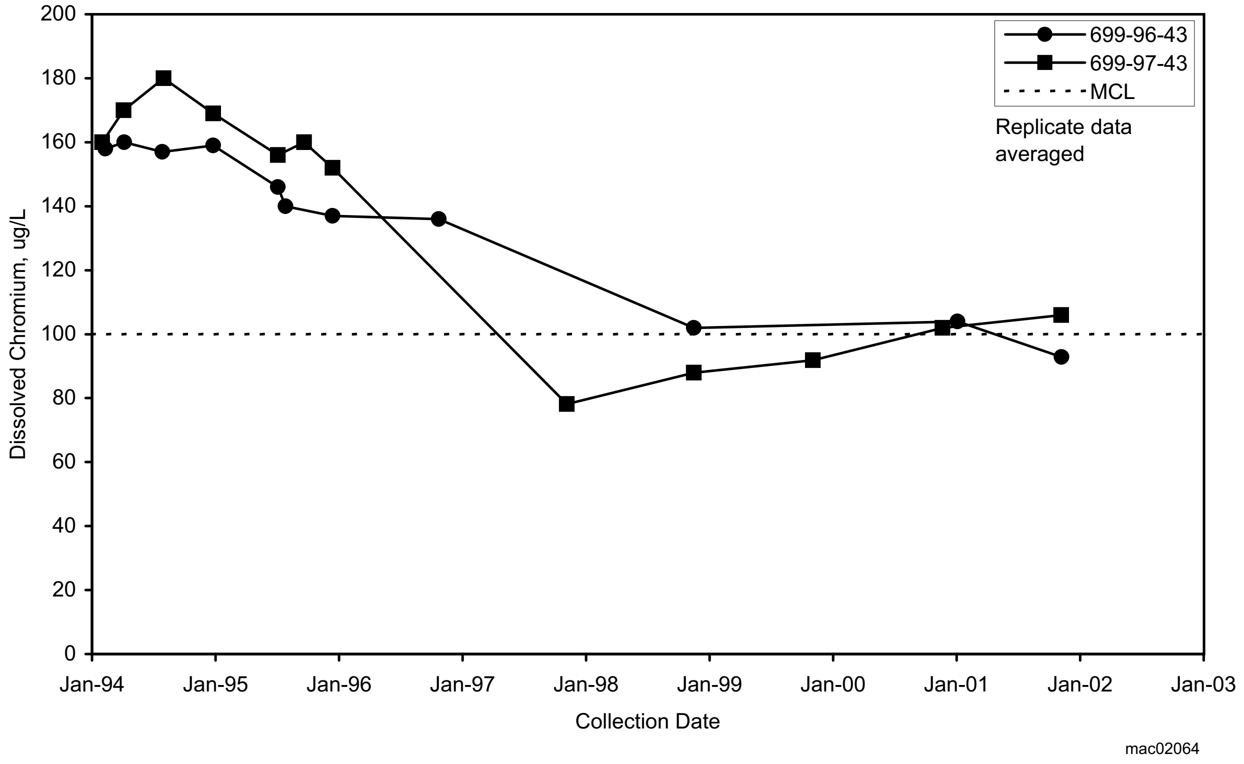

Figure 2.6-4. Dissolved Chromium Concentrations Upgradient of the 100-H Area

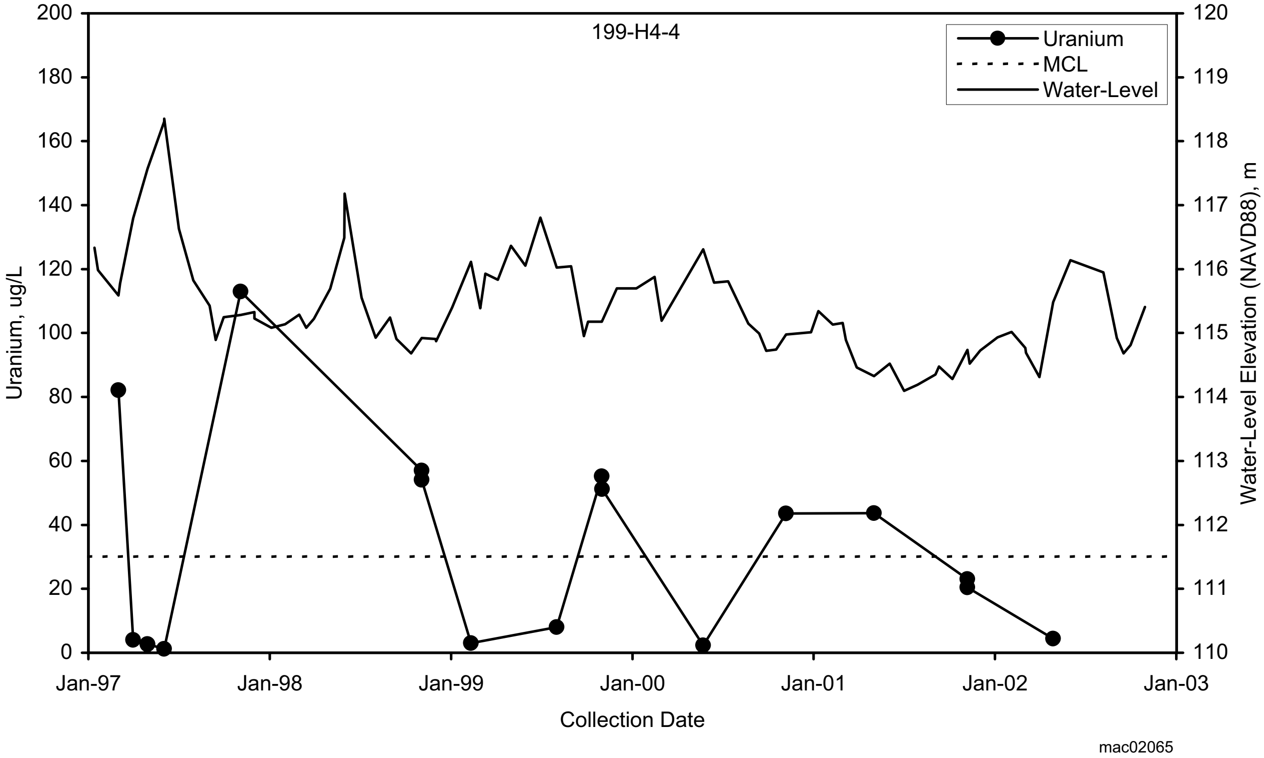

Figure 2.6-5. Uranium Concentrations and Water Levels Downgradient of 116-H-6 (183-H) Evaporation Basins

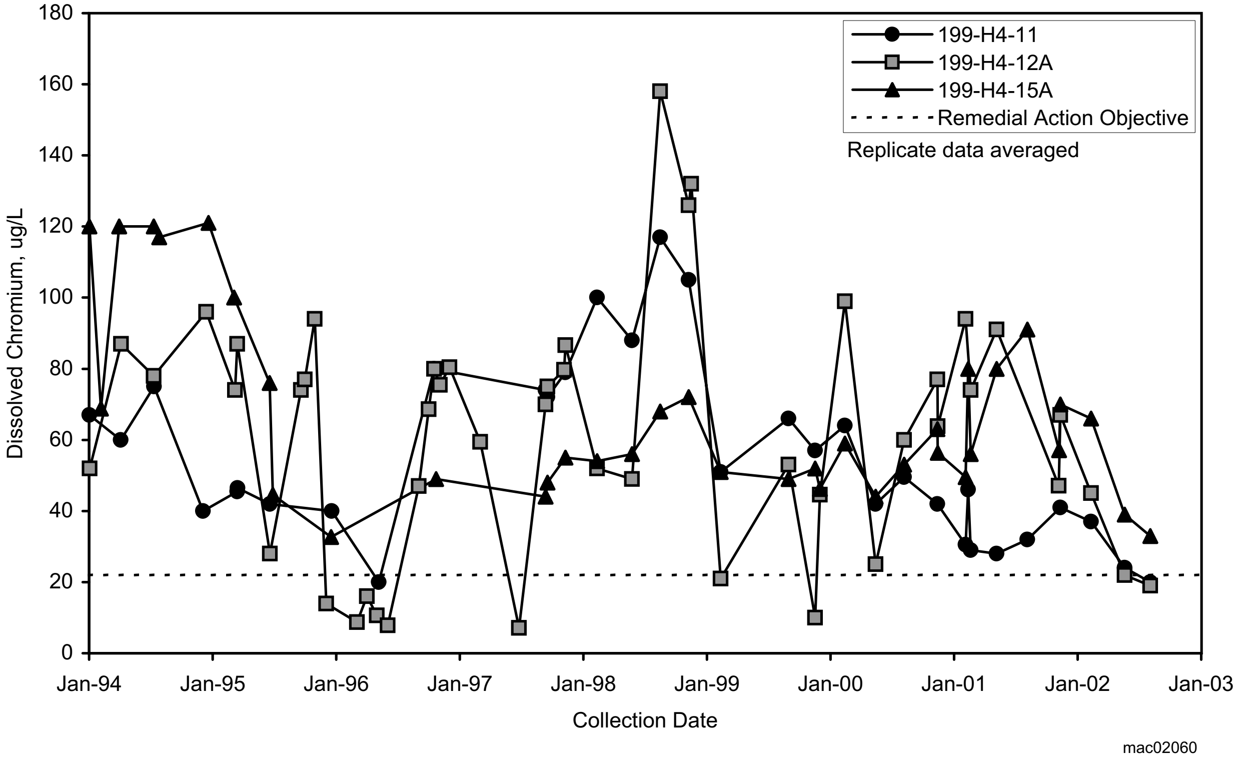

Figure 2.6-6. Dissolved Chromium Concentrations in Extraction Wells Near the Columbia River at the 100-H Area

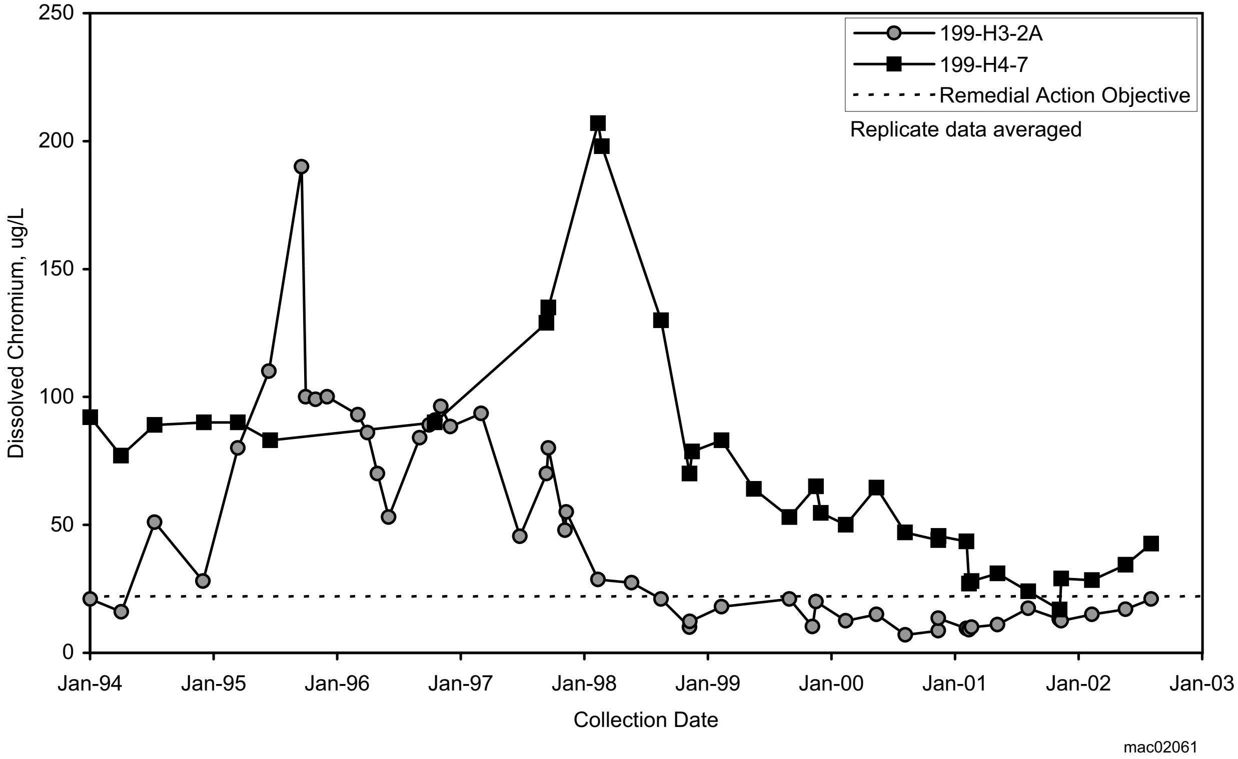

Figure 2.6-7. Dissolved Chromium Concentrations in Extraction Wells Located Inland at the 100-H Area

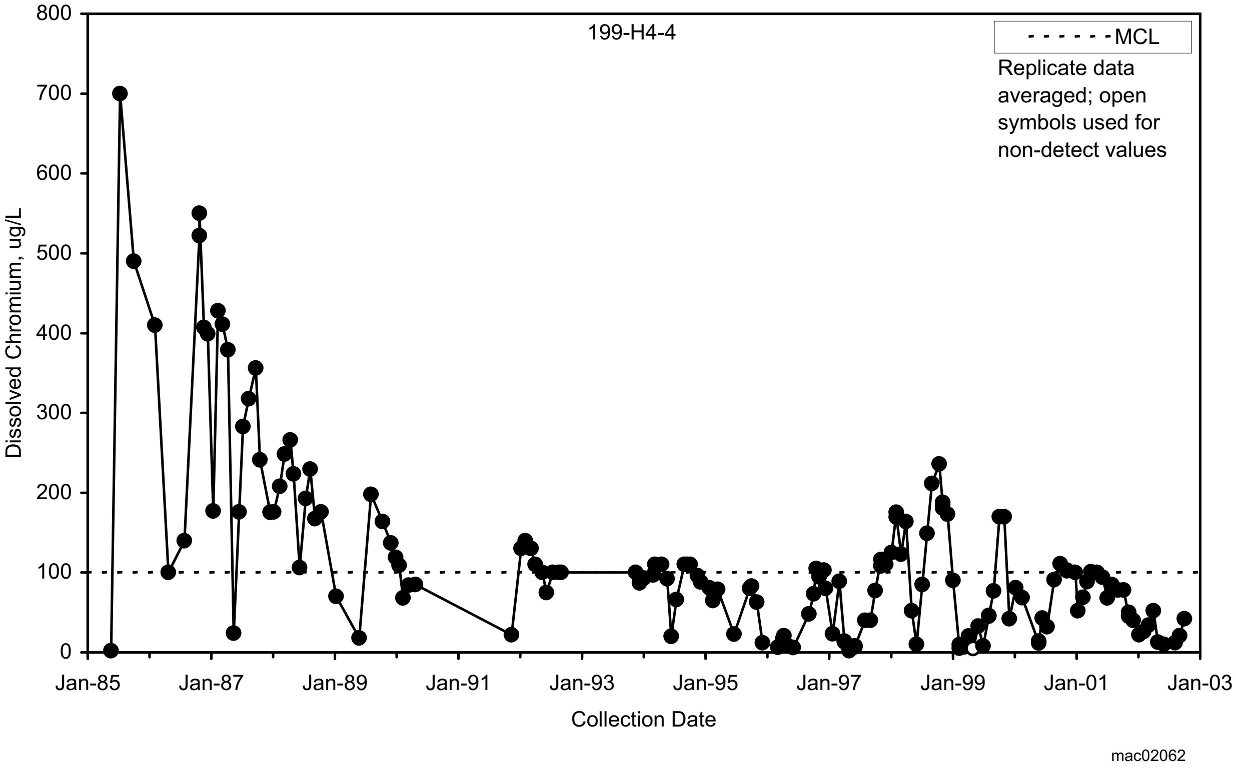

Figure 2.6-8. Dissolved Chromium Concentrations in a Compliance Well in Northeast 100-H Area

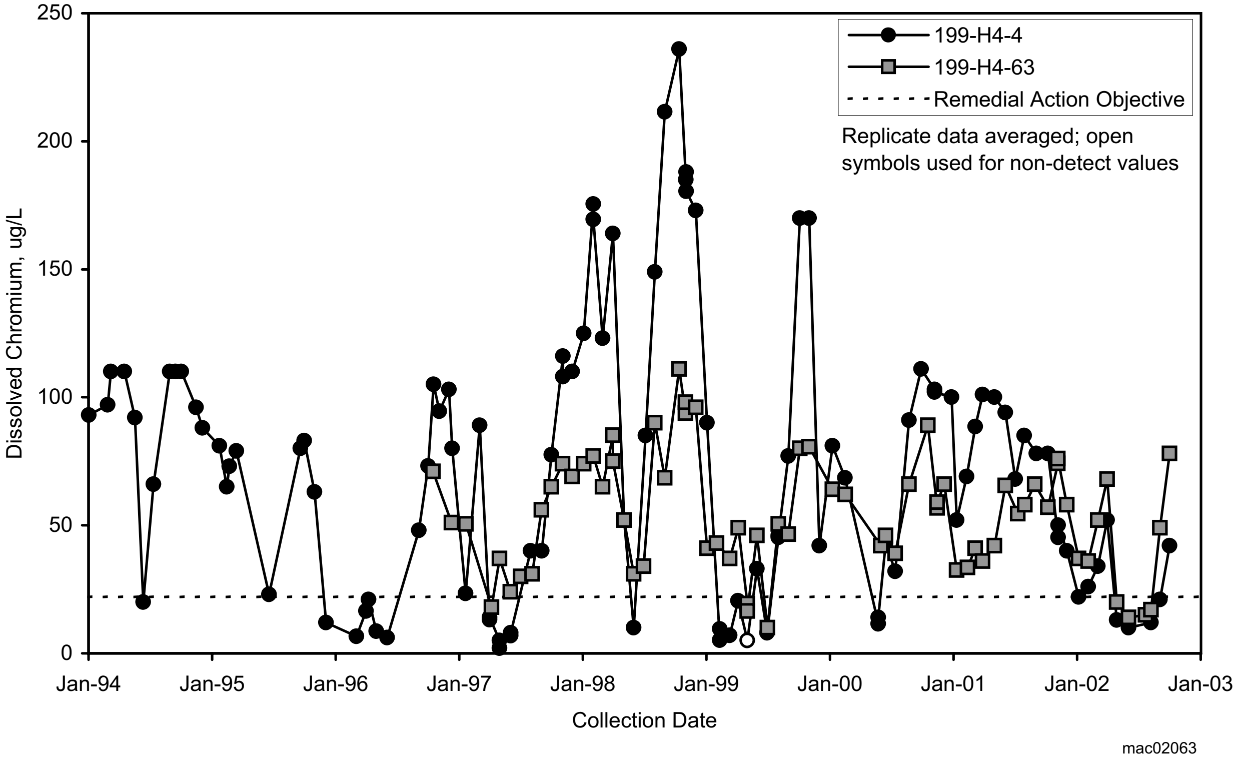

Figure 2.6-9. Dissolved Chromium Concentrations in Groundwater at Interim Action Compliance Wells

2.7 100-F Area

M. D. Sweeney and M. J. Hartman

The 100-F Area is located the farthest east and downstream of the reactor areas on the Hanford Site (Figure 2.7-1). F Reactor operated from 1945 to 1965. Like all of the other Hanford Site reactors except N Reactor, F Reactor was cooled by a single-pass system (i.e., cooling water passed through the reactor and was eventually discharged directly to the Columbia River). Waste sites in the 100-F Area include retention basins for reactor coolant, liquid waste disposal trenches, and French drains. Waste sites are described in DOE/RL-95-54 and DOE/RL-95-92. Groundwater in the 100-F Area is part of the 100-FR-3 Operable Unit. Planning is underway to integrate monitoring for *Comprehensive Environmental Response, Compensation, and Liability Act* and *Atomic Energy Act of 1954*.

Groundwater contaminants include nitrate, strontium-90, and tritium. Local contamination with chromium, trichloroethene, and uranium also has been detected. Nitrate continued to exceed its maximum contaminant level beneath the 100-F Area and in a fairly large plume extending downgradient to the southeast. Strontium-90, trichloroethene, and tritium exceeded standards in much smaller plumes or single wells.

Nitrate continued to exceed its maximum contaminant level beneath the 100-F Area and in a fairly large plume extending downgradient to the southeast. Strontium-90, trichloroethene, and tritium exceeded standards in much smaller plumes or single wells.

2.7.1 Groundwater Flow

Groundwater flows toward the east-northeast in the north 100-F Area and toward the southeast in the south 100-F Area (Figure 2.7-2). In March 2002, the

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Remedial action at waste sites continued in fiscal year 2002 at the 100-F Area, shown above. Contaminated soil is being removed and disposed at the Environmental Restoration Disposal Facility. When excavation is complete, the sites will be backfilled with clean soil.

gradient between wells 699-71-30 and 699-77-36 was 0.0009. Hydraulic conductivity of the Hanford formation in the 100-F Area ranges from 9.1 to 69 meters per day (BHI-00917). Using these values and an effective porosity of 0.1 to 0.3, the flow rate ranges from 0.08 to 0.2 meter per day toward the southeast.

A plume of groundwater contaminated with nitrate, which originates from sources in the 100-F Area, extends to the southeast of the 100-F Area, confirming the southeast direction of flow. This plume appears to discharge into the river in the vicinity of the 100-F Area slough and some additional, but uncertain, distance farther downstream. The cause for this preferential pathway may be a buried former river channel that lies parallel to the current channel. Evidence for erosional features on the top of the Ringold Formation (which lies below the water table) was noted during earlier investigations of the hydrogeology of the 100-F Area.

Monitoring Objectives in 100-F Area

Groundwater monitoring is conducted in the 100-F Area:

- triennially to annually to describe the nature and extent of contamination
- quarterly to monitor trends in variable constituents/wells

2.7.2 Tritium

Tritium concentrations in most wells in the 100-F Area ranged from undetected to 3,800 pCi/L in fiscal year 2002 and are declining. The only well exceeding the drinking water standard of 20,000 pCi/L in recent years is well 199-F8-3, located near the 118-F-1 burial ground. This well is sampled every other year and had a result of 38,600 pCi/L in fiscal year 2001.

2.7.3 Strontium-90

Strontium-90 concentrations exceed the drinking water standard in a stable plume near the Columbia River.

A plume of strontium-90 at levels above the 8-pCi/L drinking water standard underlies the 116-F-14 retention basins and the 116-F-9 and 116-F-2 trenches. The maximum value in fiscal year 2002 was 33 pCi/L in well 199-F5-1, which shows an overall decrease since 1998 (Figure 2.7-3). Nearby well 199-F5-3 typically has concentrations ~250 pCi/L; it is sampled every other year and there are no fiscal year 2002 data. Well 199-F5-6 is located north of the 116-F-14 retention basins and had a strontium-90 concentration of 10 pCi/L in fiscal year 2002 (see Figure 2.7-3). Well 199-F5-46, located west of the retention basins, also exceeded the drinking water standard for strontium-90 in fiscal year 2002, at 9 pCi/L with a steady trend.

2.7.4 Nitrate

Nitrate exceeds the maximum contaminant level of 45 mg/L in a fairly large plume originating in the 100-F Area and extending downgradient to the southeast (see Figure 2.1-4). Unlike other contaminants in this area, nitrate is not elevated in wells downgradient of the retention basins, but rather in the central and south 100-F Area.

Wells 199-F5-45 and 199-F5-46, located northeast of the reactor building, detect elevated levels of nitrate (Figure 2.7-4). Levels are stable in well 199-F5-45 since 1999, but appear to be increasing in well 199-F5-46.

Wells 199-F7-1 and 199-F7-3 are located in the southwest 100-F Area. Recent concentrations are fairly stable in well 199-F7-1, after a brief peak in 1998 (Figure 2.7-5). Concentrations are increasing gradually in well 199-F7-3, which did not show a sudden peak in nitrate.

Two wells (699-71-30 and 699-77-36) outside the boundary of the 100-F Area (see Figure 2.2-2 for location) showed peaks in nitrate concentration in 1998-1999 (Figure 2.7-6). Nitrate has decreased since then in both wells. However, the concentration in fiscal year 2002 in well 199-71-30 was higher than in fiscal year

2001. Similar nitrate trends have been observed in other wells in the 100 Areas, and the cause of the pattern is not known.

Throughout the last 10 years, nitrate results from the 100-F Area have shown that concentrations are rising near the facilities inside the 100-F Area boundary and in a few downgradient wells. The persistence of nitrate concentration, and its wide areal distribution, indicate that the source areas for this contaminant are from either multiple sources outside the 100-F Area or from a variety of smaller sources originating from within the 100-F Area boundary.

For the last 10 years, nitrate concentrations have increased in the 100-F Area.

2.7.5 Chromium

Chromium concentrations are greater than background in a few wells in the northeast 100-F Area. The highest value in fiscal year 2002 was 98 µg/L in well 199-F5-46, located west of the 116-F-14 retention basins. This value is higher than the concentration in fiscal year 2001, but lower than the historical trend in this well. No wells sampled in fiscal year 2002 exceeded the 100-mg/L maximum contaminant level for hexavalent chromium.

2.7.6 Trichloroethene

Trichloroethene continued to be detected in the west and southwest corner of the 100-F Area and in the adjacent 600 Area. Wells 199-F7-1, 199-F7-3, and 699-77-36 exceeded the 5-µg/L maximum contaminant level in fiscal year 2002. Trichloroethene concentrations have increased slightly in wells 199-F7-1 and 199-F7-3 (Figure 2.7-7). Well 699-77-36 (see Figure 2.7-1 for location) continues to exhibit a gradual decline in concentration.

Trichloroethene continued to be detected in the west and southwest corner of the 100-F Area and in the adjacent 600 Area.

Well 199-F7-2, located near the 116-F-2 trench, slightly exceeded the maximum contaminant level in fiscal year 2002, at 5.6 pCi/L. This was the first time the well exceeded this level since 1994. No specific sources have been identified for the trichloroethene contamination in and near the 100-F Area.

2.7.7 Waste Site Remediation

Remedial action of waste sites in the 100-F Area (Table 2.7-1) continued in fiscal year 2002. These activities consisted of excavating contaminated soil and debris for disposal at the Environmental Restoration Disposal Facility. Water obtained from fire hydrants was applied as necessary to control dust. Application of water was held to a minimum to reduce the potential for mobilizing contaminants from the vadose zone to the groundwater. After excavation is completed, the sites will be backfilled and re-vegetated.

2.7.8 Monitoring at River Shoreline

Groundwater near the Columbia River is sampled annually in October/November via aquifer sampling tubes and riverbank seeps. The sampling tubes are polyethylene tubes that were installed in the aquifer at locations near the low-water shoreline. Seeps are natural areas of groundwater discharge above the water line. Two aquifer tubes and two seeps were sampled near 100-F Area in fiscal year 2002 (Table 2.7-2).

The most widespread groundwater contaminant in the 100-F Area is nitrate. Concentrations were elevated in both seeps in fiscal year 2002, with one exceeding the maximum contaminant level at 55.8 mg/L. Strontium-90 was undetected, while tritium and chromium concentrations were relatively low. Chromium concentration also were low in the aquifer sampling tubes.

Table 2.7-1. 100-F Area Waste Sites Remediated in Fiscal Year 2002

Waste Site Designation	Fiscal Year Excavated	Maximum Depth of Excavation (m)
100-F pipelines	2001	6.0
116-F-14 retention basin	2001	4.6
116-F-2 liquid waste disposal trench	2001	4.6
116-F-9 animal waste leaching trench	2001	4.6
126-F-1 ash pit	2001	4.6
1607-F2 and 1607-F6 septic tanks	2001	4.6
UPR-100-F-2 basin leak ditch	2001	4.6
116-F-12 French drain	2001	4.6
100-F-34 French drain	2001	4.6
100-F-2 strontium garden	2001	2.0
116-F-3 liquid waste disposal trench	2002	4.6
116-F-6 liquid waste disposal trench	2002	4.6
116-F-10 French drain	2002	4.6
100-F-35 Discovery Site	2002	1.0
116-F-1 Lewis Canal	2002	4.6
100-F-15 French drain	2002	4.6
100-F-11 French drain	2002	4.6
100-F-4 French drain	2002	4.6
100-F-16 French drain	2002	4.6

Table 2.7-2. Shoreline Monitoring Data for the 100-F Area, Fiscal Year 2002

Location Name	Sample From(a)	Sample Date(b)	Specific Conductance (µS/cm)(c)	Chromium (µg/L)(d)	Gross Alpha (pCi/L)	Gross Beta (pCi/L)	Nitrate (mg/L)	Strontium-90 (pCi/L)	Tritium (pCi/L)
64-D	Tube	11/07/01	299	10					
66-M	Tube	11/07/01	218	6					
SF-207-1	Seep	10/22/01	452	18	5.2	9.4	56	0.267 U	1,470
SF-211-1	Seep	10/22/01	512	15	3.4	7.2	44	-0.091 U	1,340
RF-190-T1	River	09/10/01		0			0.24	0.1	34
RF-190-T1	River	09/09/02					0.35	0.0	23
RF-180-SHR	River	09/10/01		1			0.28	0.1	35
RF-180-SHR	River	09/09/02					0.34	0.0	27
RF-230-SHR	River	09/10/01		1			0.26	0.1	37
RF-230-SHR	River	09/09/02					0.35	0.0197 U	24
RF-240-SHR	River	09/09/02					0.35	0.1	21

U = Below detection limit.

(a) Tube = aquifer sampling tube near shoreline; Seep = riverbank seepage; River = nearshore river water.

(b) Data from September 2001 (fiscal year 2001) included to provide comparison for October 2001 (fiscal year 2002).

(c) Specific conductance provides an indication of the amount of river water in the sample; uncontaminated groundwater is typically in the range of 350 to 450 µS/cm and river water in the range of 120 to 150 µS/cm.

(d) Chromium includes hexavalent chromium and total chromium for filtered samples.

Data sources: Hanford Environmental Information System and various project records.

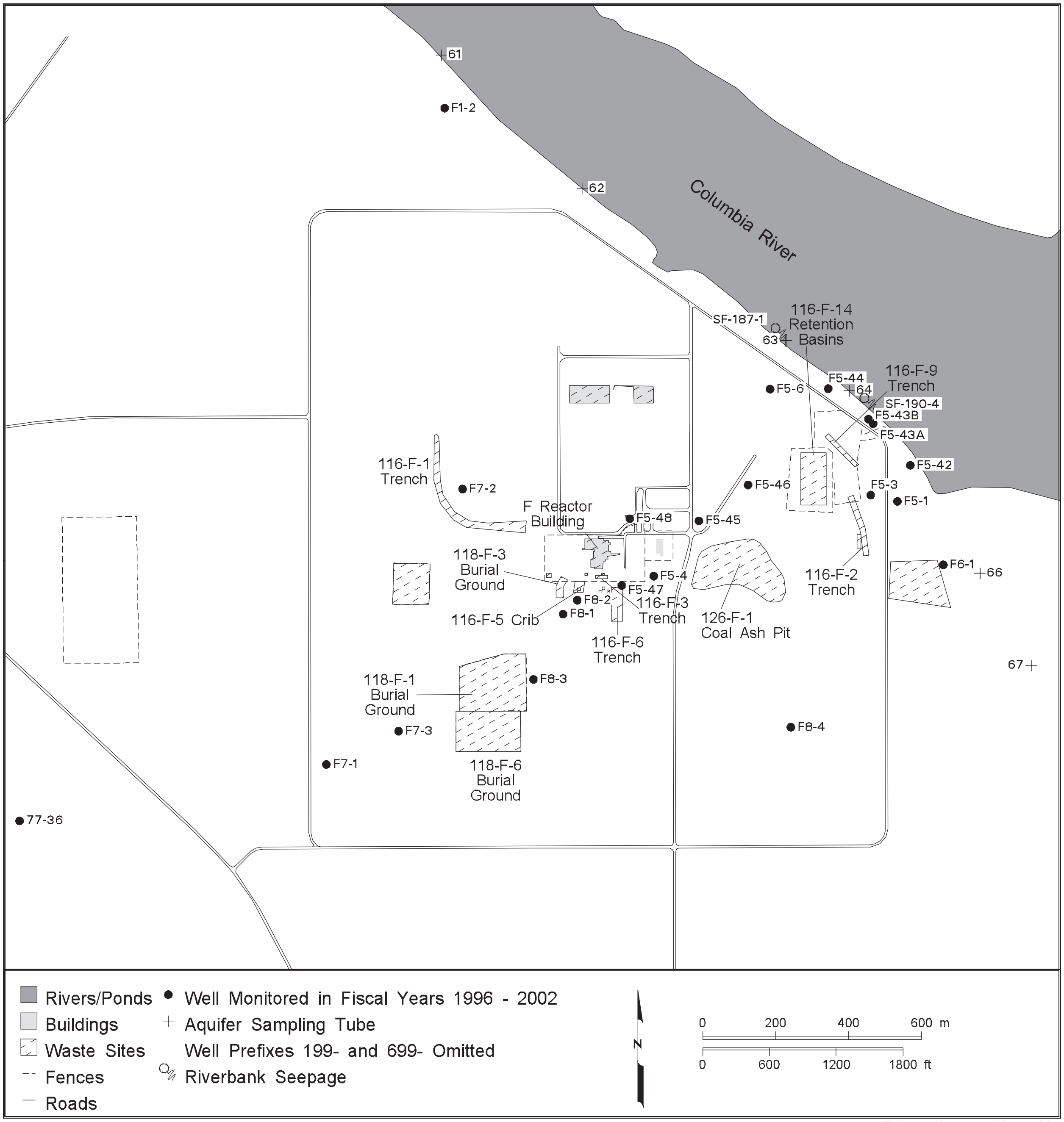

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Figure 2.7-1. Groundwater Monitoring Wells in the 100-F Area

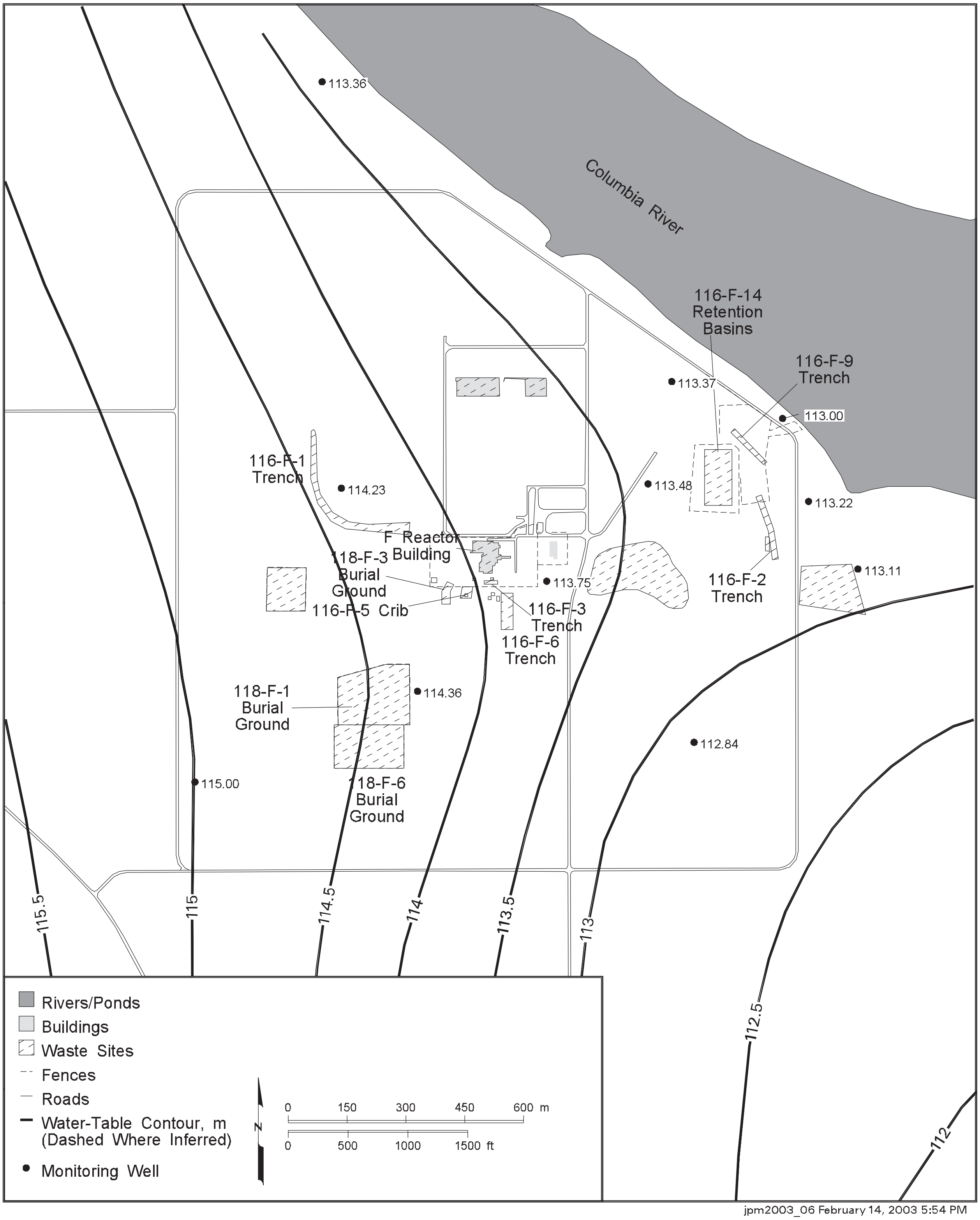

Figure 2.7-2. 100-F Area Water-Table Map, March 2002

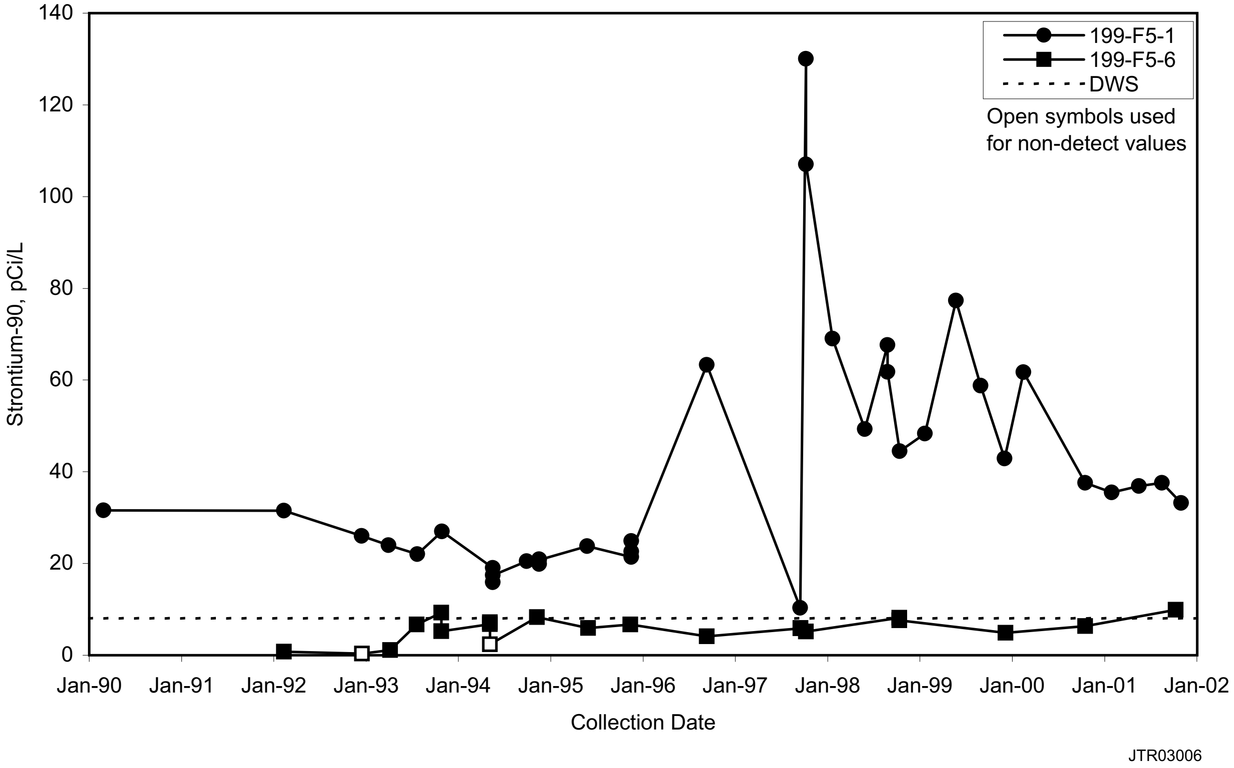

Figure 2.7-3. Strontium-90 Concentrations in Wells at Northeast 100-F Area

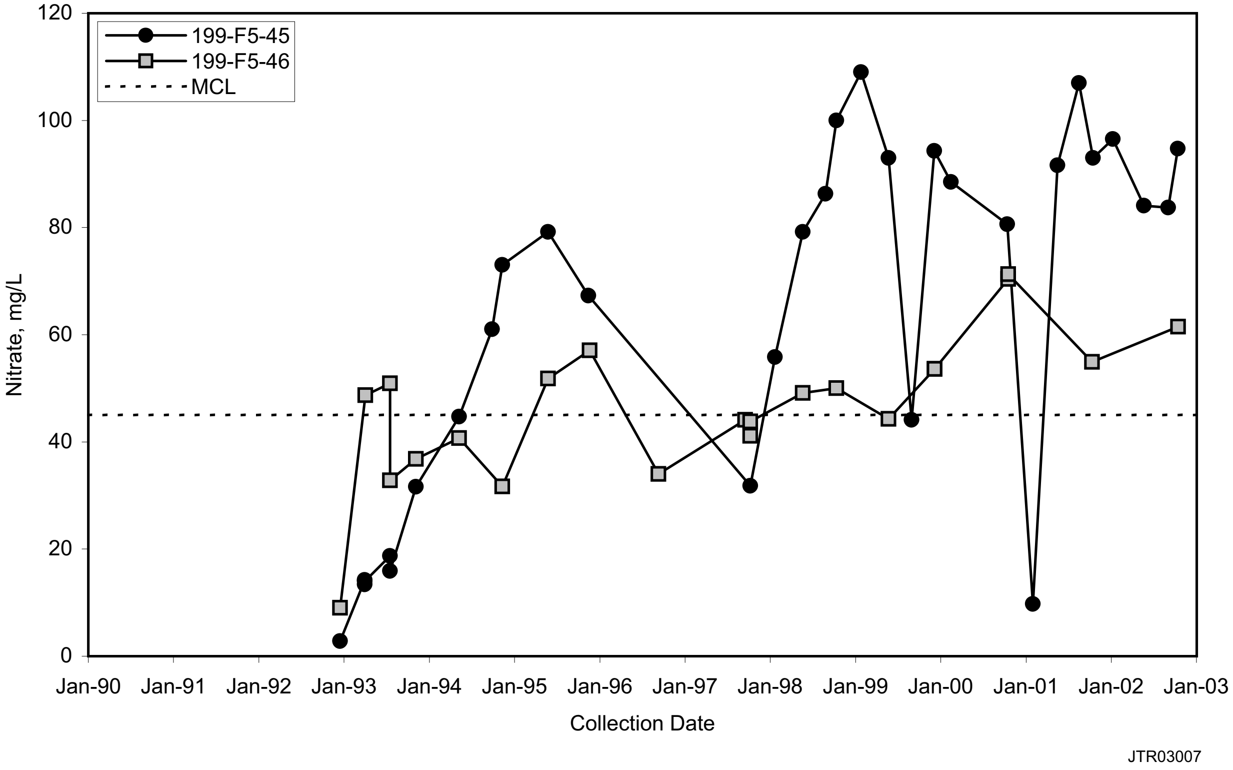

Figure 2.7-4. Nitrate Concentrations in 100-F Area Wells Northeast of Reactor Building

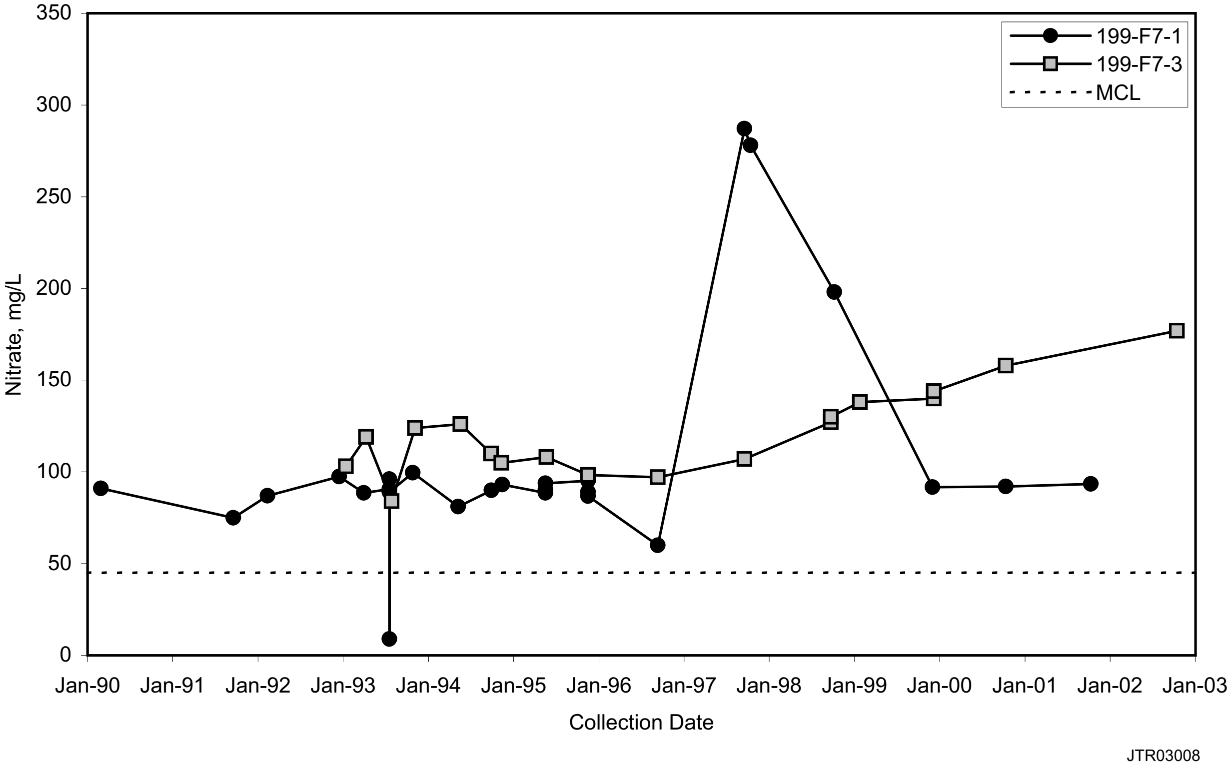

Figure 2.7-5. Nitrate Concentrations in 100-F Area Wells in Southwest 100-F Area

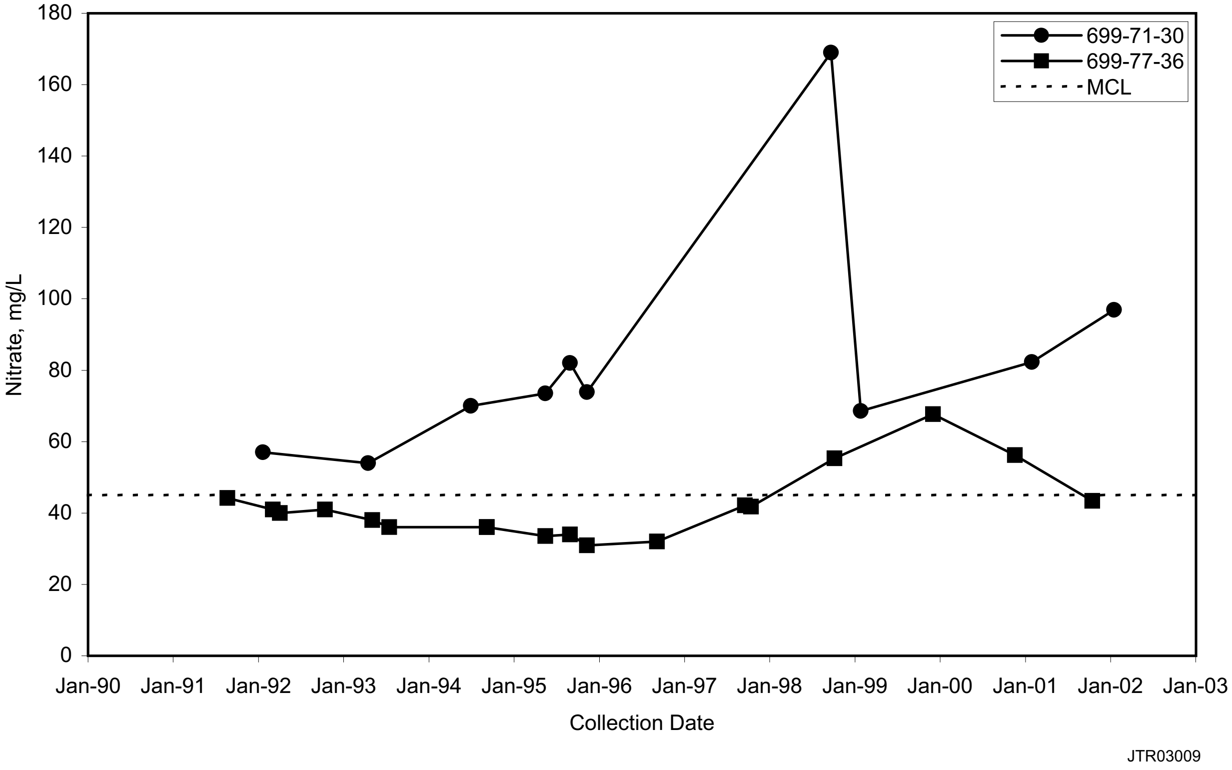

Figure 2.7-6. Nitrate Concentrations in 100-F Area Wells Outside 100-F Area

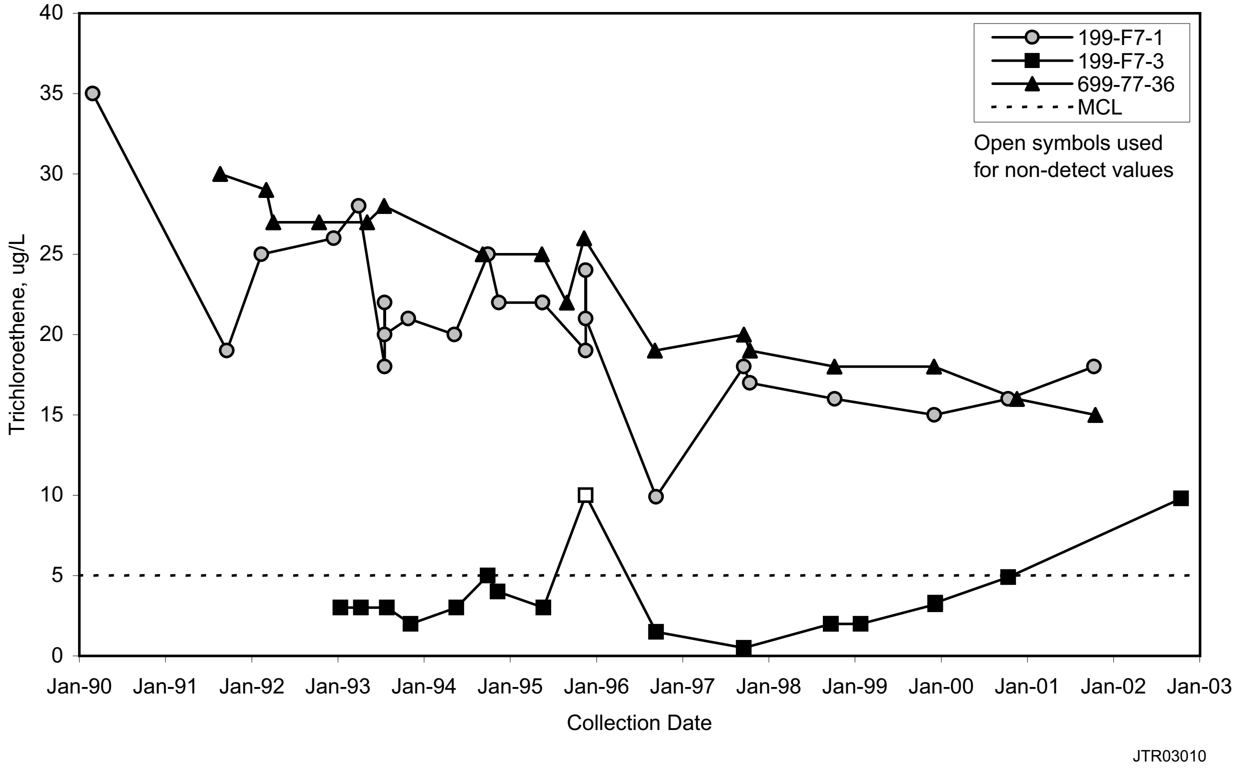

Figure 2.7-7. Trichloroethene in the Southwest 100-F Area

2.8 200 West Area

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Groundwater beneath the 200 West Area is contaminated with widespread plumes of carbon tetrachloride, nitrate, tritium, and iodine-129. Chromium, fluoride, strontium-90, technetium-99, trichloroethene, and uranium also are present at levels above their drinking water standards. The eastward spread of contamination from this area is relatively slow because of low-permeability sediment in the aquifer.

The 200 West Area, located on the Central Plateau of the Hanford Site, was used to process irradiated reactor fuel to extract and purify plutonium between 1944 and 1987. The extraction took place at the T Plant and later the Reduction-Oxidation (REDOX) Plant. The Plutonium Finishing Plant was used for plutonium purification. U Plant was used to extract uranium from process waste. Currently, the 200 West Area is used for waste management and disposal. Further details are provided in PNNL-13080.

The 200 West Area contains two *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA) Groundwater Operable Units, 200-ZP-1 and 200-UP-1, and eight *Resource Conservation and Recovery Act* (RCRA) treatment, storage, and disposal facilities with groundwater monitoring requirements. The 200 West Area can be divided into four major regions for the purpose of describing groundwater contamination:

- *Plutonium Finishing Plant.* This is the source of carbon tetrachloride, which is the main contaminant plume of concern for the 200-ZP-1 Operable Unit. The carbon tetrachloride and other volatile organic compounds form extensive plumes that have migrated into the area of the 200-UP-1 Operable Unit to the south. The Low-Level Waste Management Area 4 burial grounds (RCRA

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Groundwater monitoring wells are sampled within the SX Tank Farm. The well is inside a subsurface vault.

treatment, storage, and disposal facilities) are found in this area. A CERCLA interim action pump-and-treat system is remediating the carbon tetrachloride contamination in this region.

- *T Plant.* Contaminants within this area are generally considered part of the 200-ZP-1 Operable Unit. RCRA treatment, storage, and disposal facilities, Waste Management Area T single-shell tank farm, Waste Management Area TX-TY single-shell tank farm, and Low-Level Waste Management Area 3 burial grounds are located in this area. This year, the discussion of groundwater monitoring at the State-Approved Land Disposal Site is included in the section on T Plant because of the close proximity between the State-Approved Land Disposal Site and T Plant and because several wells are monitored for both areas. A separate section was included for the State-Approved Land Disposal Site in previous annual reports. The State-Approved Land Disposal Site is a permitted liquid waste disposal system where liquid waste contaminated with tritium is discharged to the ground. This site is regulated under a state of Washington waste discharge permit.
- *U Plant.* The main contaminant plumes of concern at the 200-UP-1 Operable Unit, technetium-99 and uranium, have a source from U Plant disposal facilities. Two RCRA treatment, storage, and disposal facilities are located in this area: Waste Management Area U single-shell tank farm and the 216-U-12 crib. An interim action pump-and-treat system is remediating the technetium-99 and uranium contamination in this region.
- *REDOX Plant.* Contaminants within this area are generally considered part of the 200-UP-1 Operable Unit, except when the source is from within 200-ZP-1. Two RCRA treatment, storage, and disposal facilities are located in this area: Waste Management Area S-SX single-shell tank farm and the 216-S-10 pond and ditch.

CERCLA Operable Units

Groundwater contamination in the 200 West Area falls under two CERCLA operable units, 200-ZP-1 and 200-UP-1:

- 200-ZP-1 includes contamination originating in the Plutonium Finishing Plant and T Plant regions.
- 200-UP-1 includes contamination originating in the U Plant and REDOX Plant regions.

This section discusses groundwater flow, major contaminants, specific RCRA facility monitoring, and performance of remediation systems for each region. The major contaminant plumes found in 200 West Area are carbon tetrachloride, chloroform, iodine-129, nitrate, technetium-99, trichloroethene, tritium, and uranium. Chromium, fluoride, and strontium-90 are also found in small areas. Monitoring well locations in the 200 West Area are shown in Figure 2.8-1. Water-table contours for the 200 West Area are shown in Figure 2.8-2.

2.8.1 Plutonium Finishing Plant

The Plutonium Finishing Plant performed the final stages of plutonium purification from 1949 through 1987. Carbon tetrachloride and other volatile organic compounds form the major plumes attributable to the Plutonium Finishing Plant. Relatively widespread nitrate contamination also is present. The Plutonium Finishing Plant has not been a significant contributor to the major radiological contaminant plumes in groundwater. Migration of plutonium contamination from the vadose zone is of considerable concern because large quantities of plutonium, in the presence of organic complexing agents, were disposed to ground in the area. The formation of plutonium-bearing colloids that could enhance mobility is also a concern. No further investigation of the mobility of plutonium was undertaken in fiscal year 2002. Past data suggest minor plutonium groundwater contamination (PNNL-12086).

The only facilities near the Plutonium Finishing Plant with RCRA monitoring requirements are the burial grounds in Low-Level Waste Management Area 4. These are not believed to contribute to groundwater contamination. Sampling of vent risers in Low-Level Waste Management Area 4 during fiscal year 2002 detected carbon tetrachloride contamination in the air indicating its presence in the buried waste. Remediation of volatile organic compounds in groundwater and the vadose zone near the Plutonium Finishing Plant is being undertaken in this area using pump-and-treat and vapor extraction systems. Carbon tetrachloride continues to be removed from the vadose zone by vapor extraction, reducing this source of groundwater contamination (see Section 3.2.3). The groundwater pump-and-treat system removes carbon tetrachloride as groundwater is withdrawn, treated, and re-injected upgradient. The carbon tetrachloride concentration in the treated water is usually <5 µg/L (DOE/RL-2001-53). The pump-and-treat extraction and re-injection of the treated groundwater has caused significant changes in groundwater flow and contaminant distribution.

Monitoring Objectives Near Plutonium Finishing Plant

Groundwater monitoring is conducted near the Plutonium Finishing Plant:

- triennially to annually to describe the nature and extent of contamination
- semiannually to detect the possible impact of one RCRA waste management area
- semiannually to monitor trends in variable constituents/wells
- various time intervals to evaluate the performance of a pump-and-treat system for carbon tetrachloride

2.8.1.1 Groundwater Flow

Groundwater near the Plutonium Finishing Plant flows generally from west to east, but is heavily influenced by the ongoing 200-ZP-1 Operable Unit pump-and-treat activities (see Figure 2.8-2). During fiscal year 2002, there were five extraction wells along an arc from north of the Plutonium Finishing Plant to the east and southeast. There are also five injection wells (only the three northernmost are active) located to the southwest of the Plutonium Finishing Plant and to the west of Low-Level Waste Management Area 4. A small groundwater mound is associated with the injection wells, and a region of drawdown is associated with the extraction wells, causing flow to converge on the extraction zone from all directions. These flow conditions are expected to continue until the end of the pump-and-treat program, at which time the flow direction will resume a west to east pattern. Groundwater flow beneath Low-Level Waste Management Area 4 is discussed in Section 2.8.1.6, and flow beneath the pump-and-treat system is discussed in Section 2.8.1.5. The pump-and-treat system also has had an impact on flow at Waste Management Area TX-TY and U tank farms as discussed in Sections 2.8.2.12 and 2.8.3.9.

2.8.1.2 Carbon Tetrachloride

Carbon tetrachloride contamination is present in the unconfined aquifer system beneath most of the 200 West Area and has migrated past the 200 West Area boundary (Figure 2.8-3), covering an area of over 11 square kilometers. The maximum carbon tetrachloride concentration shown in Figure 2.8-3 in the 200 West Area was near the north extraction wells in well 299-W15-1, where the average concentration was 5,800 µg/L. The maximum contaminant level for carbon tetrachloride allowed in drinking water is 5 µg/L. The interim remedial action goal for the pump-and-treat system, under the interim record of decision (ROD 1995), is to contain the portion of the plume with concentrations greater than 2,000 µg/L.

Carbon tetrachloride contamination beneath the 200 West Area originated primarily in waste sites near the Plutonium Finishing Plant. In fiscal year 2002, concentrations generally remained stable or declined slightly in the core of the plume.

The carbon tetrachloride contamination is believed to be from pre-1973 waste from the Plutonium Finishing Plant. The major identified sources are the 216-Z-9 trench, the 216-Z-1A tile field, and the 216-Z-18 crib. The 216-Z-12 crib, the 216-Z-19 ditch, and the 216-T-19 tile field also may have contributed. These sources are shown in Appendix A, Figure A.13.

Carbon tetrachloride concentrations have generally remained stable or declined slightly in the center of the plume in fiscal year 2002. Concentrations of carbon tetrachloride did not change greatly in the northernmost extraction wells 299-W15-33, 299-W15-34, and 299-W15-35 and nearby monitoring wells such as well 299-W15-1 (Figure 2.8-4). Concentrations in the south extraction wells 299-W15-32 and 299-W15-36 and nearby monitoring wells remained stable in fiscal year 2002. Overall, however, concentrations have declined since the start of pump-and-treat operations in 1997. Concentrations are low around the active injection wells as shown by the depression in the contours in Figure 2.8-3.

A new monitoring well, 299-W15-42 was installed within the Plutonium Finishing Plant security area. This well was a characterization boring to determine carbon tetrachloride concentrations with depth, in both the vadose zone and groundwater. The well was drilled to 18 meters below the water table then screened at the upper 15 meters. Carbon tetrachloride concentrations collected after well development ranged from 1,100 to 1,800 µg/L, with an average of 1,500 µg/L. Further information on characterization during drilling of this well is available in BHI-01631.

The part of the carbon tetrachloride plume with concentrations >2,000 µg/L extends to the north, reaching the vicinity of Waste Management Area TX-TY. This northern contamination is outside the target area for the current remediation system (see Section 2.8.1.5). Concentrations remained above the 2,000-µg/L interim cleanup level to the west of Waste Management Area TX-TY, in wells 299-W10-5 and 299-W15-40 (Figure 2.8-5). Several wells in the north part of the 200 West Area had carbon tetrachloride concentrations exceeding 1,000 µg/L in the past but concentrations have declined. For example, on the east side of Low-Level Waste Management Area 3, well 299-W10-20 had persistent concentrations of carbon tetrachloride near or above 1,000 µg/L until March 2001, even though it is not located near any known sources. Concentrations have declined to 62 µg/L in fiscal year 2002 (see Figure 2.8-5).

Carbon tetrachloride concentrations have increased in the south part of the plume near Waste Management Area S-SX.

The greatest concern for transport of carbon tetrachloride from the 200 West Area remains in the east part of the plume. Concentrations greater than the drinking water standard extended northeast beyond the 200 West Area boundary in fiscal year 2002. Carbon tetrachloride concentration changes near the periphery of the plume and at key locations within the plume are shown in Figure 2.8-6. Carbon tetrachloride concentrations increased to 7.6 µg/L in well 699-48-71 as the plume migrated to the northeast. High concentrations are found near the east boundary of the 200 West Area, where carbon tetrachloride reached 1,300 µg/L in well 299-W11-10. The well network is too sparse to define the extent of carbon tetrachloride downgradient of this well. Carbon tetrachloride contamination extends southeast of the Plutonium Finishing Plant to the east edge of the Environmental Restoration Disposal Facility, between the 200 West and 200 East Areas. Concentrations in fiscal year 2002 increased to 9.8 µg/L in well 699-38-68A. Along the west boundary, the concentration remained low in well 299-W18-21, after a peak in 1995. The decline in concentration in wells on the west side of the plume is likely due to a combination of transport downgradient to the east and displacement by clean injection water around the pump-and-treat system.

Carbon tetrachloride concentrations have increased markedly in some wells in the vicinity of Waste Management Area S-SX. For example, concentrations in well 299-W23-15, located directly south of the SX Tank Farm, rose from <5 µg/L in fiscal year 1995 to an average of 200 µg/L in fiscal year 2002 (see Figure 2.8-6). The previously low concentrations in this area could have been caused by the discharge of water free of carbon tetrachloride to portions of the 216-U-14 ditch, north of the tank farms, until 1995. This discharge may have affected groundwater flow, so that carbon tetrachloride spread to the east and west of the tank farms. A number of other wells in the area remain low in carbon tetrachloride.

Information on the distribution of carbon tetrachloride in the east half of the 200 West Area is very sparse. The original monitoring well network had large gaps in this area and several key wells have gone dry. Whether a low concentration area exists in the east-central part of the 200 West Area, as shown on the map (see Figure 2.8-3), is uncertain. This low concentration area may have resulted from past discharges to the 218-W-B powerhouse ponds and the 216-W-LWC laundry waste crib.

Carbon tetrachloride contamination has been detected to depths >60 meters below the water table. In places, contamination at depth extends greater distances laterally than contamination at the water table, as reported previously (PNNL-12086). Little information is available on the distribution of carbon tetrachloride at depth. Available data are from a few well nests completed at different depths and from depth-discrete samples collected at specific points in RCRA boreholes and in older wells with large open intervals. One disadvantage of the depth-discrete samples within an open well bore is the potential for vertical mixing within the well or along the annulus. The highest carbon tetrachloride concentration detected in a well monitoring at depth within the unconfined aquifer was in well 299-W19-34A, located near the U Plant. The carbon tetrachloride concentration in fiscal year 2002 samples from this well ranged from 100 to 180 µg/L. This indicates that contamination has moved considerable distances downgradient of the source area in deeper parts of the aquifer. The top of the screen in this well is ~19 meters below the water table.

2.8.1.3 Chloroform and Trichloroethene

Two sources of chloroform in Hanford Site groundwater are from chlorination of organic matter during purification of potable water and then its subsequent disposal to ground, or from biodegradation of carbon tetrachloride. Biodegradation is believed to be the major source of chloroform in the 200 West Area. The drinking water standard maximum contaminant level for chloroform is 100 µg/L (total trihalomethanes). In January 2002, the maximum contaminant level for total trihalomethanes was reduced to 80 µg/L. Values for chloroform were all below the maximum contaminant level in fiscal year 2002, with the exception of several samples collected during the installation in January of well 299-W15-42, located near the center of the carbon tetrachloride plume, where concentrations up to 680 µg/L were detected. Sample concentrations quickly declined to <40 µg/L in samples collected in February and later.

The distribution of trichloroethene near the Plutonium Finishing Plant is shown in Figure 2.8-7. The trichloroethene plume is entirely contained within the extent of the carbon tetrachloride plume. Disposal of trichloroethene near T Plant also may have contributed to this plume. The maximum annual average trichloroethene found in fiscal year 2002 was found west of Waste Management Area TX-TY, 16 µg/L in well 299-W15-40. The maximum contaminant level allowable in drinking water for trichloroethene is 5 µg/L.

Waste sites near the Plutonium Finishing Plant have contributed to the large nitrate plume in groundwater beneath the 200 West Area.

2.8.1.4 Nitrate

A nitrate plume originates at Plutonium Finishing Plant disposal facilities. The 216-Z-9 trench received an estimated 1.3 million kilograms of chemicals containing nitrate during its operation from 1955 to 1962. Other liquid waste disposal facilities associated with the Plutonium Finishing Plant received smaller but still significant amounts of nitrate. Additional sources of nitrate from disposal facilities near T Plant also contribute to the contamination downgradient. The extent of nitrate in the central and north 200 West Area is shown in Figure 2.8-8. The highest nitrate concentrations are associated with facilities near T Plant and are discussed in Section 2.8.2.6.

Nitrate concentrations are increasing in wells downgradient from the injection wells for the 200-ZP-1 pump-and-treat system. This increase is apparently because the injected water was not treated for nitrate removal. Thus, nitrate concentrations in wells 299-W18-23 averaged 52 mg/L in fiscal year 2002, though the values fluctuate in response to varying injection rates.

2.8.1.5 Groundwater Remediation at 200-ZP-1 Operable Unit

Groundwater is pumped out of wells in the carbon tetrachloride plume and treated to remove the contamination. The objective of the interim remedial action is to keep the center of the plume from spreading. In fiscal year 2002, ~301 million liters of groundwater were treated and 1,053 kilograms of carbon tetrachloride were removed.

The pump-and-treat system for the 200-ZP-1 Operable Unit is successfully containing and capturing the high concentration portion of the carbon tetrachloride plume near the top of the aquifer in the immediate vicinity of the Plutonium Finishing Plant. The current remediation system is not designed to capture the area of contamination >2,000 μg/L shown east of Waste Management Area TX-TY outside of the baseline plume area (see Figure 2.8-3). Contamination in the groundwater was reduced in the area of highest concentration through mass removal; additional information was collected through hydraulic monitoring, contaminant monitoring, and treatment system operations that should support the final record of decision.

The pump-and-treat system for the 200-ZP-1 Operable Unit, located north of the Plutonium Finishing Plant, was implemented in three phases as an interim remedial action (Table 2.8-1). The interim action objectives (ROD 1995) are the following:

- prevent further movement of contaminants from the highest concentration area of the plume (i.e., containing carbon tetrachloride inside the 2,000- to 3,000-μg/L contour)
- reduce contamination in the area of highest carbon tetrachloride concentrations
- provide information that will lead to development of a final remedy that will be protective of human health and the environment

The following information is summarized from the annual report for pump-and-treat operations for fiscal year 2001 (DOE/RL-2001-53) and the 2002 report, which is in preparation.[a] The 200-ZP-1 Operable Unit facilities and Phase III extraction, injection, and monitoring well locations are shown in Appendix A, Figure A.24.

Contaminant Removal

Carbon tetrachloride contamination in the upper part of the aquifer was reduced in the area of highest concentrations through mass removal. Approximately 301 million liters of contaminated groundwater were treated in fiscal year 2002 at an average flow rate of 568 liters per minute. Production rates for each of the five extraction wells ranged from 34 to 301 liters per minute. The average influent concentration for the five extraction wells was 3,144 μg/L, a decrease from 3,600 μg/L in fiscal year 2001 and less than fiscal year 1999 concentrations (3,788 μg/L). Influent concentrations ranged from 1,145 to 4,973 μg/L.

Treatment of ~301 million liters of contaminated water resulted in the removal of 1,053 kilograms of carbon tetrachloride in fiscal year 2002. Since initiation of pump-and-treat operations in August 1994, 1.89 billion liters of water have been treated, resulting in removal of 6,874 kilograms of carbon tetrachloride.

(a) DOE/RL-2002-67, Revision 0, Decisional Draft. 2002. *Fiscal Year 2002 Annual Summary Report for 200-UP-1 and 200-ZP-1 Pump-and-Treat Operations*. U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Extraction well 299-W15-37 was converted to a monitoring well in fiscal year 2001. This well is located southeast of the high concentration portion of the carbon tetrachloride plume (see Appendix A, Figure A.24). It was concluded prior to shutdown that this well was not contributing significantly to hydraulic capture of the high concentration area. Recent sampling results support that conclusion. Although the January 2002 carbon tetrachloride concentrations briefly spiked to an average of 780 µg/L, April values averaged only 115 µg/L.

Technetium-99 samples were collected to make sure that the pump-and-treat system is not being negatively affected by radiological contamination. The origin of technetium-99 may be the 216-T-19 crib area or Waste Management Area TX-TY, located north-northeast of extraction wells 299-W15-34 and 299-W15-35. Concentrations at the four northernmost extraction wells ranged from 30 to 325 pCi/L, near the concentration range measured in fiscal year 2001 (32 to 325 pCi/L). In fiscal year 2002, technetium-99 concentrations at well 299-W15-41, which is adjacent to the 216-T-19 cribs and south of the TX Tank Farm, reached 1,180 pCi/L and averaged 1,100 pCi/L.

Northeast of primary injection well 299-W15-29, technetium-99 concentrations increased at well 299-W15-15 from 18 pCi/L in fiscal year 1994 to 124 pCi/L in fiscal year 2002. This change was anticipated based on the average concentrations of ~100 pCi/L that pass through the treatment system and are disposed at the injection wells. None of the results exceeded the drinking water standard of 900 pCi/L.

Overall Effectiveness

The >2,000 µg/L center of the carbon tetrachloride plume for fiscal year 2002 contracted but has a similar shape and concentration distribution as the fiscal year 2001 plume. High concentrations of carbon tetrachloride present beneath the Plutonium Finishing Plant area are somewhat more suspect as only one out of eleven samples at the new monitoring well, 299-W15-42, exceeded 2,000 µg/L. This well's data may indicate that the carbon tetrachloride has already been drawn toward the extraction wells from beneath the Plutonium Finishing Plant area, or was less extensive to begin with. In the area of the injection wells, concentrations continue to decline both from injection of treated groundwater into the aquifer, and as hydraulic mounding drives groundwater toward the extraction wells. The high concentration area of the plume in the upper part of the aquifer appears to be shrinking in size, evidenced by decreasing concentrations in monitoring and extraction wells, and decreasing concentrations in the influent tank from 3,600 µg/L in fiscal year 2001 to 3,492 µg/L in fiscal year 2002. Figure 2.8-9 shows details of the 2002 carbon tetrachloride plume map in the area of the remediation system, and Figure 2.8-10 shows the June 1996 baseline plume map.

Contaminant concentrations appear to be level or declining in extraction wells 299-W15-32, 299-W15-33, 299-W15-34, 299-W15-35, and 299-W15-36 (Figures 2.8-11 and 2.8-12). Initial increases in carbon tetrachloride concentrations at the north extraction wells indicate that a plume is being pulled from around or beneath the Plutonium Finishing Plant area northeast to these wells. The peak and decline in concentration trends at the extraction wells implies that the center of this dissolved mass has arrived at the extraction wells.

The highest average fiscal year 2002 concentrations of carbon tetrachloride in extraction wells were measured at the two northernmost wells, 299-W15-33 (4,300 µg/L) and 299-W15-34 (5,000 µg/L) (see Figure 2.8-9). The lowest average concentration was at 299-W15-36 at 1,100 µg/L. Table 2.8-2 compares average carbon tetrachloride concentrations at the extraction wells for fiscal years 1998, 1999, 2000, 2001, and 2002.

Carbon tetrachloride concentrations continue to decrease at extraction well 299-W15-32 (see Figure 2.8-12). Average concentrations have declined from 7,100 µg/L in fiscal year 1997 to 2,700 µg/L in fiscal year 2002. This well is located on the northeast corner of the 216-Z-9 cribs, where the highest volumes of carbon tetrachloride were discharged.

There were no significant changes in chloroform and trichloroethene concentrations in the extraction wells for fiscal year 2002. Chloroform concentrations ranged from 15 to 30 µg/L, while trichloroethene concentrations ranged from 2 to 13 µg/L. All chloroform concentrations were below the drinking water standard of 100 µg/L. The drinking water standard for trichloroethene is 5 µg/L.

Monitoring wells near the injection and extraction wells and around the Plutonium Finishing Plant have declining carbon tetrachloride concentrations. A few examples given below support this conclusion. Appendix A shows the locations of these wells.

Most monitoring wells near the injection and extraction wells, and around the Plutonium Finishing Plant have declined in carbon tetrachloride concentrations since the start of operations.

- Well 299-W15-15 has changed from ~1,000 µg/L in 1997 to a yearly average of 36 µg/L in 2002 (located northeast of injection well 299-W15-29).
- Well 299-W15-16 decreased rapidly in 2 years from ~5,400 µg/L in October 1999 to 900 µg/L in January 2002. This well, situated on the west side of the Plutonium Finishing Plant, has had the highest concentrations historically of any groundwater-monitoring well (8,700 µg/L in March 1990).
- Well 299-W15-39 increased to 2,500 µg/L in January 2000, then decreased to 400 µg/L in August 2002. This monitoring well lies approximately halfway between extraction wells 299-W-15-32 and 299-W15-36 and slightly to the east.
- Well 299-W18-24 declined from ~1,400 µg/L in 1998 to 6.5 µg/L in August 2002 (located south of the Plutonium Finishing Plant).
- Well 299-W15-7 decreased from a high of 4,900 µg/L in October 1999 to ~2,800 µg/L in August 2002 (located just southeast of extraction well 299-W15-34).
- Well 299-W15-38 has decreased from a high of 4,000 µg/L in February 2000 to 1,900 µg/L in August 2002. This monitoring well is immediately northeast of extraction well 299-W15-32 near the 216-Z-9 trenches. A decline in concentration at this well is consistent with the rapid decline at extraction well 299-W15-32.

Water-Level Impact and Capture-Zone Analysis

Regional groundwater flow in the vicinity of the extraction wells is still east-northeast in this area (see Figure 2.8-2). Water levels are continuing to decline at a rate of ~0.4 meter per year (DOE/RL-2001-67) due to the regional decline in the water table (see Section 2.1.1.2). The extraction wells are apparently influencing water levels and flow direction farther north in Waste Management Area TX-TY (PNNL-13342), Waste Management Area U (to the south), and Low-Level Waste Management Area 4 (to the west).

The high concentration area of the plume (>2,000 µg/L) in the immediate vicinity of the Plutonium Finishing Plant was contained hydraulically in fiscal year 2002 (DOE/RL-2001-53), based on the measured radius of influence of the pumping wells across the high concentration area and in monitoring wells situated between the pumping wells. The pumping influence extends over 124 meters from extraction well 299-W15-33 at least to monitoring well 299-W15-31A where a drawdown of 0.08 meter was measured.

Summary

In summary, the high concentration portion of the carbon tetrachloride plume continues to move toward the extraction wells and appears to be hydraulically contained based on the contaminant plume maps, contaminant trends, and hydraulic capture analysis. Contaminant concentrations appear to be declining in most of the extraction wells, implying that the peak of dissolved mass originating beneath the Plutonium Finishing Plant area has arrived at these wells. The injection wells have diluted the west and south portions of the plume and are driving dissolved contaminant mass toward the extraction wells. Most monitoring wells in the core area of the plume have decreasing contaminant concentrations, although the rate of change varies from well to well.

2.8.1.6 Low-Level Waste Management Area 4

RCRA monitoring at Low-Level Waste Management Area 4 indicates no groundwater contamination from this facility. Dropping water levels have caused wells to go dry, resulting in fewer than the necessary monitoring wells.

Wells were sampled semiannually for contamination indicator parameters in accordance with RCRA interim status regulations and for performance assessment for the low-level burial grounds under the *Atomic Energy Act of 1954* (DOE/RL-2000-72). Additional constituents are also monitored as required by the groundwater monitoring plan, WHC-SD-EN-AP-015, and subsequent revisions to the plan. The monitoring well network for Low-Level Waste Management Area 4 remained the same in fiscal year 2002. For more information about Low-Level Waste Management Area 4, refer to Appendix A.

An application was submitted to the Washington State Department of Ecology in June 2002 to incorporate the low-level burial grounds into the Hanford Part B RCRA permit. This would have the effect of changing the groundwater monitoring requirements for the burial grounds from interim status monitoring to final status monitoring. As part of the application, new groundwater monitoring wells, constituents, and statistical evaluations are proposed.

Groundwater flow beneath Low-Level Waste Management Area 4 is generally to the east (see Figure 2.8-2). It is affected to a large degree by the 200-ZP-1 pump-and-treat system, which has extraction wells to the east and injection wells to the west of this RCRA site. A series of calculations were made to fit planes to water-level measurements from different sets of three wells in the Low-Level Waste Management Area 4 network. A gradient and flow direction was determined from each plane. Because of the sparse network, two additional wells, 299-W15-31A and 299-W18-31, were included in the calculations. March 2002 water-level measurements were used in the calculations. The distribution of calculated flow directions was narrow, with the exception of a few sets indicating a gradient to the south (Figure 2.8-13). The vector mean flow direction is 89 degrees. However, if the few sets with a gradient to the south are removed, the vector mean flow direction is 77 degrees. The mean gradient is 0.0024. The groundwater velocity is 0.2 to 0.6 meter per day (see Appendix A, Table A.2).

Extraction and injection of groundwater from a nearby remediation system has changed flow directions and contaminant concentrations at Low-Level Waste Management Area 4.

There is no evidence that Low-Level Waste Management Area 4 has contributed to contaminants found in the groundwater. Downgradient well 299-W15-16 continued to exceed the critical mean for total organic halides. This well is still affected by contamination from other sources and was at one time an upgradient monitoring well. The U.S. Department of Energy (DOE) reported the exceedance to the U.S. Environmental Protection Agency (EPA) and Washington State Department of Ecology in August 1999. Critical mean values and contaminant concentrations that exceeded drinking water standards are listed in Appendix A. The elevated total organic halide concentrations are attributed to carbon tetrachloride from Plutonium Finishing Plant operations (see Section 2.8.1.2). However, air sampling of vent risers from trenches in Low-Level Waste Management Area 4 indicated the presence of high levels of carbon tetrachloride. Subsequent soil-gas sampling was performed to determine if carbon tetrachloride contamination is present in the vadose zone (CP-13514; see Section 3.1.1.3).

Nitrate continues to exceed the maximum contaminant level (45 mg/L) at many of the Low-Level Waste Management Area 4 monitoring wells. This contamination is not believed to be related to waste disposal at the burial grounds. In the southwest corner of Low-Level Waste Management Area 4, upgradient well 299-W18-21 has increasing nitrate concentrations that have not been associated with the large contaminant plumes in the 200 West Area. The fiscal year average nitrate concentration in this well was 96 mg/L. Only a few trenches have received waste in this part of the burial ground, so it is unlikely that the contamination is related to the burial ground itself.

2.8.2 T Plant

T Plant operated from 1944 through 1953 to separate plutonium from irradiated fuel using the bismuth phosphate process. The plant subsequently was converted to an equipment decontamination facility. Chlorinated hydrocarbons (carbon tetrachloride and trichloroethene), iodine-129, nitrate, and tritium form the most extensive contaminant plumes in the vicinity of T Plant. The majority of the chlorinated hydrocarbon contamination appears to originate in the vicinity of the Plutonium Finishing Plant, though there may be a contribution from T Plant facilities. Nitrate contamination appears to originate from both T Plant and Plutonium Finishing Plant facilities. Technetium-99 contamination at levels above drinking water standards is not as extensive as the plume listed above, but high levels are found near Waste Management Areas T and TX-TY. Small chromium and fluoride plumes are found in near Waste Management Area T, and uranium contamination is found near the T Plant canyon building. Groundwater contamination near T Plant is considered part of the CERCLA 200-ZP-1 Operable Unit.

Monitoring Objectives Near T Plant

Groundwater monitoring is conducted near T Plant:

- triennially to annually to describe the nature and extent of contamination
- semiannually to monitor trends in variable constituents/wells
- semiannually to detect the possible impact of one RCRA waste management area
- quarterly to assess contamination from two RCRA waste management areas

Waste Management Areas T and TX-TY are monitored as RCRA treatment, storage, and disposal facilities. They were both monitored according to interim status assessment requirements in fiscal year 2002. The RCRA groundwater assessments have indicated that Waste Management Areas T and TX-TY are probable sources of some of the groundwater contamination in this vicinity and further assessment is ongoing. Several facilities outside the waste management areas also affected groundwater in this vicinity, so the RCRA assessment must consider those impacts. This section includes required annual reporting of the RCRA assessments. The specific conclusions from monitoring the assessment sites are discussed in Sections 2.8.2.11 and 2.8.2.12. Low-Level Waste Management Area 3 was monitored under RCRA interim status detection requirements and is discussed in Section 2.8.2.13. The State-Approved Land Disposal Site was monitored under a state waste discharge permit and is discussed in Section 2.8.2.14. The State-Approved Land Disposal Site is located north of the 200 West Area boundary.

Waste sites associated with T Plant have contaminated groundwater with iodine-129, nitrate, technetium-99, tritium, and possibly some carbon tetrachloride. This area also contains minor chromium, fluoride, and uranium contamination.

2.8.2.1 Groundwater Flow

Groundwater in the north portion of the 200 West Area predominantly flows toward the east-northeast but is locally influenced by the 200-ZP-1 Operable Unit pump-and-treat system and effluent discharges to the State-Approved Land Disposal Site (see Figure 2.8-2). The flow direction in the vicinity of T Plant has changed

~35 degrees over the past decade from a north-northeast direction to a more easterly direction. This is due to decreased effluent discharges to the soil column in the 200 West Area, which is causing flow to return to its pre-Hanford direction.

The water table is influenced locally by the 200-ZP-1 Operable Unit pump-and-treat system. This causes flow in the south-central portion of this region to have a component toward the extraction wells to the south. Also, effluent discharges at the State-Approved Land Disposal Site, just north of the 200 West Area, have resulted in a local groundwater mound beneath this facility and a downward component of groundwater flow. Groundwater flow beneath Waste Management Area T is discussed in Section 2.8.2.11, flow beneath Waste Management Area TX-TY is discussed in Section 2.8.2.12, and flow beneath Low-Level Waste Management Area 3 is discussed in Section 2.8.2.13. Groundwater flow beneath the State-Approved Land Disposal Site is discussed in Section 2.8.2.14.

2.8.2.2 Tritium

A tritium plume lies beneath much of the north half of the 200 West Area and extends to the northeast (Figure 2.8-14). The plume geometry suggests the major tritium source is near the 242-T evaporator, the TY Tank Farm, and associated disposal cribs. Other contributing sources are likely present in the vicinity of the T and TX Tank Farms and associated cribs and trenches. Tritium concentrations remain high in the area immediately east of the TY Tank Farm. In June 1998, tritium concentrations increased to 3.21 million pCi/L near the 216-T-28 crib, in well 299-W14-2. Tritium concentrations were highly erratic in that well until it went dry after December 2000. Concentrations in nearby well 299-W14-13 peaked at nearly 3 million pCi/L in fiscal year 2000, but the fiscal year 2002 samples were between 1.4 and 1.7 million pCi/L (Figure 2.8-15). These were the largest tritium concentrations present in the 200 West Area during fiscal year 2002. Thus, all tritium concentrations measured in the 200 West Area in fiscal year 2002 were less than the 2 million-pCi/L DOE derived concentration guide. The hydraulic gradient in this vicinity is relatively flat due to the interaction of the regional gradient and the influence of the 200-ZP-1 Operable Unit pump-and-treat system. Possible sources for this tritium contamination are the 216-T-26, 216-T-27, 216-T-28 cribs, 242-T evaporator, and the 216-T-19 crib and tile field. The erratic concentration trend in well 299-W14-2 suggests that contamination in the vadose zone could be remobilized by a fresh water source such as a leaking water line, but this has not been confirmed. The overall extent of this plume has not changed greatly over the past 7 years.

Tritium concentrations in one well near the TY Tank Farm exceeded 1 million pCi/L in fiscal year 2002.

2.8.2.3 Iodine-129

Iodine-129 near T Plant (Figure 2.8-16) coincides generally with the tritium plume and appears to be mainly associated with sources near the TY Tank Farm. The extent of detectable iodine-129 is smaller than that of tritium. The interpretation of iodine-129 results is somewhat complicated by a number of samples reported with detection limits greater than the 1-pCi/L drinking water standard. The elevated detection limit is due to the absence of a secondary peak to confirm the presence of iodine-129 and interference from technetium-99. However, the reported counts, in most cases likely are due to iodine-129, based on spatial and temporal trends. Thus, the iodine-129 plume map is drawn to include these uncertain detections. The highest fiscal year 2002 average iodine-129 concentration in the north 200 West Area was 28 pCi/L, measured along the east side of the TY Tank Farm in well 299-W14-13 (maximum measured concentration was 31.6 pCi/L). The highest iodine-129 concentration noted during the previous year was 64 pCi/L, measured at well 299-W14-2 (now dry) near the 216-T-28 crib. The

Iodine-129 near T Plant appears to be mainly associated with sources near the TY Tank Farm. The extent of detectable iodine-129 is smaller than that of tritium.

242-T evaporator or cribs that received condensate are likely sources for the iodine-129 contamination. The overall extent of this plume has not changed greatly over the past several years.

2.8.2.4 Technetium-99

Technetium-99 plumes are present in the T Plant area (Figure 2.8-17), but the concentrations are less than the 900-pCi/L drinking water standard in most of the area. Technetium-99 is found at concentrations greater than the standard near the east (downgradient) side of Waste Management Area T. The technetium-99 concentration in wells along the central and south part of the downgradient side of the waste management area increased in 2002. Either the plume is moving toward the south or a previously undetected portion of the plume is now encountered by more southerly wells. Technetium-99 concentrations above the drinking water standard are found in only two wells at Waste Management Area TX-TY. Concentrations increased slightly on the east side of Waste Management Area TX-TY but decreased slightly on the south side during fiscal year 2002. Evaluation of the data indicates that Waste Management Areas T and TX-TY are the source of at least some of the technetium-99 (PNNL-13929; PNNL-14099). Other possible technetium-99 sources include the 216-T-7, 216-T-32, 216-T-36, 216-T-19, and other cribs. Further details on the technetium-99 contamination are discussed with the tank farm assessment summaries in Sections 2.8.2.11 and 2.8.2.12.

2.8.2.5 Uranium and Gross Alpha

Few analyses for uranium were performed on groundwater samples from the vicinity of T Plant in fiscal year 2002 because most wells showed insignificant levels in previous monitoring. Some wells monitored near the single-shell tank farms are sampled for gross alpha measurements, which would show an increase if uranium contamination appeared. Uranium was detected above the 30-μg/L maximum contaminant level near the T Plant building. The uranium is detected far from major disposal facilities, so the source of the contamination is unknown. The single sample from well 299-W11-37, located north of T Plant, contained 410 μg/L of uranium.

High concentrations of nitrate in groundwater continued to be found in wells near T Plant disposal facilities. The maximum value in fiscal year 2002 was 1,500 mg/L, an increase from fiscal year 2001.

2.8.2.6 Nitrate

Nitrate continued to be present in groundwater at concentrations in excess of the 45-mg/L maximum contaminant level beneath much of the north part of 200 West Area (see Figure 2.8-8). The maximum concentration in this vicinity in fiscal year 2002 was 1,500 mg/L in well 299-W10-4 near the 216-T-36 crib, south of Waste Management Area T. Concentrations in this well continued to increase sharply through the year, reaching a maximum of 1,740 mg/L in the August 2002 sample. The 216-T-32 and 216-T-7 cribs, west of Waste Management Area T also appear to contribute to the high nitrate concentrations. The nitrate contamination is more widespread than the iodine-129, technetium-99, or tritium contamination discussed previously. There probably are multiple sources of nitrate in this area, including disposal facilities near the Plutonium Finishing Plant.

Nitrate is found at concentrations greater than the maximum contaminant level at considerable depth within the unconfined aquifer near T Plant. For example, 394 mg/L of nitrate was detected in a sample from well 299-W6-3 that is completed ~60 meters below the water table. This well is completed above the top of the Ringold lower mud unit.

2.8.2.7 Chromium

Chromium at levels above the 100-μg/L maximum contaminant level in filtered samples is restricted to the immediate vicinity of Waste Management Areas T and TX-TY (Figure 2.8-18). The maximum average annual concentration detected in fiscal year 2002 was 330 μg/L in well 299-W14-13, east of Waste Management Area TX-TY. Concentrations have been generally increasing in this well.

A chromium plume has been identified in the vicinity of Waste Management Area T. The specific source for this persistent plume has not been identified but the 216-T-36 crib, which received steam condensate, decontamination waste, and miscellaneous waste from the T and U Plants is a likely contributor. Chromate was frequently used in equipment decontamination. Thus, the crib and the vitreous clay pipe leading to the crib are likely sources of chromium contamination. Chromium is of interest because it has been identified in tank waste and may help form a signature of mobile tank waste components. However, similar waste was disposed to cribs and trenches in the immediate vicinity. Chromium is discussed further in Sections 2.8.2.11 and 2.8.2.12.

2.8.2.8 Fluoride

Fluoride was detected above the 4-mg/L maximum contaminant level in two wells near the T Plant waste disposal facilities. The fluoride contamination was found at lower levels in a number of wells in the vicinity of Waste Management Area T. The highest value measured in fiscal year 2002, 4.4 mg/L, was on the east side of Waste Management Area T in well 299-W11-42. Fluoride may be associated with single-shell tank waste or discharges to cribs. Fluoride is discussed further in Section 2.8.2.11.

2.8.2.9 Chlorinated Hydrocarbons

Although the bulk of the carbon tetrachloride plume in the 200 West Area is known to have originated from liquid waste disposal facilities in the vicinity of the Plutonium Finishing Plant, a second source may exist in the vicinity of T Plant. According to WHC-SD-EN-TI-248, carbon tetrachloride dissolved in the 242-T evaporator overhead and discharged to the 216-T-19 crib from 1973 to 1976 may contribute to the groundwater contamination. The carbon tetrachloride distribution in the 200 West Area is shown in Figure 2.8-3. Of particular interest are relatively low carbon tetrachloride concentrations in the vicinity of the southeast corner of Waste Management Area TX-TY, where levels are <500 μg/L but still above the 5-μg/L maximum contaminant level. This area is within the hydraulic influence of the 200-ZP-1 Operable Unit pump-and-treat system discussed in Section 2.8.1.5. Although data are sparse, there appears to be low carbon tetrachloride concentrations in the east-central part of the 200 West Area.

Although the bulk of the carbon tetrachloride plume in the 200 West Area is known to have originated from liquid waste disposal facilities in the vicinity of the Plutonium Finishing Plant, a second source may exist in the vicinity of T Plant.

Trichloroethene also is found at levels above the maximum contaminant level in the vicinity of T Plant but at levels considerably lower than carbon tetrachloride. The area of trichloroethene concentrations greater than the maximum contaminant level extends from the Plutonium Finishing Plant northeast through the T Plant vicinity (see Figure 2.8-7). The trichloroethene contamination is not as extensive as that of carbon tetrachloride.

2.8.2.10 Iron, Manganese, and Nitrite

High levels of iron, manganese, and nitrite have been reported east of Waste Management Area T in filtered samples. Manganese in well 299-W11-24 reached a fiscal year 2002 maximum level of 361 μg/L. Elevated nitrite was detected at levels (expressed as NO_2^-) up to 7.55 mg/L in well 299-W11-24 for fiscal year 2002.

Iron was also elevated in this well. The high iron, manganese, and nitrite are indicative of reducing conditions; however, the cause of the reducing conditions is unknown.

2.8.2.11 Single-Shell Tank Waste Management Area T

RCRA Waste Management Area T contains single-shell tank farms that have contaminated groundwater with nitrate, technetium-99, and possibly chromium. Assessment monitoring continued in fiscal year 2002.

Waste Management Area T, located in the north-central portion of the 200 West Area, consists of the T single-shell tank farm and ancillary equipment (e.g., diversion boxes). The tank farm contains twelve 2-million-liter tanks and four 208,000-liter tanks constructed between 1943 and 1944. The tanks began receiving waste in 1944, initially receiving waste from the bismuth phosphate process. During early operations, tank waste was cascaded through sets of three tanks and overflow from the third tank was discharged to the ground in cribs and trenches to the west of the waste management area. Seven of the tanks in the waste management area are known or suspected to have leaked.

Waste Management Area T was originally placed in assessment monitoring because of elevated specific conductance in downgradient well 299-W10-15 (WHC-SD-EN-AP-132). However, it remained in assessment because of contaminants observed in downgradient well 299-W11-27 (PNNL-11809). A detailed well location map for this waste management area is shown in Appendix A, Figure A.19. This site continued to be monitored under an assessment program in fiscal year 2002. The well and analyte lists for this unit are given in Appendix A, Table A.36.

Groundwater Flow

The direction of groundwater flow at Waste Management Area T has varied over the life of the facility because of changing effluent discharge patterns within the 200 West Area. The flow direction when the RCRA monitoring network was established was toward the northeast. The groundwater presently flows generally toward the east as indicated by the water-table map (see Figure 2.8-2). A flow direction towards the east is supported by trend surface analyses. A trend surface analysis in the vicinity of well 299-W10-24 using March 1999 water-level data yielded a flow direction of 5 degrees north of east (PNNL-13378). A similar analysis in the vicinity of well 299-W11-40 using August 2001 water levels gave a flow direction of 6 degrees south of east. Finally, a third trend surface analysis in the vicinity of well 299-W11-39 using September 2001 water levels gave a flow direction of 6 to 8 degrees south of east (PNNL-14113).

Hydraulic conductivity data were obtained from slug tests and drawdown tests conducted in wells 299-W10-23 and 299-W10-24 in 2000 (PNNL-13378). Effective porosity was determined using tracer drift and pumpback test methods. The water-table gradient was determined from data used to generate the annual water-table map. Calculated Darcy velocities for data from wells 299-W10-23 and 299-W10-24 are 0.024 and 0.023 meter per day, respectively. A measured velocity from a tracer pumpback test in well 299-W10-24 was 0.029 meter per day. The calculated Darcy velocity for well 299-W10-24 is in good agreement with the measured velocity.

Data from tracer pumpback tests indicate a downward vertical in-well flow in two downgradient wells at Waste Management Area T. Downward in-well velocities of 0.001 to 0.002 meter per minute were measured in well 299-W11-39 and downward flow velocities of 0.011 to 0.02 meter per minute in well 299-W11-40 (PNNL-14113).

Locally, the direction of groundwater flow may diverge from the regional pattern because variable cementation and grain size distribution within the Ringold Formation may result in preferred groundwater flow paths. Indications of variable aquifer permeability are found in the geologist's description of the lithologies encountered during drilling, variations in drawdown during well development, and the results of aquifer testing at Waste Management Area T.

Groundwater Contamination

Several contaminants continued to be detected in the vicinity of Waste Management Area T during fiscal year 2002. High carbon tetrachloride, chromium, fluoride, nitrate, trichloroethene, and tritium are from upgradient sources and are components of a contaminant plume crossing the waste management area from west to east. These contaminants were discussed in previous sections. Technetium-99 and possibly some of the chromium, fluoride, and nitrate have a local source within the tank farm and are discussed here. Based on current data, it is not possible to differentiate chromium, fluoride, and nitrate from Waste Management Area T from chromium, fluoride, and nitrate from upgradient sources.

A technetium-99 plume has been identified northeast and east of the waste management area. Technetium-99 concentrations began increasing in downgradient well 299-W11-27 in late 1995 and early 1996, soon after effluent discharges to ground stopped in the 200 West Area. The concentration of technetium-99 peaked at 21,700 pCi/L in February 1997. Technetium-99 concentration subsequently decreased to a low of 6,000 pCi/L when the last sample was taken from well 299-W11-27 in March 1999 prior to the well going dry.

Technetium-99 concentrations in replacement well 299-W10-24 (Figure 2.8-19), drilled immediately adjacent to well 299-W11-27, were much lower than in well 299-W11-27 and have ranged between 707 and 3,660 pCi/L (707 to 972 pCi/L during fiscal year 2002) with a trend toward lower values. Results from groundwater analyses of samples from well pairs and from samples obtained at specific depths during drilling indicate that the technetium-99 contamination east and northeast of Waste Management Area T is relatively shallow within the upper few meters of the aquifer (PNNL-13929). Therefore, the lower technetium-99 concentration in well 299-W10-24 may be due to the longer sampled interval below the water table in the replacement well relative to well 299-W11-27. Current technetium-99 concentrations are less than they have been in the past, which may indicate that the technetium-99 contamination is moving east away from well 299-W10-24. Specific conductance measurements taken at 13 depths within the 9.5-meter screened interval in September 2002 indicated a nearly constant specific conductance profile throughout the screened interval. This also suggests that the major part of the shallow contaminant plume is leaving the area.

The tank-related contaminants at Waste Management Area T appear to be restricted to a zone of lower permeability in the upper portion of the aquifer. The lateral extent to this low permeability zone is uncertain.

Technetium-99 concentrations in well 299-W11-23, a non-Washington Administrative Code (WAC)-compliant well located east of well 299-W11-27, started to increase in November 1997, reaching a high of 8,540 pCi/L in November 1998 (see Figure 2.8-19). Technetium-99 concentrations in well 299-W11-39, the replacement well for 299-W11-23, ranged from 1,490 to 5,180 pCi/L between November 2001 and August 2002 sampling. The highest concentration was the latest measurement from August 2002. Technetium-99 concentrations showed considerable variability in well 299-W11-27 and that variability has continued in the replacement well 299-W10-24. The concentrations of technetium-99 in well 299-W11-39 initially indicated that technetium-99 was distributed through the upper portion of the aquifer and not just at the very top as it was at well 299-W10-24 (PNNL-13788). However, subsequent aquifer testing has shown a slight downward in-well flow (PNNL-14113), which may be redistributing technetium-99 from the shallow part of the aquifer deeper in the screened interval.

Technetium-99 concentrations steadily increased from 532 to 1,200 pCi/L in 299-W11-41 and from 461 to 812 pCi/L in well 299-W11-42 during fiscal year 2002. This suggests that either (1) the plume first noted at the northeast corner of the waste management area is spreading to these more southerly wells, (2) that these wells are encountering a different, previously undetected part of the plume, or (3) the wells are detecting a separate plume.

Nitrate concentrations remained above the drinking water standard in all wells in the Waste Management Area T network during fiscal year 2002. The highest reported concentrations were in upgradient wells 299-W10-28 and 299-W10-4 where the maximum nitrate concentrations reached 1,460 and 1,740 mg/L, respectively. The highest downgradient concentrations of nitrate are found in wells 299-W11-41 (584 mg/L in August 2002) and 299-W11-42 (708 mg/L in August 2002). Previous investigations have indicated that nitrate at Waste Management Area T is relatively deep in the aquifer and is from upgradient sources (PNNL-13788; PNNL-13929). The most likely source for nitrate in upgradient well 299-W10-4 and in downgradient wells 299-W11-41 and 299-W11-42 is the 216-T-36 crib. The source for nitrate in upgradient well 299-W10-28 is not known for certain but may be the 216-T-5 trench, which received 2.6 million liters of waste from the 221-T Building by way of single-shell tank 241-T-112. The waste contained 145,000 kilograms of nitrate. Figure 2.8-8 shows the nitrate plume in the area of Waste Management Area T.

All evidence indicates that the chromium found at Waste Management Area T is from a source external to the waste management area and the most likely source is the 216-T-36 crib. Filtered samples from the chromium concentration exceeded the drinking water standard (100 µg/L) in three wells in the area of Waste Management Area T (see Figure 2.8-18). The highest chromium concentration was in well 299-W10-4 located upgradient of the waste management area (Figure 2.8-20). The maximum concentration of chromium in this well was 252 µg/L in fiscal year 2002. Well 299-W10-4 is located at the 216-T-36 crib, and the crib is the most likely source for the chromium.

Chromium observed in wells at the T Tank Farm is most likely associated with an upgradient source, not the tank farm itself.

Chromium in excess of the drinking water standard also was found in two downgradient wells: 299-W11-41 and 299-W11-42. The maximum concentration of chromium was 134 µg/L in well 299-W11-41 and 131 µg/L in well 299-W11-42 during fiscal year 2002. Chromium has shown a slight decreasing concentration trend in both wells since they were drilled in 2000 (see Figure 2.8-20). Prior to about 1997, groundwater flow was to the north at Waste Management Area T, and since that time, groundwater flow shifted eastward from well 299-W10-4 toward wells 299-W11-41 and 299-W11-42.

With one possible exception, the concentrations of chromium and technetium-99 do not track each other through time (Figure 2.8-21). This suggests the two constituents have different sources. The possible exception is in well 299-W11-39 (see Figure 2.8-21) where the chromium and technetium-99 concentrations appear to track each other through time.

Finally, comparisons of chromium and technetium-99 concentrations in three well pairs where one of the wells in each pair has gone dry and the other is its replacement, show that the concentration of chromium is higher and the concentration of technetium-99 is lower in the replacement wells than in the older wells (PNNL-13929). The last sample from each older well represents the concentrations very near the water table. The concentrations in the replacement wells represent the concentration throughout the 10.7-meter screened interval. That is, the concentration in samples from the replacement wells are mixtures of high technetium-99, low chromium-bearing water near the water table with lower technetium-99, higher chromium-bearing water from deeper in the aquifer. This suggests different sources for the two constituents.

Fluoride exceeded the drinking water standard of 4 mg/L in two wells at Waste Management Area T during fiscal year 2002 (Figure 2.8-22). The largest fluoride concentration was 4.4 mg/L in well 299-W11-42 in February 2002. Fluoride concentration reached 4.3 mg/L in well 299-W10-24 in November 2001 and has subsequently decreased to 4 mg/L. Fluoride concentration was >2.2 mg/L in eight wells during fiscal year 2002 including upgradient well 299-W10-28, with concentrations between 1.4 and 2.1 mg/L and upgradient well 299-W10-4 with concentrations between 2.2 and 2.7 mg/L. Fluoride concentrations had been as high as 5.25 mg/L in upgradient well 299-W10-4 in August 1999.

The fact that high concentrations of fluoride exist upgradient of the waste management area indicates an upgradient source for the fluoride. However, no readily discernible source is evident, and the lack of wells upgradient of the area does not allow for tracking fluoride in that direction. Also, the fluoride/technetium-99 ratios vary from well to well at Waste Management Area T and with time in some wells. If the technetium-99 has a source within the waste management area, as is currently assumed, the fluoride/technetium-99 ratios suggest a different source for the fluoride.

RCRA Assessment Summary

The groundwater monitoring network at Waste Management Area T consists of three upgradient wells and eight near-field downgradient wells (see Appendix A, Table A.36). In addition, two far-field downgradient wells are used to track plume distribution. This section discusses contaminant monitoring and investigations that relate directly to the RCRA assessment activities at the waste management area. General discussions of the contaminants in this vicinity are discussed in other sections of this chapter.

Groundwater flow is generally toward the east at Waste Management Area T (see Figure 2.8-2). Trend surface analyses indicate a flow direction between about 5 degrees north of east and 8 degrees south of east. The groundwater flow rate (~0.024 meter per day) is calculated from Darcy's Law using hydraulic conductivity from slug test data.

Chromium is the only dangerous waste constituent found in the groundwater beneath Waste Management Area T. The chromium concentration exceeded the drinking water standard (100 µg/L) in three wells. The highest chromium concentration in fiscal year 2002 was 252 µg/L in upgradient well 299-W10-4. Well 299-W10-4 is located at the 216-T-36 crib and the crib is the most likely source for the chromium.

Chromium in excess of the drinking water standard also was found in downgradient well 299-W11-41 (maximum concentration of 134 µg/L in fiscal year 2002) and in downgradient well 299-W11-42 (maximum concentration of 131 µg/L in 2002). Both well 299-W11-41 and well 299-W11-42 are located downgradient of well 299-W10-4 and the 216-T-36 crib. The chromium found downgradient of Waste Management Area T is most likely from the same source as that found in well 299-W10-4. Figure 2.8-18 shows a plume map of chromium in the area of the waste management area.

2.8.2.12 Single-Shell Tank Waste Management Area TX-TY

Waste Management Area TX-TY contains single-shell tank farms that may have contaminated groundwater with chromium, nitrate, and technetium-99. These plumes may also have sources outside the waste management area.

Waste Management Area TX-TY, located in the north-central portion of the 200 West Area, consists of the TX and TY Tank Farms and ancillary equipment (e.g., diversion boxes). The tank farms contain twenty-four 2.9-million-liter tanks constructed between 1944 and 1952. The tanks began receiving waste in 1944, initially receiving waste from the bismuth phosphate process. During early operations, tank waste was cascaded through sets of two or three tanks and overflow from the final tank was discharged to the ground in cribs and trenches to the west of the waste management area. Twelve of the tanks in the waste management area are known or suspected to have leaked.

Waste Management Area TX-TY was originally placed in RCRA assessment monitoring because of elevated specific conductance in downgradient wells 299-W10-17 and 299-W14-12 (WHC-SD-EN-AP-132). This site continued to be monitored under an assessment program in fiscal year 2002. The well and analyte lists for this unit are given in Appendix A, Table A.37. A detailed well location map for this waste management area is shown in Appendix A, Figure A.19.

Groundwater Flow

The direction of groundwater flow at Waste Management Area TX-TY has been highly variable over the life of the facility. When the RCRA monitoring network was established, the flow direction was toward the northeast. The pre-Hanford Site flow direction in the vicinity of the waste management area is believed to have been from west to east, and it is expected that groundwater flow will eventually return to that direction. In about 1998, the 200-ZP-1 pump-and-treat system began to affect the groundwater flow direction beneath the south part of Waste Management Area TX-TY.

The direction of groundwater flow is estimated based on the gradient in the water-table elevations in the Waste Management Area TX-TY network monitoring wells. This approach assumes the aquifer is isotropic. Because there is evidence that the aquifer is non-homogeneous and an isotropic, this limitation must be kept in mind when applying the gradient analysis approach to estimate flow direction.

Water-table elevations for the area around Waste Management Area TX-TY are illustrated in Figure 2.8-2, based on March 2002 water-level measurements. Contours on the water-table map indicate that general groundwater flow direction below Waste Management Area TX-TY changes with location. The general flow direction is toward the east or southeast below the north part of the waste management area and toward the south, or possibly the south-southwest, below the south part of the waste management area. Groundwater beneath the south part of the waste management area is strongly influenced by the 200-ZP-1 pump-and-treat system.

Trend-surface analyses were applied to monitoring well water-level elevations at Waste Management Area TX-TY (PNNL-12278; PNNL-13514). Analyses of May 1999 water-level data in the vicinity of wells 299-W10-26 and 299-W14-13 indicate a flow direction of 18 degrees east of south. Analysis of May 2000 water-level data in the vicinity of well 299-W15-41 indicates a flow direction 16 degrees east of south. The trend-surface derived flow direction for the former two wells at the north part of the waste management area is in good agreement with the flow direction inferred from the water-table map. The trend-surface derived flow direction for the south well, 299-W15-41, is more directly to the east than the direction indicated on the water-table map. This is because the trend-surface analysis did not include wells south or southwest of well 299-W15-41, which are influenced by the 200-ZP-1 pump-and-treat operations.

The operation of a pump-and-treat system in an area south of Waste Management Area TX-TY has changed flow directions in that area over the past several years. The remediation may have a significant impact on the distribution of contaminants.

New hydraulic conductivity data were obtained from slug tests and drawdown tests conducted in five new wells installed since 1999 (PNNL-13378; PNNL-13514). Effective porosity was determined using tracer drift and tracer pumpback test methods and specific yield was determined from constant-rate pumping tests. The water-table gradient was determined from data used to generate the annual water-table map. Calculated Darcy velocities from tests in three downgradient wells (299-W10-26, 299-W14-13, and 299-W14-14) and one upgradient well (299-W15-40) range from 0.012 to 0.026 meter per day. The calculated groundwater velocity for well 299-W15-41 is 0.29 meter per day and is an order of magnitude greater than the velocities in the other wells. The relatively rapid groundwater flow velocity for well 299-W15-41, located at the south end of Waste Management Area TX-TY, is likely a result of higher hydraulic gradients in the vicinity of the pump-and-treat system at the 200-ZP-1 Operable Unit.

Groundwater Contamination

A number of contaminants were detected in the vicinity of Waste Management Area TX-TY during fiscal year 2002. Carbon tetrachloride from upgradient sources was discussed in previous sections of this chapter. Chromium, iodine-129, some of the nitrate, technetium-99, and tritium may have a local source and are discussed in more detail in the following paragraphs.

Contamination from two areas near Waste Management Area TX-TY warrants consideration: east and downgradient of the waste management area in the area of well 299-W14-13 and south of the waste management area near well 299-W15-41. The contaminants of interest east of Waste Management Area TX-TY are technetium-99, tritium, iodine-129, nitrate, and chromium. The contaminant of interest south of the waste management area is technetium-99.

Contamination East of Waste Management Area TX-TY. Contaminant levels for chromium, nitrate, technetium-99, and tritium were high in well 299-W14-12 when RCRA monitoring began in April of 1992 (WHC-SD-EN-AP-132). Contaminant levels peaked in late 1992 and then declined until 1997, the steepest decline corresponding to the rapid drop in the water table after 1995. Contaminant concentrations reached their minimum values in the 1996 to 1997 time period and began to increase in 1997 and 1998, at about the time of the change in groundwater flow direction from northeast to southeast. Concentration levels continued to increase until the well became unsampleable in January 1999. The contaminant histories for technetium-99, nitrate, chromium, and tritium in well 299-W14-12 are shown in Figures 2.8-23 through 2.8-26. Iodine-129 and cobalt-60 also were present and showed similar trends. The upward trends observed in well 299-W14-12 continued in replacement well 299-W14-13 (see Figures 2.8-23 through 2.8-26) except for cobalt-60, which has not been detected in the replacement well.

Figure 2.8-17 shows the fiscal year 2002 plume map for technetium-99. Technetium-99 was detected in two wells east of Waste Management Area TX-TY in fiscal year 2002 above the drinking water standard of 900 pCi/L. Technetium-99 concentration in downgradient well 299-W14-13, located east of the waste management area, increased from 4,910 pCi/L at the end of the previous year to 6,200 pCi/L in August 2002. The most likely source for most of the technetium-99 east of Waste Management Area TX-TY is tank waste from the waste management area.

The most likely source for most of the technetium-99 east of Waste Management Area TX-TY is tank waste from the waste management area.

Three other sources also may have contributed some technetium-99 to groundwater contamination east of Waste Management Area TX-TY. First, data from gross gamma-ray logs in well 299-W14-1, located 38 meters southeast of the 216-T-28 crib, show lateral spreading of radioactive contaminants from the crib to the well (ARH-ST-156). The same report states that the data indicate breakthrough to the groundwater could have occurred at that site. The 216-T-28 crib received about 10.9 curies of technetium-99 (PNNL-11800). Thus, some of the technetium-99 in groundwater may be from the 216-T-28 crib.

The 216-T-19 crib and tile field are also potential sources for some of the technetium-99 east of Waste Management Area TX-TY. The tile field received 455 million liters of primarily steam condensate from the 242-T evaporator (DOE/RL-91-61), which contained 9.89 curies of technetium-99. A third potential source for some of the technetium-99 east of the waste management area is leaks from the 242-T evaporator itself.

The plume map for technetium-99 (see Figure 2.8-17) shows that the technetium-99 plume is relatively small and centered near well 299-W14-13. Technetium-99 concentrations drop sharply both to the north and the south. Well 299-W14-17 is downgradient of well 299-W14-13 and technetium-99 concentrations ranged between 430 and 496 pCi/L during fiscal year 2002, which was slightly less than the previous fiscal year.

Chromium was detected in one downgradient well (299-W14-13) above the drinking water standard of 100 µg/L during fiscal year 2002 (see Figure 2.8-25). Chromium concentrations increased from 248 µg/L at the end of the last fiscal year to 361 µg/L in August 2002. The nearest potential source for the chromium is Waste Management Area TX-TY. However, data from the upgradient well pair 299-W15-12 and its replacement well 299-W15-765 and downgradient well pair 299-W14-12 and its replacement well 299-W14-13, suggest that technetium-99 is concentrated near the water table, whereas chromium is more concentrated at depth in the aquifer. If the source of the technetium-99 and chromium in downgradient well 299-W14-13 is Waste Management Area TX-TY, it is unclear what mechanism caused the apparent separation of the two contaminants in the aquifer.

Figure 2.8-8 shows the fiscal year 2002 plume map for nitrate. All wells in the groundwater monitoring network at Waste Management Area TX-TY, including the upgradient wells, had nitrate concentrations greater than the maximum contamination level of 45 mg/L in fiscal year 2002. The highest nitrate concentration was at well 299-W14-13 where the nitrate concentration ranged between 315 and 390 mg/L.

Nitrate in the area of Waste Management Area TX-TY is probably from several sources including the waste management area, the 216-T-19 crib and tile field, and possibly the 216-T-28 trench and the 241-T evaporator.

Nitrate in the area of Waste Management Area TX-TY is probably from several sources including the waste management area, the 216-T-19 crib and tile field, and possibly the 216-T-28 trench and the 241-T evaporator. Also, Waste Management Area TX-TY is in the middle of a regional nitrate plume that originates from facilities near Z Plant. Nitrate concentration in upgradient well 299-W15-40 was 78 to 98.7 mg/L and nitrate concentration in upgradient well 299-W15-765 was 150 to 170 mg/L in fiscal year 2002.

An area of relatively low nitrate, north of well 299-W14-13, has existed since at least the mid-1990s. Dilution by liquids disposed to the 216-T-26 through 216-T-28 cribs is probably not the cause of the low nitrate in the area because 1 million kilograms of nitrate were in the waste stream sent to the 216-T-26 crib (DOE/RL-91-61). The cause of the low nitrate in that area is not known.

Figure 2.8-14 shows the fiscal year 2002 plume map for tritium. Tritium was detected in one downgradient well (299-W14-13) above the drinking water standard of 20,000 pCi/L in fiscal year 2002 (Figure 2.8-26). Like nitrate, tritium most likely has several sources that include Waste Management Area TX-TY and several cribs and trenches in the area. Tritium/technetium-99 ratios show that contamination in the area of well 299-W14-13 (and in well 299-W14-12) is probably a mixture of regional contamination with tank waste (PNNL-11809).

High concentrations of iodine-129, up to 64 pCi/L, have been noted in the area of wells 299-W14-2, 299-W-14-12, and 299-W14-13, east of the waste management area since early 1992 and have continued since that time (Figure 2.8-27). Wells 299-W14-2 and 299-W14-12 are now dry but high iodine-129 concentrations continued in well 299-W14-13 through fiscal year 2002. Concentrations of iodine-129 in that well increased from 22.4 pCi/L in August 2001 to 31.6 pCi/L in August 2002.

The iodine-129 and tritium contamination in the area of well 299-W14-13 has been attributed to condensate from the 242-T evaporator (PNNL-13788). This was based on the iodine-129 plume also containing significant tritium but very little technetium-99. However, other potential sources are in the area and include the 216-T-28 crib, the 216-T-19 crib and tile field, and the Waste Management Area TX-TY.

Contaminant distributions along the east side of Waste Management Area TX-TY have been affected by changing flow directions. The direction of groundwater flow in the vicinity of well 299-W14-13 was toward the northeast when monitoring was initiated. Flow is currently toward the southeast. Groundwater flow directions indicate that the source for the initial plume detected in well 299-W14-12 was within the TX Tank Farm. The present direction of groundwater flow at well 299-W14-13 is from the TY Tank Farm. However, given a flow velocity of 0.02 meter per day, it is unlikely that contaminants could have arrived from that source in the available time. The most reasonable explanation for the tank waste contaminants in well 299-W14-13 is the presence of a plume north of this well that moved toward the southeast as a result of the change in groundwater flow direction in about 1998.

South Boundary of Waste Management Area TX-TY. The 200-ZP-1 Operable Unit pump-and-treat system has affected the distribution of groundwater contaminants south of Waste Management Area TX-TY. The pump-and-treat system at 200-ZP-1 Operable Unit began operating in 1994 with one extraction well. The operation was expanded to three wells in 1996 and, finally, to six wells in August 1997. The first effects of the pump-and-treat system on groundwater flow direction beneath Waste Management Area TX-TY appear on the June 1998 water-table map (PNNL-12086).

Technetium-99 in wells along the south boundary of Waste Management Area TX-TY started to increase ~1 year after Phase II of the 200-ZP-1 Operable Unit pump-and-treat system began. (Phase II, consisting of three extraction wells, began the use of the closest extraction wells to the waste management area.) Given the groundwater flow directions imposed on the south portion of the waste management area by the pump-and-treat system, the most reasonable explanation for the increasing technetium-99 is that groundwater contaminated with technetium-99 is being drawn from beneath the waste management area into the pump-and-treat system. Alternatively, technetium-99 may be originating from the 216-T-19 crib and tile field (DOE/RL-2001-53). Given the changing direction of groundwater flow along the south boundary of the waste management area, the few available monitoring wells, and the lack in continuity of monitoring data due to dry wells and new wells, it is currently impossible to fully evaluate this problem.

Increasing technetium-99 concentrations along the south boundary of Waste Management Area TX-TY are believed to be due to contamination beneath the waste management area being drawn toward the 200-ZP-1 pumping wells.

RCRA Assessment Summary

The groundwater monitoring network at Waste Management Area TX-TY consists of two upgradient wells and eleven near-field downgradient wells (see Appendix A, Table A.37). In addition, two far-field downgradient wells are used to track plume distribution. This section discusses the results of contaminant monitoring and investigations that relate directly to the RCRA assessment activities at the waste management area. General discussion of the contaminants in this vicinity are discussed in other sections of this chapter.

Groundwater flow is generally toward the east or southeast at the north and central parts of the waste management area where trend surface analyses indicate a flow direction of about east 18 degrees south (see Figure 2.8-2). The groundwater flow rate calculated from Darcy's Law and slug test data from wells in this area is between 0.014 and 0.026 meter per day.

Groundwater conditions south of the waste management area are different from those in the north because of the pump-and-treat system. There, groundwater flow is to the south or southwest toward the 200-ZP-1 Operable Unit extraction wells. The groundwater flow rate calculated from slug test data in well 299-W15-41 is 0.29 meter per day and is certainly influenced by the steeper water-table gradient due to the extraction wells.

RCRA assessment monitoring at Waste Management Area TX-TY continued in fiscal year 2002. Chromium is the only dangerous waste constituent present.

Chromium is the only dangerous waste constituent found in the groundwater beneath Waste Management Area TX-TY. Chromium was detected in one downgradient well (299-W14-13) above the drinking water standard of 100 µg/L during fiscal year 2002 (see Figure 2.8-25). Chromium concentrations increased from 248 µg/L at the end of the last fiscal year to 361 µg/L in August 2002. The nearest potential source for the chromium is Waste Management Area TX-TY. Although there are data to suggest that the waste management area may not be the source of the chromium, no upgradient source has been identified. Therefore, Waste Management Area TX-TY is tentatively considered the source for the chromium in well 299-W14-13.

2.8.2.13 Low-Level Waste Management Area 3

This site continued to be monitored under RCRA interim status indicator evaluation requirements and for performance assessment for the low-level burial grounds under the *Atomic Energy Act of 1954* (DOE/RL-2000-72). Groundwater monitoring wells were sampled semiannually in fiscal year 2002. Appendix A, Table A.24 lists the current monitoring wells and constituents. Because of the changing flow direction and the continuing decline in water levels, this network only marginally monitors this waste management area. Wells 299-W7-8, 299-W7-9, 299-W7-11, and 299-W10-13 were not able to be sampled during fiscal year 2002 due to declining water levels. Under current flow directions (discussed in the following paragraphs), the two remaining wells, 299-W10-19 and 299-W10-20, designated as upgradient wells, remain upgradient of the east portion of the waste management area but are downgradient of the southwest part of the waste management area. No additional wells were installed in calendar year 2002.

RCRA monitoring at Low-Level Waste Management Area 3 has not detected any groundwater contamination from this facility.

An application was submitted to the Washington State Department of Ecology in June 2002 to incorporate the low-level burial grounds into the Hanford Part B RCRA permit. This would have the effect of changing the groundwater monitoring requirements for the burial grounds from interim status monitoring to final status monitoring. As part of the application, new groundwater monitoring wells, constituents, and statistical evaluations are proposed.

The groundwater flow in this portion of 200 West Area is to the east-northeast (66 degrees) with a calculated gradient of 0.0012. A series of calculations were made to fit planes to different sets of three wells in the Low-Level Waste Management Area 3 network. A gradient and flow direction was determined from each plane. March 2002 water level measurements were used in the calculations. The distribution of calculated flow directions was very narrow, so the confidence in the calculated flow direction is high (Figure 2.8-28). The flow direction is returning to the pre-Hanford conditions and will continue to change until the direction is predominately west to east. Groundwater velocity is in the range of 0.0001 to 0.12 meter per day (see Appendix A, Table A.2).

There are no indications that Low-Level Waste Management Area 3 has contributed to groundwater contamination. Indicator parameter data from upgradient wells were statistically evaluated, and values from downgradient wells were compared to values established from the upgradient wells. Contamination indicator parameters were not exceeded in any wells monitoring this waste management area during fiscal year 2002.

Nitrate and carbon tetrachloride routinely exceed the allowed maximum contaminant levels at Low-Level Waste Management Area 3. This contamination is related to widespread plumes originating to the south and are not believed to be a result of waste disposal practices at this site.

2.8.2.14 State-Approved Land Disposal Site (616-A Crib)

The Hanford Site 200 Areas Effluent Treatment Facility processes contaminated liquids from Hanford Site facilities. The treated water may contain tritium and is discharged to the State-Approved Land Disposal Site in the 200 Areas. This site is regulated by State Waste Discharge Permit ST-4500 (Ecology 2000), which is administered under WAC 173-216. The permit requires groundwater monitoring for tritium and other constituents at 22 wells (Figure 2.8-29). The groundwater monitoring requirements are defined in PNNL-13121. A discussion of fiscal year 2002 groundwater monitoring results is presented in PNNL-14038 and is summarized below.

Approximately 89 million liters of water containing 8.5 curies of tritium were discharged from the facility during fiscal year 2002. Most of the tritium was discharged during February 2002. Over 550 million liters of effluent have been discharged since the State-Approved Land Disposal Site began operating in 1995. This brings the total inventory disposed since 1995 to slightly over 334 curies. Most waste streams sent to the State-Approved Land Disposal Site are low in tritium and wastewater containing high tritium activity (e.g., the 242-A evaporator process condensate) is only processed periodically.

Eight wells in the original tritium-tracking network at the State-Approved Land Disposal Site can no longer be sampled due to declining water levels (PNNL-14038).

Groundwater Flow

The State-Approved Land Disposal Site is used to dispose treated water that occasionally contains tritium. Tritium continued to exceed the drinking water standard in nearby wells in fiscal year 2002, but no new tritium was detected in wells farther from the site.

The regional flow near the State-Approve Land Disposal Site is towards the northeast. Water levels measured during fiscal year 2002 indicate that a small groundwater mound resulting from operations at the facility persists in the vicinity of the State-Approved Land Disposal Site (see Figure 2.8-2). This mound produces a downward component to the flow. The center of the mound is not necessarily located at well 699-48-77A as shown; the location is partially an artifact of well coverage. The actual center is probably located somewhere between well 699-48-77A and the facility. The site could eventually affect groundwater quality at wells to the south of the facility, along the north boundary of the 200 West Area. It is not known exactly how far south the effluent will actually flow before turning east. Well 699-51-75 is sampled to look for the arrival of tritium downgradient from the State-Approved Land Disposal Site.

The hydraulic gradient near the State-Approved Land Disposal Site was ~0.08 to 0.8, as measured between wells 699-48-77A and 699-48-77D in March 2001 (see Appendix A, Table A.2). The gradient is probably somewhat higher between well 699-48-77A and the State-Approved Land Disposal Site.

Groundwater Contamination

Results of tritium analyses in the State-Approved Land Disposal Site tritium-tracking well network for fiscal year 2002 are shown on Figure 2.8-29. Wells close to the State-Approved Land Disposal Site (699-48-77A, 699-48-77C, and 699-48-77D) have been affected by tritium discharges from the State-Approved Land Disposal Site since 1996. Several wells along the north boundary of the 200 West Area continue to be affected by tritium from within the 200 West Area and still do not appear to be affected by the State-Approved Land Disposal Site.

Figure 2.8-30 illustrates the trends in tritium concentrations in the three State-Approved Land Disposal Site proximal wells. Well 699-48-77A was first affected by discharges in July 1996. Although this well is farthest away from the facility of the three proximal State-Approved Land Disposal Site wells, subsurface geologic features allowed the effluent to reach this well before any others (PNNL-11665; PNNL-13121). This well produced tritium concentrations two orders of magnitude lower during most of fiscal year 2002 than in fiscal year 2001. However, the concentration increased to 150,000 pCi/L in the latest sample (July 2002). The reason for this increase is most likely arrival of tritium from the February 2002 discharges to the State-Approved Land Disposal Site.

The maximum tritium result for the well nearest to the State-Approved Land Disposal Site, well 699-48-77D, in fiscal year 2002 was 240,000 pCi/L, which is down from a maximum of 280,000 pCi/L in fiscal year 2001. Well 699-48-77D is nearest the State-Approved Land Disposal Site, but showed tritium arrival ~18 months later than the more distant well 699-48-77A. The reason for this delay is related to the fact that the State-Approved Land Disposal Site drainfield fills from the south end of the facility farthest away from well 699-48-77D and the geologic features beneath the State-Approved Land Disposal Site. These two conditions are interpreted to shunt the subsurface flow of effluent away from well 699-48-77D before it reaches the water table.

Well 699-48-77C is screened ~20 meters deeper in the aquifer than wells 699-48-77A and 699-48-77D. Because of its deeper position, tritium concentrations from State-Approved Land Disposal Site operation have been historically lower in concentration and intermittent in this well until recently. During times of high discharge, the hydraulic head beneath the State-Approved Land Disposal Site is increased, and effluent is forced deeper into the aquifer. The historical high tritium concentration of 980,000 pCi/L was measured in well 699-48-77C in February 2001, indicating that the downward-moving effluent from earlier (prior to April 1999), tritium-rich discharges is still reaching this location in considerable strength. However, the trend shown in Figure 2.8-30 indicates concentrations are declining, suggesting that the highest tritium levels from the early discharges may have reached this well.

Tritium from the State-Approved Land Disposal Site appears not to have reached wells on the border of the 200 West Area. Concentrations of all constituents remained below permit limits in fiscal year 2002.

A few wells along the border of the 200 West Area, generally southeast of the State-Approved Land Disposal Site, have shown elevated concentrations of tritium as a result of historical disposal practices in the 200 West Area. No wells in the north 200 West Area show compelling evidence for the arrival of tritium from the State-Approved Land Disposal Site, although the July 2002 tritium concentrations of 790 to 860 pCi/L in samples from well 299-W7-5 were the highest on record for that well.

Concentrations of all constituents were below permit enforcement limits in fiscal year 2002. Groundwater from the State-Approved Land Disposal Site proximal wells (699-48-77A, 699-48-77C, and 699-48-77D) are analyzed for a list of 15 constituents in addition to tritium, as required by the State Waste Discharge Permit ST-4500. Enforcement limits were set for most of these constituents (acetone, benzene, total cadmium, chloroform, total copper, total lead, total mercury, pH, sulfate, tetrahydrofuran, total dissolved solids). Gross alpha, gross beta, strontium-90, and tritium are not assigned enforcement limits, but are monitored and reported. Additional parameters, such as alkalinity and dissolved oxygen, were sought for determination of general groundwater characteristics and verifying the quality of analytical results. Maximum concentrations for these constituents, and the corresponding sample months for fiscal year 2002, are listed in Table 1 of PNNL-14308.

Strontium-90 is the only radionuclide, other than tritium, that is specifically monitored at the State-Approved Land Disposal Site. Reported detections of strontium-90 are likely erroneous because the results historically have been subject to high counting errors and do not agree with independent analyses from a different laboratory which were all below detection levels.

Based on the latest arrival of elevated tritium in well 699-48-77A (between February 2002 and July 2002) and the timing of resumed tritium discharges to the State-Approved Land Disposal Site (February 2002), travel time from the facility to the well is estimated from 3 to 5 months. Actual travel time to groundwater from the facility will be less than the maximum of this range, because the effluent is thought to enter groundwater somewhere between the State-Approved Land Disposal Site and the well (PNNL-13121).

2.8.3 U Plant

U Plant refers to the area around the 221-U process canyon and associated facilities. U Plant was built to recover plutonium from irradiated fuel using the bismuth phosphate process but was never used for that purpose. The 221-U process canyon was used to recover uranium from bismuth phosphate process waste from 1952 until 1958, although ancillary facilities continued to be used after this.

The U Plant area coincides with the north part of the CERCLA 200-UP-1 Operable Unit. Groundwater monitoring in the U Plant area is largely performed under the 200-UP-1 sampling and analysis plan (DOE/RL-2002-10). RCRA groundwater monitoring is performed at the U Tank Farm and 216-U-12 crib. In addition, monitoring is also conducted to assess the performance of a pump-and-treat system near U Plant.

Monitoring Objectives Near U Plant

Groundwater monitoring is conducted near U Plant:

- triennially to semiannually to describe the nature and extent of contamination
- quarterly to assess the impact from RCRA Waste Management Area U and the 216-U-12 crib
- various time intervals to evaluate the performance of a pump-and-treat system for technetium-99 and uranium in the 200-UP-1 Operable Unit

The 216-U-1 and 216-U-2 cribs were active from 1951 through 1967, and are the major source of groundwater contamination in the U Plant area. In 1984, liquid waste disposal operations began at the 216-U-16 crib, located about 150 meters south of the 216-U-1 and 216-U-2 cribs. The effluent became perched on a caliche layer and migrated north to the 216-U-1 and 216-U-2 cribs. Waste in the soil column beneath these cribs was remobilized and reached the water table using existing groundwater monitoring wells as a pathway (WHC-EP-0133). The remobilized waste included technetium-99, uranium, iodine-129, and nitrate. Other sources of contaminants in the U Plant area also include the U Tank Farm and the 216-U-17, 216-U-8, and 216-U-12 cribs.

Interim action remediation using a groundwater pump-and-treat system is taking place in the vicinity of U Plant as part of the 200-UP-1 CERCLA operable unit. Because of the effects of remediation and past injection of treated water into the aquifer, the plume maps in this report are somewhat generalized in the area of system influence. This section discusses the contamination from the facilities in the vicinity of U Plant and includes the contamination being remediated in accordance with CERCLA as well as the specific reporting requirements for RCRA monitoring at the 216-U-12 crib and Waste Management Area U single-shell tank farm.

2.8.3.1 Groundwater Flow

Groundwater flow in the vicinity of U Plant is primarily toward the east (see Figure 2.8-2). Although water-level elevations have been falling in the 200 West Area since the 1980s, the flow direction at U Plant has changed only slightly (5 to 10 degrees) from east-southeast to a more easterly direction during this time. This is because many of the former liquid effluent disposal sites in the 200 West Area are to the west of U Plant. Groundwater flow in this area is not significantly influenced by the pump-and-treat system at the 200-UP-1 Operable Unit. This is because there are only two extraction wells compared to the six extraction and three injection wells at the 200-ZP-1 Operable Unit pump-and-treat system. Groundwater flow at the 200-UP-1 Operable Unit pump-and-treat system is discussed in Section 2.8.3.7, flow beneath the 216-U-12 crib is discussed in Section 2.8.3.8, and flow beneath Waste Management Area U is discussed in Section 2.8.3.9.

2.8.3.2 Uranium

The highest concentrations of uranium in Hanford Site groundwater in fiscal year 2002 were detected near U Plant in wells downgradient from the 216-U-1 and 216-U-2 cribs and adjacent to the 216-U-17 crib (Figure 2.8-31). Many wells in this vicinity have gone dry, so the extent of contamination is difficult to determine precisely. The maximum annual average uranium concentration detected near U Plant in fiscal year 2002 was 1,700 µg/L in well 299-W19-36, the former injection well for this site and now an extraction well brought online in December 2001. At the nearby well, 299-W19-43, uranium concentrations increased throughout the fiscal year for an average concentration of 1,350 µg/L. The uranium concentrations for several wells in the U Plant vicinity constitute dose values greater than the DOE derived concentration guide dose level. Assuming natural isotopic abundance, a uranium concentration of 790 µg/L represents the 100-millirem-per-year dose equivalent for ingestion of drinking water.

Waste sites associated with U Plant have contaminated groundwater with uranium at the highest concentrations currently detected on the Hanford Site. The current extent of contamination appears about the same as in fiscal year 2001. Carbon tetrachloride, iodine-129, nitrate, technetium-99, and trichloroethene contamination is also found in this area.

Wells near the 216-U-1 and 216-U-2 cribs showed a large pulse of uranium in the mid-1980s that was re-mobilized by effluent disposed of at the 216-U-16 crib. Trends in uranium concentrations in well 299-W19-3, immediately downgradient from the cribs, are shown in Figure 2.8-32. The uranium levels in this well decreased considerably since the maximum of 20,400 µg/L in 1986. This well is nearly dry and can no longer be sampled.

The distribution of uranium at the CERCLA 200-UP-1 Operable Unit pump-and-treat site is complicated by operation of this system. In December 2001, a former injection well at this site (299-W19-36) was converted into an extraction well. Uranium concentrations peaked in this well at 3,100 µg/L in October, prior to the start of extraction, and have been declining since (Figure 2.8-33). At well 299-W19-20, near the other extraction well (299-W19-39), uranium concentrations peaked in fiscal year 1999 at 2,800 µg/L and have been declining since (see Figure 2.8-33). Uranium concentrations near both extraction wells remain above the cleanup goal (480 µg/L). See Section 2.8.3.7 for a more thorough discussion of uranium at the pump-and-treat area.

2.8.3.3 Technetium-99

Technetium-99 typically followed uranium throughout much of the fuel cycle. Thus, a sizable technetium-99 plume is associated with the 216-U-1, 216-U-2, and 216-U-17 cribs in essentially the same location as the uranium plume (Figure 2.8-34). The distribution of technetium-99 in this vicinity is complex, in part because of the operation of the pump-and-treat system that re-injected treated water until March 1997. The maximum annual average technetium-99 concentration associated with this plume in fiscal year 2002 was 19,000 pCi/L, found in well 299-W19-43 near the extraction well 299-W19-36. Technetium-99 concentrations in most wells in the central part of the plume have declined during the period of pump-and-treat operations, however, the concentration at 299-W19-43 increased throughout fiscal year 2002 (Figure 2.8-35).

This technetium-99 plume has apparently split into two lobes, one contained by the pump-and-treat system, and one farther downgradient to the east and northeast. The depiction of the east lobe in Figure 2.8-34 is subject to uncertainty. There are few monitoring wells in this area and the downgradient well, 699-38-70, has not been sampled since March 2000. See Section 2.8.3.7 for a more thorough discussion of technetium-99 at the pump-and-treat area.

Technetium-99 concentrations are elevated in wells downgradient of Waste Management Area U, when compared to upgradient wells. However, levels are below the drinking water standard. The concentrations in three of the four downgradient wells increased slightly in fiscal year 2002, while they declined in the fourth.

2.8.3.4 Nitrate

Near U Plant, nitrate concentrations at levels greater than the maximum contaminant level is considerably more widespread than technetium-99 or uranium (Figure 2.8-36). This reflects the multiple sources of nitrate in the area. In particular, the 216-U-1, 216-U-2, 216-U-8, and 216-U-12 cribs contributed to nitrate levels above the maximum contaminant level. Nitrate sources near the REDOX Plant have also contributed to contamination in this vicinity (see Section 2.8.4.6).

The maximum nitrate concentration in fiscal year 2002 in the U Plant area was 240 mg/L in well 299-W19-20, a decline from fiscal year 2001. The main nitrate source is believed to be past disposal to the 216-U-1 and 216-U-2 cribs, the same as the technetium-99 and uranium source.

2.8.3.5 Iodine-129

Iodine-129 concentrations at levels above the drinking water standard extends from the immediate vicinity of the 216-U-1, 216-U-2, and 216-U-12 cribs to the east beyond the 200 West Area boundary (Figure 2.8-37). Downgradient, the iodine-129 plumes from U Plant operations merge with, and become indistinguishable from, the REDOX Plant plume (see Section 2.8.4.3). The highest annual average iodine-129 concentration measured in the U Plant area during fiscal year 2002 was 2 pCi/L in well 299-W22-79 downgradient from the 216-U-12 crib. The source is believed to be upgradient from this crib.

2.8.3.6 Trichloroethene

Trichloroethene concentrations in the U Plant area exceeded the maximum contaminant level of 5 µg/L in two wells, both in the vicinity of the technetium-99 and uranium plume (Figure 2.8.38). Well 299-W19-35 had a fiscal year average concentration of 8 µg/L, and well 299-W19-34B had an average of 6 µg/L. Well 299-W19-35 is screened across the water table, but well 299-W19-34B is screened between 46 and 49 meters below the water table.

Groundwater in the U Plant area is pumped and treated to reduce the highest concentration portions of the technetium-99 and uranium plumes. The system operates as an interim action until a final remedy is selected. During fiscal year 2002, 14.5 grams of technetium-99 and 26.4 kilograms of uranium were removed.

2.8.3.7 Groundwater Remediation at 200-UP-1 Operable Unit

The pump-and-treat system at the 200-UP-1 Operable Unit is located southeast of U Plant (221-U) (see Appendix A, Figure A.23). The system is designed to contain the high concentration portions of the technetium-99 and uranium plumes emanating from the 216-U-1 and 216-U-2 cribs, and to reduce the concentrations in these plumes. The specific interim remedial action objectives are listed in Table 2.1-2. Table 2.8-3 gives more detail regarding the history of operations at this site.

At the end of fiscal year 2002, technetium-99 remained above the 9,000-pCi/L remediation goal in only one monitoring well, 299-W19-43. Concentrations have also been declining rapidly at extraction well 299-W19-36 since calendar year 2000, and by the end of fiscal year 2002 the concentrations were at the remedial action objective. Uranium concentrations generally remained above the 480-µg/L remediation goal in almost all wells. The loss of many of the monitoring wells the last several years due to declining water levels has created a situation where the contaminant plumes can no longer be tracked accurately. For more detailed information about operations during fiscal year 2002, refer to DOE/RL-2002-67.[b]

Contaminant Removal

Approximately 85.8 million liters of contaminated groundwater from the 200-UP-1 Operable Unit were treated at the Effluent Treatment Facility in fiscal year 2002. A total volume of 609 million liters have been treated since startup in fiscal year 1994. The average extraction flow rate from both wells was 200 liters per minute. The amount of contamination removed this fiscal year is summarized in the following list:

- Technetium-99
    - 90.2 grams removed since startup (March 1994)
    - 14.5 grams removed during fiscal year 2002
- Uranium
    - 158.3 kilograms removed since startup
    - 26.4 kilograms removed during fiscal year 2002
- Carbon tetrachloride
    - 22.9 kilograms removed since startup
    - 2.75 kilograms removed during fiscal year 2002
- Nitrate
    - 23,200 kilograms removed since startup
    - 3,686 kilograms removed during fiscal year 2002

Table 2.8-4 shows additional detail about the amount of contamination removed since startup of operations.

Carbon tetrachloride concentrations again decreased while groundwater was transported along the 11-kilometer pipeline between the extraction well in the 200 West Area to the Effluent Treatment Facility in the 200 East Area. The dissolved carbon tetrachloride is lost to the atmosphere. Given the volume of groundwater pumped in fiscal year 2002 (88.5 million liters), the estimated amount of carbon tetrachloride mass lost to the atmosphere was 7.6 kilograms. This loss is in addition to the mass removed during treatment.

Overall Effectiveness

As of July 2002, the high concentration portions of the technetium 99 and uranium plumes were hydraulically contained (9,000 pCi/L and 480 µg/L contours, respectively). However, they were not remediated to the levels required by the interim action objectives (ROD 1997). Significant progress was made to reduce

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(b) DOE/RL-2002-67, Revision 0, Decisional Draft. 2002. *Fiscal Year 2002 Annual Summary Report for 200-UP-1 and 200-ZP-1 Pump-and-Treat Operations*. U.S. Department of Energy, Richland Operations Office, Richland, Washington.

the size and concentration of the technetium-99 plume. Less progress has been made to remediate the uranium plume because of its tendency to sorb to the soil.

The general plume configuration for both technetium-99 and uranium is similar to past years, with two distinct high concentration areas: one near extraction well 299-W19-39, and the other near monitoring well 299-W19-43 and extraction well 299-W19-36 (Figures 2.8-39 and 2.8-40). Well 299-W19-37, located about halfway between the two extraction wells, is the basis for distinguishing between these two areas because of low contaminant concentrations here (fiscal year average of <600 pCi/L technetium-99 and <270 µg/L uranium).

Several wells monitoring the progress of the 200-UP-1 pump-and-treat system have gone dry in recent years. This makes it difficult to estimate the current plume configuration.

The capability for monitoring and tracking changes in plume configuration continues to be hampered by the lack of well control in the baseline plume area (see Figures 2.8-39 and 2.8-40), even though another monitoring well, 299-W19-43, was installed at the end of fiscal year 2001. As a result, the plume maps and the discussion on the extent of remediation are based on historical information and a limited amount of data collected in fiscal year 2002. Only three monitoring wells are still viable within the original baseline plume area: 299-W19-20, 299-W19-37, and 299-W19-43. These wells span the target remediation area between the two extraction wells. Additional wells are planned to be installed during fiscal year 2003 and beyond to provide more complete coverage of the plumes.

To accelerate remediation in the upgradient plume area, well 299-W19-36 was converted to an extraction well in fiscal year 2002 and tied into the same cross-site transfer line as well 299-W19-39 for transporting contaminated groundwater to the Effluent Treatment Facility for treatment and disposal. To accelerate remediation, monitoring well 299-W19-43 will also be converted to an extraction well in fiscal year 2003.

Technetium-99. Technetium-99 has declined consistently in response to remediation efforts. The remedial action objective of 9,000 pCi/L is thought to have been met in all wells except in upgradient monitoring well 299-W19-43 and extraction well 299-W19-36 (see Figures 2.8-35 and 2.8-39). For the extraction well, concentrations at the beginning of the fiscal year were 20,000 pCi/L. By the end of the fiscal year, concentrations were 8,915 pCi/L (averaged duplicate) bordering on the remedial action objective. This rapid decline contrasts with a peak concentration of 27,700 pCi/L in November 2000. At monitoring well 299-W19-43, technetium-99 concentrations were measured at 14,700 pCi/L in October 2001 and had increased to 22,400 pCi/L in August 2002.

Technetium-99 concentrations at extraction well 299-W19-39 (see Figure 2.8-39) are below the remedial action objective but above the drinking water standard, and have been relatively constant since 1999. The last sample result in fiscal year 2002 was 1,160 pCi/L.

Contaminant concentrations at downgradient well 299-W19-40 ranged between 186 and 264 pCi/L for fiscal year 2002, thus indicating that extraction well 299-W19-39 is containing the high concentration area of the plume. This conclusion is further substantiated by the relatively low concentrations measured at cross-gradient monitoring wells 299-W19-35 (northeast, 615 pCi/L) and 299-W19-38 (southwest, currently dry, 771 pCi/L in fiscal year 2000).

The pump-and-treat system appears to have remediated most of the technetium-99 to below its target level. The system has been less successful for uranium.

Uranium. Uranium concentrations have declined in response to remediation efforts, but are still above the 480-µg/L remedial action objective in most monitoring wells located within the baseline remediation area (see Figure 2.8-40). Only a few monitoring wells are still available to evaluate contaminant concentrations. The remedial action objective has been met in only one active monitoring well within the target remediation area, well 299-W19-37. All wells outside of the targeted remediation area are also below the remedial action objective.

Concentrations have declined slowly but steadily since 1997 at extraction well 299-W19-39. Initial levels were as high as 366 μg/L in 1997 but have decreased to 134 μg/L at the end of fiscal year 2002. While uranium has never been above the remedial action objective at extraction well 299-W19-39, it is above the remedial action objective of 480 μg/L at nearby monitoring well 299-W19-20. Uranium has declined rapidly in well 299-W19-20, from 2,800 μg/L in 1999 to 581 μg/L in fiscal year 2002.

Uranium increased significantly at extraction well, 299-W19-36, rising from 170 μg/L in January 2000 to 3,110 μg/L in early fiscal year 2002 prior to the start of pumping (see Figure 2.8-33). In August 2002, the concentration had declined to 969 μg/L. Prior to going dry in 1999, two upgradient monitoring wells were also above the remedial action objective: wells 299-W19-28 (560 μg/L) and 299-W19-29 (1,335 μg/L). Concentrations were steady or increasing at that time.

Uranium concentrations have never been above 480 μg/L at downgradient monitoring well 299-W19-40. During startup of operations (1995), uranium values changed rapidly, decreasing from near 300 μg/L to around 140 μg/L (mid-1996). They have remained at about this level for the last 5 years (there was a slight increase from 1998 to 2000 to ~190 μg/L).

In summary, most of the high concentration portion of the technetium-99 plume in the southeast 200-UP-1 Operable Unit appears to have been remediated to below the 9,000 pCi/L remedial action objective. An area of high concentration is still present in the upgradient portion of the plume near extraction well 299-W19-36 and monitoring well 299-W19-43. Technetium-99 concentrations reached 27,700 pCi/L at well 299-W19-36 in November 2000, but are now are now on a steep downward trend. By contrast, technetium-99 concentrations have increased to 22,400 pCi/L at well 299-W19-43.

Uranium concentrations are above the 480-μg/L remedial action objective in only one well, 299-W19-20, near extraction well 299-W19-39; however, most monitoring wells have gone dry, and the plume configuration at this time can only be estimated using historical data. Total uranium in well 299-W19-36 has risen rapidly as groundwater diluted by previous injection of treated effluent now moves downgradient. For a detailed discussion on the likely reason why contaminant concentrations have increased so dramatically, refer to DOE/RL-2001-53.

Water-Level Impact and Capture-Zone Analysis

Based on water-level data collected during fiscal year 2002, the water table beneath the 200-UP-1 Operable Unit declined at a rate of 0.36 meter per year (DOE/RL-2002-67). This is slightly less than the rate of 0.4-meter-per-year rate calculated in fiscal year 2001. The decrease in water level resulted in the loss of well 299-W19-38 from the sampling network in fiscal year 2001. This well will be replaced with a new nearby monitoring well in fiscal year 2003.

The radius of influence of extraction well 299-W19-39 is estimated at ~205 meters, somewhat more than the 155 meters calculated in fiscal year 2001. The extraction well appears to be capturing the targeted plume area based on drawdown detected in observation wells located outside of the targeted remediation area, previous modeling results, and the low concentrations of contaminants in downgradient well 299-W19-40 (DOE/RL-2000-71). However, the limited monitoring network is not robust enough to confirm that interior plume concentrations are below the remedial action objectives.

2.8.3.8 216-U-12 Crib

The 216-U-12 crib is located ~600 meters south of U Plant in the southeast portion of the 200 West Area. The crib is an unlined, gravel-bottom, percolation crib 3 meters by 30 meters, and 4.6 meters deep. The crib received process effluent from U plant, including the 224-U Building, and operated from 1960 through 1972 and from 1981 until February 1988.

Groundwater Flow

The 216-U-12 crib is a RCRA facility that has contributed to groundwater contamination in the U Plant area. Nitrate and technetium-99 are elevated in downgradient wells. Concentrations of these contaminants are generally declining.

Based on regional groundwater elevations, the direction of groundwater flow continues relatively unchanged to the east-southeast to east (see Figure 2.8-2). The pre-Hanford flow direction in the vicinity of the 216-U-12 crib is believed to have been from west to east, and it is expected that groundwater flow will eventually return to a more easterly direction. Groundwater flow rates have not changed significantly since last year and range from 0.02 to 0.08 meter per day (see Appendix A, Table A.2).

No changes in the number of network monitoring wells occurred during fiscal year 2002. Declining water levels in the 200 West Area have reduced the 216-U-12 crib monitoring network from the original four wells to just two downgradient wells (299-W22-79 and 699-36-70A), which is fewer than the minimum required number of wells. These wells are sampled quarterly for the constituents of interest (see Appendix A, Table A.17). The Washington State Department of Ecology and DOE annually negotiate installation of future monitoring wells under interim milestone agreement M-24-00M (Ecology et al. 1998).

Groundwater Contamination

The 216-U-12 crib is the source of elevated nitrate and technetium-99 that have been detected in downgradient wells. The regional nitrate and technetium-99 plumes are a co-mingled series of smaller plumes with sources from several cribs (216-U-1, 216-U-2, 216-U-8, and 216-U-12) in the U Plant area. Iodine-129 and tritium were detected repeatedly in several monitoring wells downgradient from the 216-U-12 crib, but the sources appear to be the REDOX Plant effluent disposal cribs that are upgradient of the 216-U-12 crib. These plumes are discussed further in Section 2.8.4.

Technetium-99 concentrations ranged from 12 to 76 pCi/L in the two downgradient wells during fiscal year 2002, which is well below the 900-pCi/L drinking water standard (Figure 2.8-41). Technetium-99 concentration trends in both wells have remained relatively stable over the past 2 years.

RCRA Assessment Summary

The 216-U-12 crib was placed in assessment monitoring because of elevated specific conductance in downgradient wells 299-W22-41 and 299-W22-42 in 1993 (WHC-SD-EN-AP-108). The results and findings of the assessment monitoring program are presented in PNNL-11574. The elevated levels of specific conductance in the downgradient wells are attributed to calcium and nitrate. These findings show that the crib contributed to groundwater contamination and must remain in interim status assessment monitoring. The objective of the assessment monitoring is to evaluate the flux of constituents into the groundwater beneath the crib and monitor these constituents until a corrective action is defined or a final status monitoring plan is implemented for the crib. This site continued to be monitored quarterly under a RCRA assessment monitoring program during fiscal year 2002. The RCRA assessment monitoring well network and analyte lists for this site are provided in Appendix A, Table A.17.

Some of the wells in the 216-U-12 monitoring network have gone dry in recent years. The network currently includes only two wells.

The assessment indicator parameter, specific conductance, remained below the 457-µS/cm critical mean value in well 299-W22-79 and remained above the critical mean value in 699-36-70A (ranging from 530 to 537 µS/cm) during fiscal year

2002. Nitrate was detected at levels greater than the 45-mg/L maximum contaminant level in both downgradient wells 299-W22-79 and 699-36-70A during fiscal year 2002. In downgradient well 299-W22-79, nitrate concentrations increased throughout the fiscal year (ranging from 45 mg/L to 69.5 mg/L), whereas the trend in the far field well, 699-36-70A, has declined steadily (currently at 82 mg/L) (Figure 2.8-42). Additional information on the groundwater quality at this site can be found above in the "Groundwater Contamination" section.

2.8.3.9 Single-Shell Tank Waste Management Area U

Waste Management Area U, located in the central portion of the 200 West Area, consists of 16 single-shell underground storage tanks, 8 diversion boxes, and associated pipelines and valve boxes. The tanks received high-level radioactive liquid wastes from T Plant, U Plant, and REDOX Plant between 1946 and 1980.

Groundwater Flow

Groundwater flow conditions at Waste Management Area U have varied greatly over the past several decades because of changing wastewater disposal in areas surrounding the waste management area. Since 1996, groundwater flow has been generally to the east (see Figure 2.8-2). During fiscal year 2002, the groundwater flow direction and rate have remained the same as in the previous year, but the rate at which the water table is dropping has decreased from ~0.4 to ~0.3 meter per year. The groundwater flow velocity is ~0.08 meter per day, calculated based on a hydraulic conductivity of 6.12 meters per day, a specific yield of 0.17 determined in well 299-W19-42 (PNNL-13378), and a gradient of 0.0021 (see Appendix A, Table A.2).

Measured water-level elevations in the new upgradient well, 299-W18-40, located on the southwest corner of the waste management area were anomalously low (by about ~0.3 meter) when compared to water levels in the other upgradient well (299-W18-31), previous trends in well 299-W18-25, which the new well replaced, and regional trends in the water table. The surveyed casing elevation and the water-level elevation calculations were determined to be correct. A gyroscopic survey of the well showed that the horizontal elevation from vertical was 7.3 meters at the bottom of the well resulting in a 0.37-meter vertical correction in the water-level measurements. The corrected water levels are consistent with regional trends and other water levels measured in the waste management area.

Fiscal year 2002 data continued to indicate that Waste Management Area U has contaminated the groundwater with nitrate and technetium-99.

Groundwater Contamination

Concentration trends for technetium-99 and nitrate (Figures 2.8-43 and 2.8-44) indicate that the waste management area continues to affect groundwater quality with increasing concentrations of these constituents. Technetium-99 and nitrate continued to rise in well 299-W19-12, but technetium-99 concentrations dropped in well 299-W19-41, indicating that the area affected by the waste management area has shifted to the north. Because nitrate concentrations continued to rise in well 299-W19-41 during the year while technetium-99 concentrations decreased, it appears that these constituents have separate sources within the waste management area.

Carbon tetrachloride is the only constituent found in Waste Management Area U at concentrations above the maximum contaminant level of 5 µg/L. While the concentrations are higher on the downgradient side of the waste management area, carbon tetrachloride is found at concentrations of 100 to 200 µg/L in the two upgradient wells. The regional carbon tetrachloride distribution (see Figure 2.8-3) indicates that the carbon tetrachloride found in the Waste Management Area U vicinity originates from liquid waste disposal sites associated with the Plutonium Finishing Plant located northwest of the waste management area.

The vertical variation in groundwater chemistry was evaluated in fiscal year 2002 using a specific conductance probe. Since the known contamination attributed to the waste management area contains elevated levels of nitrate and other major ions that could be detected as an increase in specific conductance, variations in specific conductance with depth would indicate plume stratification. The probe was lowered into three wells, 299-W19-12, 299-W19-41, and 299-W19-44, located on the downgradient side of the waste management area. The results indicated that there was little variation in specific conductance throughout the screened interval below the water table and the measured values were consistent with the specific conductance measured in the most recently collected water samples.

At Waste Management Area U, the vertical variation in groundwater chemistry was evaluated in fiscal year 2002 using a specific conductance probe. Results indicated that there was little variation in specific conductance throughout the screened interval below the water table

RCRA Assessment Summary

Waste Management Area U was placed into assessment status in 2000 when specific conductance in groundwater monitoring wells downgradient of the waste management area exceeded upgradient levels (PNNL-13185). An assessment of that finding determined that the waste management area had affected groundwater quality with elevated concentrations of nitrate and possibly chromium in wells downgradient of the waste management area (PNNL-13282). The contaminant concentrations did not exceed their respective maximum contaminant levels, and the area affected appeared to be limited to the southeast corner of the waste management area. A groundwater quality assessment plan (PNNL-13612) was prepared in 2001.

The only hazardous waste constituents detected at Waste Management Area U are carbon tetrachloride and chromium. The source of carbon tetrachloride is upgradient of the waste management area and will not be discussed further. The rate of movement of chromium in groundwater beneath the waste management area is considered equal to the rate of groundwater flow which has been estimated to be ~0.08 meter per day. Chromium is detected in all wells in the network due to a regional background presence at ~5 μg/L, but it is found at elevated but decreasing concentrations (21 to 16 μg/L) only on the southeast corner of the waste management area (well 299-W19-41). Because the chromium concentrations have been decreasing since 1999, it appears that the source of chromium has been significantly changed or depleted. Additional information on the groundwater quality at this site can be found above in the "Groundwater Contamination" section.

2.8.4 REDOX Plant

The REDOX Plant was used for separating plutonium from irradiated fuel from 1951 through 1967. Groundwater plumes, originating in the vicinity of the REDOX Plant and its associated waste storage and disposal facilities, include chromium, iodine-129, nitrate, technetium-99, trichloroethene, tritium, and uranium at levels above the maximum contaminant levels/drinking water standards. Strontium-90 was detected at levels above the drinking water standard in only one well in this area in fiscal year 2002.

The REDOX Plant area coincides with the middle and south part of the CERCLA 200-UP-1 Operable Unit. Groundwater monitoring is performed under the 200-UP-1 sampling and analysis plan (DOE/RL-2002-10). Two RCRA treatment, storage, and disposal facilities in this vicinity, Waste Management Area S-SX, and 216-S-10 pond and ditch, have groundwater monitoring requirements. Other facilities appear to have produced the major part of the groundwater contamination, though high concentrations of technetium-99 and other contaminants are attributed to leaking tanks or associated piping in Waste Management Area S-SX.

2.8.4.1 Groundwater Flow

The direction of groundwater flow in the south portion of the 200 West Area is principally toward the east (see Figure 2.8-2). Over the past decade, flow in this area has changed by ~30 degrees from a southeasterly direction to mostly east in response to decreased effluent discharges in the 200 West Area. Groundwater flow beneath Waste Management Area S-SX is discussed in Section 2.8.4.9, and flow beneath the 216-S-10 pond and ditch is discussed in Section 2.8.4.10.

Monitoring Objectives Near REDOX Plant

Groundwater monitoring is conducted near the REDOX Plant:

- triennially to semiannually to describe the nature and extent of contamination
- semiannually to detect the possible impact of one RCRA waste management area
- quarterly to assess contamination from one RCRA waste management area

2.8.4.2 Tritium

A tritium plume extends eastward from the vicinity of the REDOX Plant in the south 200 West Area (Figure 2.8-45). The east part of the plume curves to the north, but the tritium concentrations in the north part of this plume are declining, as illustrated by the tritium trend plot for well 699-38-65 (Figure 2.8-46). Concentrations are changing slowly to the east and appear to be declining in some wells to the south and in the center of the plume. The overall picture is of a plume that has nearly stopped spreading in most directions and has started to contract in some areas as radioactive decay dominates over the hydrologic transport. Slowly increasing concentrations are still seen in the east part of the plume. Movement within this tritium plume is expected to be slow because of the low-permeability sediment at the 200 West Area and the lower hydraulic gradient due to dissipation of the groundwater mound beneath the 200 West Area since the reduction of effluent discharge.

The tritium plume from the south 200 West Area extends to US Ecology's low-level radioactive waste disposal facility. The maximum tritium concentration detected in groundwater at that facility is in a well located on the west (upgradient) side of the facility. The fiscal year 2002 average concentration in this well (699-35-59, US Ecology well 13) was 5,680 pCi/L, down slightly from the fiscal year 2001 average concentration of 5,870 pCi/L. However, the historical trend at this well is increasing tritium concentrations due to transport from the 200 West Area. These data were provided by US Ecology and are not included in the data files included with this report.

Tritium was found above the drinking water standard near the 216-S-25 crib and Waste Management Area S-SX (Figure 2.8-47). The source of tritium in this area is attributed to the past-practice disposal sites (e.g., 216-S-4, 216-S-21, 216-S-25 cribs). Tritium concentrations in well 299-W23-9, located near the 216-S-25 crib, have fluctuated from a high of 576,000 pCi/L to a low of 95,600 pCi/L since 1990. The fiscal year 2002 average concentration was 300,000 pCi/L up from 190,000 pCi/L in fiscal year 2001.

Waste sites associated with the REDOX plant have contributed to chromium, iodine-129, technetium-99, trichloroethene, tritium, and uranium plumes in groundwater. Contaminant concentrations increased in some wells near Waste Management Area S-SX.

2.8.4.3 Iodine-129

An iodine-129 plume from the 200 West Area extends into the 600 Area to the east and coincides with the tritium plume originating near the REDOX Plant (see Figure 2.8-37). This iodine-129 plume and the iodine-129 contamination originating farther north near U Plant appear to combine downgradient and become indistinguishable at the current level of monitoring detail. The maximum iodine-129 concentration detected in this plume in fiscal year 2002 was 30 pCi/L in well 699-35-70, nearly the same as the fiscal year 2001 value of 31 pCi/L. Iodine-129 concentrations in this well have not changed significantly in the last decade.

2.8.4.4 Technetium-99

Technetium-99 continued to be found at levels above the drinking water standard in some small plumes located near Waste Management Area S-SX (Figure 2.8-48). Evidence from recent years suggests that multiple sources of technetium-99 in the Waste Management Area S-SX Tank Farm contribute to groundwater contamination (PNNL-11810). The 216-S-13 crib may have contributed to the technetium-99 detected further downgradient of Waste Management Area S-SX, but well 299-W22-21, located next to the 216-S-13 crib, can no longer be sampled due to the declining water table. There is a scarcity of wells to track the migration of technetium-99 downgradient of Waste Management Area S-SX, though recently drilled monitoring wells 299-W22-82 and 299-W22-83 provide some information. Technetium-99 in the vicinity of Waste Management Area S-SX is discussed in Section 2.8.4.9.

Multiple sources of technetium-99 in the Waste Management Area S-SX Tank Farm contribute to groundwater contamination.

2.8.4.5 Strontium-90

Strontium-90 was detected at levels above the 8-pCi/L drinking water standard in only one well in the 200 West Area. This well, 299-W22-10, is located downgradient of the 216-S-1 and 216-S-2 cribs, east of the SX Tank Farm (Figure 2.8-49). A strontium-90 concentration of 76 pCi/L was reported in the sample from 2002. Strontium-90 has been elevated in this well at about this level since fiscal year 2000.

2.8.4.6 Nitrate

Nitrate was detected in fiscal year 2002 above the maximum contaminant level in two small plumes in the vicinity of the REDOX Plant. The first plume is located near the 216-S-20 crib, which received laboratory waste from the 222-S Building (see Figure 2.8-36). Lower concentrations of nitrate also are associated with the tritium and iodine-129 plumes extending to the east of the REDOX Plant.

Nitrate was detected above the maximum contaminant level in well 299-W23-9 near the 216-S-25 crib and extends past Waste Management Area S-SX (see Figures 2.8-36 and 2.8-50). Nitrate appears to be associated with the technetium-99 plumes in this vicinity. In particular, 620 mg/L of nitrate was detected in well 299-W23-19, located in the southwest corner of Waste Management Area S-SX. This result is up from the 580 mg/L result for fiscal year 2001. The nitrate in this well is much higher than concentrations upgradient so it is likely that the tank farm also is contributing to the nitrate contamination. Nitrate levels are considerably lower in wells downgradient of the tank farm.

2.8.4.7 Chromium

In well 299-W22-20, downgradient of the 216-S-20 crib, the chromium concentration increased to 381 µg/L, up from the fiscal year 2001 result of 161 µg/L. The crib is the probable source, but this conclusion is not definitive due to the lack of upgradient wells. The chromium concentration at this well had declined from 339 µg/L in 1988 to 35 µg/L in 1997, before beginning to increase. Chromium in Waste Management Area S-SX is discussed in Section 2.8.4.9, and chromium at the 216-S-10 pond and ditch is discussed in Section 2.8.4.10. There may be a relationship between chromium disposed of at the REDOX Plant disposal sites south and southwest of the 200 West Area and chromium detected south and southeast of the 200 West Area. This is discussed in Section 2.8.4.11.

2.8.4.8 Trichloroethene

A small trichloroethene plume, with concentrations above the maximum contaminant level (5 µg/L), is found east of the REDOX Plant. The 216-S-20 crib is a likely source of the trichloroethene plume. In fiscal year 2002, the trichloroethene concentration increased to 15 µg/L in well 299-W22-20, up from 9.4 µg/L the previous year.

2.8.4.9 Single-Shell Tank Waste Management Area S-SX

Waste Management Area S-SX, located in the southwest corner of 200 West Area, consists of two single-shell tank farms and associated diversion boxes, pipelines, and valve boxes. The S Tank Farm in the north half of the waste management area contains 12 underground storage tanks, and the SX Tank Farm in the south half of the area contains 15 underground storage tanks. The tanks received high-level radioactive liquid wastes from the REDOX process in S Plant between 1952 and 1966 (LA-UR-96-3860), and some of the tanks are known to have leaked in the past.

At Waste Management Area S-SX, technetium-99 and other contaminants continued to increase in a well adjacent to a tank that is known to have leaked in the past. Technetium-99 concentrations reached 99,700 pCi/L, the highest levels detected in Hanford Site groundwater in fiscal year 2002.

Groundwater Flow

During fiscal year 2002, the groundwater flow direction and rate have remained the same as in the previous year. Estimates of the rate of groundwater flow, using travel times for tritium and technetium-99 between monitoring wells in the vicinity of Waste Management Area S-SX, suggest groundwater flow rates of 25 to 50 meters per year or 0.07 to 0.14 meter per day. Calculated Darcy flow rates (see Appendix A, Table A.2) based on hydraulic conductivity and tracer test data, also suggest similar flow rates (0.009 to 0.36 meter per day).

The water table declined equally across the waste management area during fiscal year 2002, so the hydraulic gradient is stable. The rate at which the water table is dropping is estimated at 0.33 meter per year. This rate of decline is less than that reported previously (~0.6 meter per year) and indicates that the impacts of past liquid disposal in the area are lessening. The groundwater flow direction inferred from water-table elevation contours suggests an east-southeast flow direction over the larger area around the waste management area (see Figure 2.8-2). This direction of flow is consistent with the shape of the contaminant plume on the south side of the waste management area and the direction in which it is migrating.

Groundwater Contamination

Groundwater beneath this waste management area is contaminated with nitrate, technetium-99, and hexavalent chromium attributed to two general source areas within the waste management area (see Figures 2.8-36 and 2.8-48). One source area is in the S Tank Farm and one is to the south in the SX Tank Farm. Tritium and carbon tetrachloride plumes are also present in groundwater beneath the waste management area, but their sources are upgradient of the waste management area (see Figures 2.8-3 and 2.8-47).

The north plume with an apparent source in the S Tank Farm has migrated eastward through well 299-W22-48, where chromium and nitrate concentrations have leveled off at ~40 µg/L and 73 mg/L, respectively. Technetium-99, another constituent of the plume, has a trend similar to that of chromium and nitrate where concentrations have leveled off at ~4,500 pCi/L. The similar trends of these three constituents as shown in Figure 2.8-51 indicate that they likely have the same source. The bulk of the contaminant plume responsible for these observations is limited to an area between well 299-W22-44 on the north and well 299-W22-81 on the south. Chromium concentrations have been below or near the detection limit in both of these bounding wells, and nitrate concentrations have been at 25% to 50% of the levels found in well 299-W22-48. Technetium-99 concentrations in the two bounding wells remained at less than 15% of those concentrations found in well 299-W22-48. Both nitrate and technetium-99 concentrations in well 299-W22-44 increased similarly as they did in well 299-W22-48, but at lower concentrations. These observations indicate that the plume centerline may be between wells 299-W22-48 and 299-W22-44.

The contaminant plume located on the south portion of the waste management area continues to slowly spread downgradient from its source, the SX Tank Farm. This plume is comprised of nitrate, chromium, and technetium-99 just like the S Tank Farm plume to the north. The shape of the plume has changed little during fiscal year 2002, but the extent of the plume changed significantly on the downgradient margin and significant changes in constituent concentrations within the plume were detected in several of the monitoring wells. The extent of this south contaminant plume was delineated by monitoring wells on all margins at the start of fiscal year 2002. During the year, the plume remained narrow in extent, but the downgradient migrating front, as indicated by nitrate and technetium-99 concentrations, has moved through and beyond the farthest downgradient monitoring well 299-W22-83 (Figure 2.8-52). Nitrate concentrations in well 299-W22-83 have nearly doubled to ~20 mg/L and technetium-99 concentrations have more than tripled to 1,750 pCi/L during fiscal year 2002.

Chromium, nitrate, and technetium-99 concentrations increased sharply in a well downgradient of the S Tank Farm. This new contaminant occurrence is believed to represent a vadose zone source remaining after a past leak or spill.

Within the south plume, concentrations of the major constituents used to define the plume, nitrate, technetium-99, and chromium, changed significantly in the source area as represented by well 299-W23-19 (Figure 2.8-53) and in the middle of the plume as represented by well 299-W22-46 (Figure 2.8-54). In well 299-W23-19, both nitrate and technetium-99 increased from their lowest concentrations ever reported for the well in March 2002 to their highest concentrations ever reported in June 2002. Almost identical trends have been observed for calcium, magnesium, chloride, and non-radioactive strontium. There are no known changes in tank farm operations or water releases at the site that precede these large fluctuations and would thereby account for these changes in concentrations. Since multiple constituents with differing analytical techniques produce the same varying trend, analytical errors can be eliminated as the cause.

There are two possibilities regarding the observed constituent fluctuations in well 299-W23-19: (1) they are due to actual temporal variations in the contaminant plume or, (2) they result from spatial variations in the contaminant plume (i.e., vertical stratification) combined with differences in sampling technique. This well is located inside the SX Tank Farm, and was constructed following a decision to complete a soil boring as a groundwater monitoring well. Since the start of routine sampling in early 2000, a portable submersible pump has been used to sample the well. The pump has to be lowered into the well for each sample event, creating the possibility that different sampling conditions might result from different placements of the pump. Plans are underway to re-configure the wellhead and install a permanent pump to reduce the number of sampling variables.

To test the possibility that constituent fluctuations in well 299-W23-19 arise from vertical stratification of the plume along with differences in sampling pump placement, specific conductance was measured at half-meter intervals throughout the saturated screened interval using a specific conductance probe. Specific conductance is a measure of the quantity of the major ions such as calcium, magnesium, chloride, and nitrate in the water. Because these constituents follow the same trend as that of technetium-99, specific conductance serves as a quick, easily measured indicator of the plume location. Specific conductance profiles were collected on September 20, 2002 (a failed sampling attempt), and again on October 10, 2002 (a successful sampling event). Both profiles are shown in Figure 2.8-55. These data show that the aquifer chemistry differed greatly between the two dates even though the profiles were collected only 20 days apart. The September data reflect lower concentrations, similar to that found in previous low concentration periods shown in Figure 2.8-53, that were stable throughout the screened interval. The October data reflect the higher concentrations found in previous samples, but they also indicate that plume concentrations vary significantly throughout the screened interval. Figure 2.8-55 also shows that the sample collected using the portable submersible pump in October 2002 had a specific conductance that was consistent with the profile measurements, indicating that disturbances of the aquifer by lowering the sampling pump into the groundwater are minimal. These results show that temporal variations in the plume largely explain the observed constituent fluctuations, but vertical stratification is also a factor. Studies of the temporal and spatial variability of the plume in well 299-W23-19 will continue in order to determine where to set the pump intake for future samples.

Based on the groundwater data collected to date, only the more mobile tank waste constituents (e.g., hexavalent chromium, nitrate, technetium-99, and tritium) have reached groundwater beneath Waste Management Area S-SX.

The south contaminant plume at Waste Management Area S-SX contains chromium, but historical concentrations in well 299-W23-19 do not follow the same trend as for nitrate, technetium-99 (see Figure 2.8-53), or the other four constituents discussed previously. It appears that after March 2001, the chromium concentration trend in well 299-W23-19 began to deviate from the trend for the other constituents. At the same time, chromium began to increase in the middle of the plume, as indicated by well 299-W22-46, downgradient from well 299-W23-19 (see Figure 2.8-54). These data indicate that chromium may be from a different source within Waste Management Area S-SX than the nitrate and technetium-99.

RCRA Assessment Summary

Waste Management Area S-SX was placed into assessment status in 1996 at the direction of the Washington State Department of Ecology because of elevated specific conductance in downgradient monitoring wells. A groundwater quality assessment plan (WHC-SD-EN-AP-191) was prepared in 1996 and the planned assessment work conducted in 1996 and 1997. This assessment determined that multiple sources within the waste management area had affected groundwater quality with elevated concentrations of nitrate and chromium in wells downgradient of the waste management area (PNNL-11810). A second groundwater quality assessment plan (PNNL-12114) was prepared in 1999 to further evaluate the contamination. Since that time, two groundwater quality assessment reports were published (PNNL-13441; PNNL-13801) covering the time period from November 1997 through December 2001 and the assessment plan was revised twice to account for new wells added to the monitoring network and revisions to the sampling and analysis schedule. The current well network and monitoring schedule are reported in Appendix A, Table A.35.

RCRA assessment monitoring continued at Waste Management Area S-SX in fiscal year 2002. Chromium is the only hazardous, non-radioactive contaminant that appears to have its origin within the waste management area.

The only hazardous waste constituents detected at Waste Management Area S-SX are carbon tetrachloride and chromium. The distribution of carbon tetrachloride shown in Figure 2.8-3 indicates that carbon tetrachloride has migrated from a source north of the waste management area, down the west side, and then around the south side of the waste management area. Because the carbon tetrachloride found in monitoring wells at the waste management area is from an upgradient source, it will not be discussed further.

Chromium is found in both plumes emanating from the waste management area. Chromium is found in all wells except well 299-W22-84 due to a regional background presence at ~2 to 4 µg/L. Chromium concentrations within the plumes were below the maximum contaminant level of 100 µg/L in all monitoring wells, but it was found to be increasing in wells 299-W22-46 and 299-W22-50 located in the middle of the south plume and in well 299-W22-83 on the downgradient margin of the plume. At the same time, chromium concentrations decreased in well 299-W23-19, thought to be near the source of the plume. These observations indicate that the chromium source for the south plume may consist of a short-term pulse that is now migrating downgradient. Chromium concentrations have stabilized at ~40 µg/L in the north plume. Additional information on the groundwater quality at this site can be found above in the “Groundwater Contamination” section.

2.8.4.10 RCRA Parameters for 216-S-10 Pond and Ditch

The 216-S-10 pond and ditch was active from 1951 through 1991, and received effluent primarily from the REDOX plant chemical sewer. The site is monitored semiannually under RCRA interim status indicator evaluation (see Appendix A). An updated and revised RCRA groundwater monitoring plan, PNNL-14070, was published in October 2002. RCRA groundwater monitoring has been conducted in accordance with interim status requirements since 1991. The site is also within the CERCLA 200-UP-1 Operable Unit. The 216-S-10 facility has not received liquid waste since October 1991 and is scheduled to be closed under a Part B Permit after 2006 in accordance with the Tri-Party Agreement (Ecology et al. 1998) Permit modification schedule, and in accordance with a CERCLA record of decision.

Statistical comparisons of RCRA indicator parameters at the 216-S-10 pond and ditch provide no evidence of groundwater contamination from this facility.

The updated groundwater monitoring plan (PNNL-14070) proposes a revised well network and list of constituents based on the knowledge gained from monitoring data collected over the past eleven years for this site. It also provides the current interpretation of groundwater flow and potential for contamination occurrence. Additionally, a conceptual model of contaminant transport through the vadose zone beneath the S-10 facility is presented in the plan to assist in developing an appropriate and cost-effective monitoring approach for this facility.

Since 1992, statistical evaluations of indicator parameters have not indicated that the 216-S-10 facility has affected groundwater quality in the uppermost aquifer beneath the site (see Appendix A). The only exceedance of maximum contaminant levels occurred in the shallow upgradient well 299-W26-7 for hexavalent chromium (currently just below the maximum contaminant level), and in the deep well 299-W27-2 for carbon tetrachloride. Nickel also is elevated in well 299-W27-2. The carbon tetrachloride is believed to have come from an upgradient source. The source of nickel is unknown, but it might be related to corrosion of the well casing or screen. The long, gradual increase in nickel concentrations, followed by a downward trend, suggests this occurrence is not an analytical or sampling artifact (Figure 2.8-56).

Chromium concentrations in well 299-W26-7 have varied in the past 10 years (Figure 2.8-57). This may be caused by short-term releases migrating through the vadose zone. For example, historical records document a 1983 release to the 216-S-10 facility of a high-salt waste (simulated tank waste) containing hexavalent chromium. Although well 299-W26-7 is designated an upgradient well, it is located very close to one lobe of the pond system and could easily have been impacted by drainage spreading laterally in the vadose zone (see Appendix A, Figure A.7). Fiscal year 2002 chromium values ranged from 11 µg/L up to 96 µg/L; however, this well is nearly dry, which could impact measured chromium concentrations. Nitrate (co-contaminant) concentrations are covariate with chromium concentrations in wells 299-W26-7, 299-W26-9, 299-W26-10, and 299-W26-12 (e.g., Figure 2.8-58). The upgradient well 299-W26-7 has the highest nitrate concentrations. This and other data presented in PNNL-14070 suggests that the 216-S-10 pond could be the source of this latest chromium increase.

The water table beneath the 216-S-10 pond and ditch continued to decline in fiscal year 2002. The current RCRA monitoring network consists of only two wells (the others having gone dry): one upgradient (299-W26-7) and one downgradient (299-W26-13). The upgradient well is expected to go dry during fiscal year 2003. RCRA requirements for interim status monitoring specify that a minimum of one upgradient and three downgradient monitoring wells are needed to monitor the site. The updated groundwater monitoring plan, PNNL-14070, proposes to install one new downgradient well in 2003 and deepen two existing dry wells to bring the facility back in compliance with RCRA requirements. The Washington State Department of Ecology, DOE, and EPA will negotiate installations of future monitoring wells under the Tri-Party Agreement Milestone M-24-00 (Ecology et al. 1998).

Many monitoring wells at the 216-S-10 pond have gone dry, leaving just one upgradient and one downgradient well. One new well will be installed in 2003, and two dry wells may be deepened.

Based on regional groundwater elevations, the groundwater flow direction continues toward the east-southeast. Groundwater flow rates have not changed significantly since last year (see Appendix A, Table A.2). Background values of contaminant indicator parameters for the facility have been re-calculated based on one upgradient well, 299-W26-7.

2.8.4.11 Central 600 Area

Chromium is frequently detected in filtered samples east and southeast of the 200 West Area. The concentration in well 699-32-62 was 200 μg/L in fiscal year 2000, which is twice the maximum contaminant level (see Figure 2.2-2 for well locations in the 600 Area). This well was not sampled in fiscal years 2001 or 2002, and is next scheduled for sampling in fiscal year 2003. The chromium concentrations have declined slowly since it was first analyzed for in 1992. The sources and extent of this contamination are uncertain. The location of this plume is consistent with disposal to the REDOX ponds/ditches south and southwest of the 200 West Area. Chromium is detected in several other wells in this area, but its extent to the south of well 699-32-62 is poorly defined.

Table 2.8-1. History of Operations for the 200-ZP-1 Pump-and-Treat System

Phase	Start	End	Extraction Wells	Injection Wells
I	August 29, 1994	July 19, 1996	299-W18-1	299-W18-4
II	August 5, 1996	August 8, 1997	299-W15-33 299-W15-34 299-W15-35	299-W15-29
III	August 29, 1997	Present	299-W15-32 299-W15-33 299-W15-34 299-W15-35 299-W15-36 299-W15-37[(a)]	299-W15-29 299-W18-36 299-W18-37

(a) Converted to monitoring well in fiscal year 2001.

Table 2.8-2. Average Carbon Tetrachloride Concentrations for Each of the Extraction Wells and the Influent Tank at the 200-ZP-1 Operable Unit for Fiscal Year 2002

Well Name[(a)]	FY 1998 Mean Concentration (μg/L)	FY 1999 Mean Concentration (μg/L)	FY 2000 Mean Concentration (μg/L)	FY 2001 Mean Concentration (μg/L)	FY 2002 Mean Concentration (μg/L)	FY 2002 Min. Value (μg/L)	FY 2002 Max. Value (μg/L)	Mean Flow Rate (L/min)
299-W15-33	6,000	6,218	5,956	4,865	4,269	2,600	5,900	41.7
299-W15-34	3,770	4,700	5,517	5,355	4,989	2,300	6,900	84.6
299-W15-35	3,660	3,858	3,842	3,413	3,244	1,800	4,500	301
299-W15-32	6,560	5,023	4,224	3,255	2,668	1,600	3,800	34
299-W15-36	2,040	1,697	1,779	1,377	1,145	680	1,700	106
299-W15-37[(b)]	235	358	556	464	443	100	860	
Influent Tank (T-01)	3,530	3,788	4,041	3,600	3,556	2,500	4,800	

FY = Fiscal year.
(a) Wells listed from north to south.
(b) Operated as a monitoring well since January 2001.

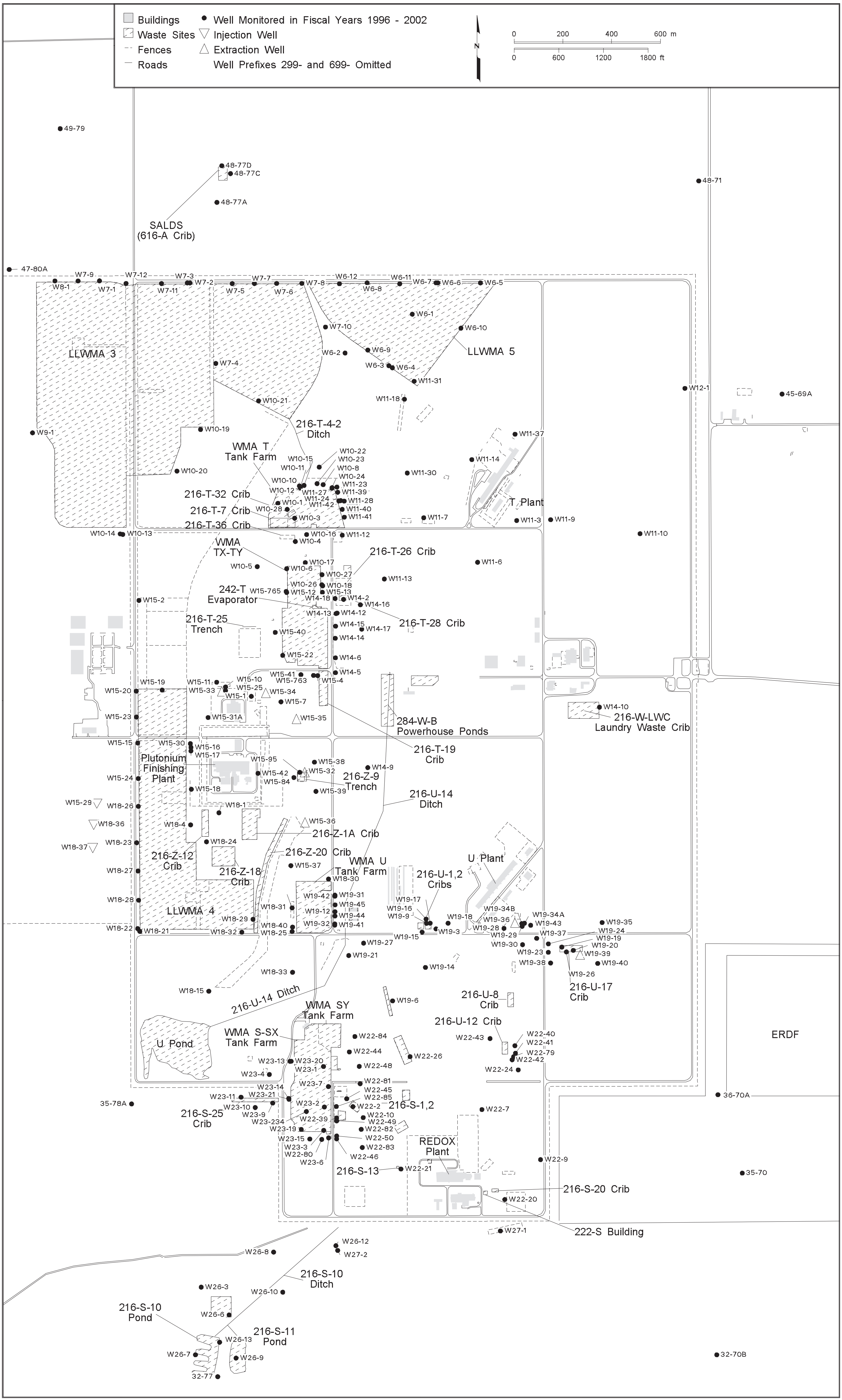
Table 2.8-3. History of Operations for the 200-UP-1 Pump-and-Treat System

Phase	Start	End	Extraction Wells	Injection Wells
I	March 1994	August 16, 1996	299-W19-23 299-W19-24	299-W19-25
II	September 25, 1995	February 27, 1997	299-W19-39	299-W19-36
III	March 31, 1997	December 26, 2001	299-W19-39	None
III	December 27, 2001	Present	299-W19-39 299-W19-36	None

Table 2.8-4. Quantity of Treated Groundwater and Contaminant Mass Removed Since Initiation of 200-UP-1 Pump-and-Treat Operations

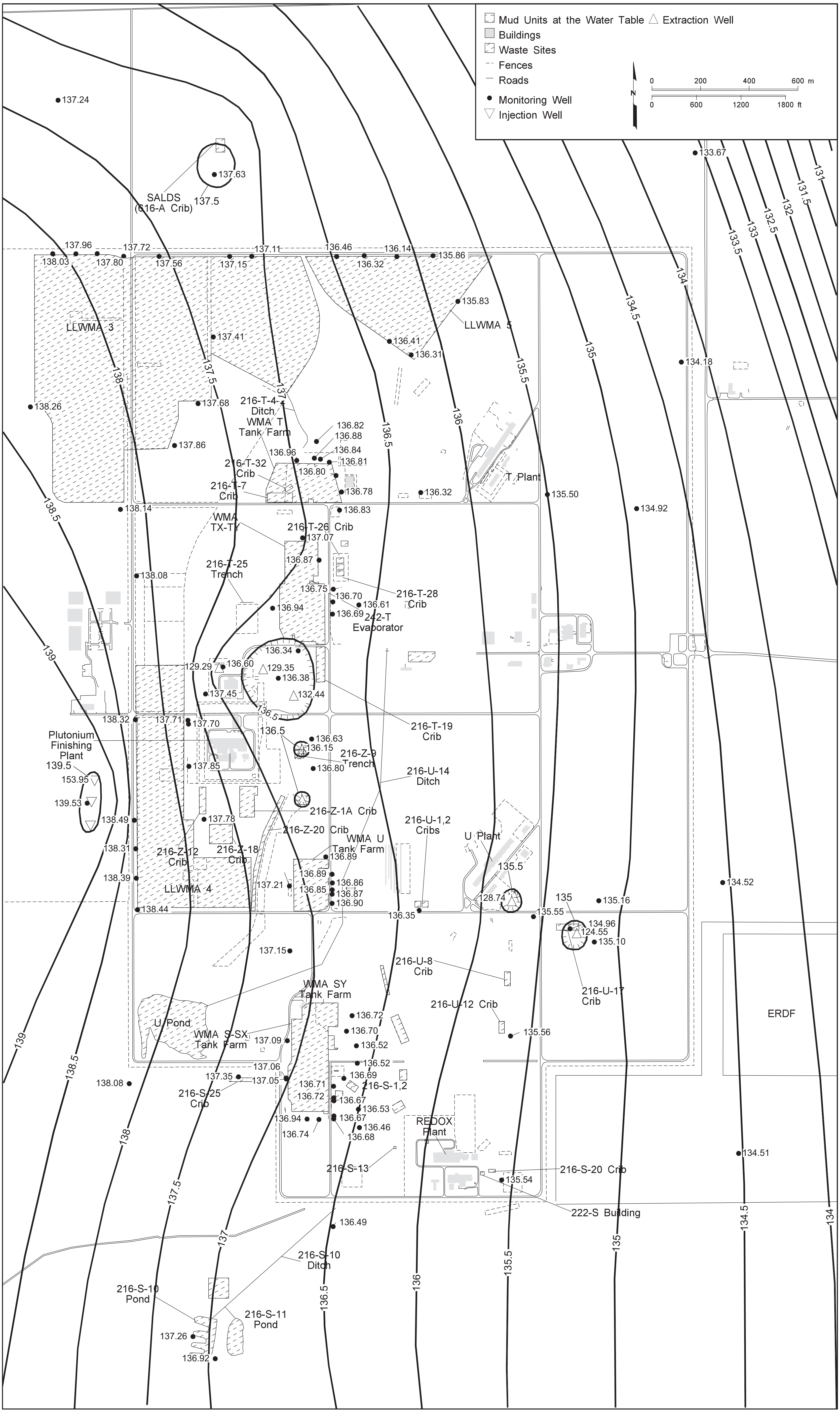
Reporting Period	Liters Treated	Mass Technetium-99 Removed (g)	Mass Total Uranium Removed (g)	Mass Carbon Tetrachloride Removed (g)	Mass Nitrate Removed (kg)
March 1994 - September 1996[a]	108,629,387	33.6	39,232	7,590	NA
Fiscal year 1997[b]	55,382,081	9.8	17,570	3,941	2,260
Fiscal year 1998	100,067,035	10.5	23,630	2,235	5,650
Fiscal year 1999	93,471,260	7.8	20,700	2,002	4,859
Fiscal year 2000	63,229,380	5.6	13,640	1,659	2,807
Fiscal year 2001	102,475,318	8.4	17,128	2,744	3,924
Fiscal year 2002	85,886,455	14.5	26,420	2,747	3,686
Total	609,140,916	90.2	158,320	22,918	23,186

(a) Incorporates data from the treatability test (March 1994 to November 1994) as reported in DOE/RL-95-02.
(b) Includes estimated values for January and February based on 189 L/min flow, running 24 hours/day, at 97.5% efficiency.
NA = Not applicable.



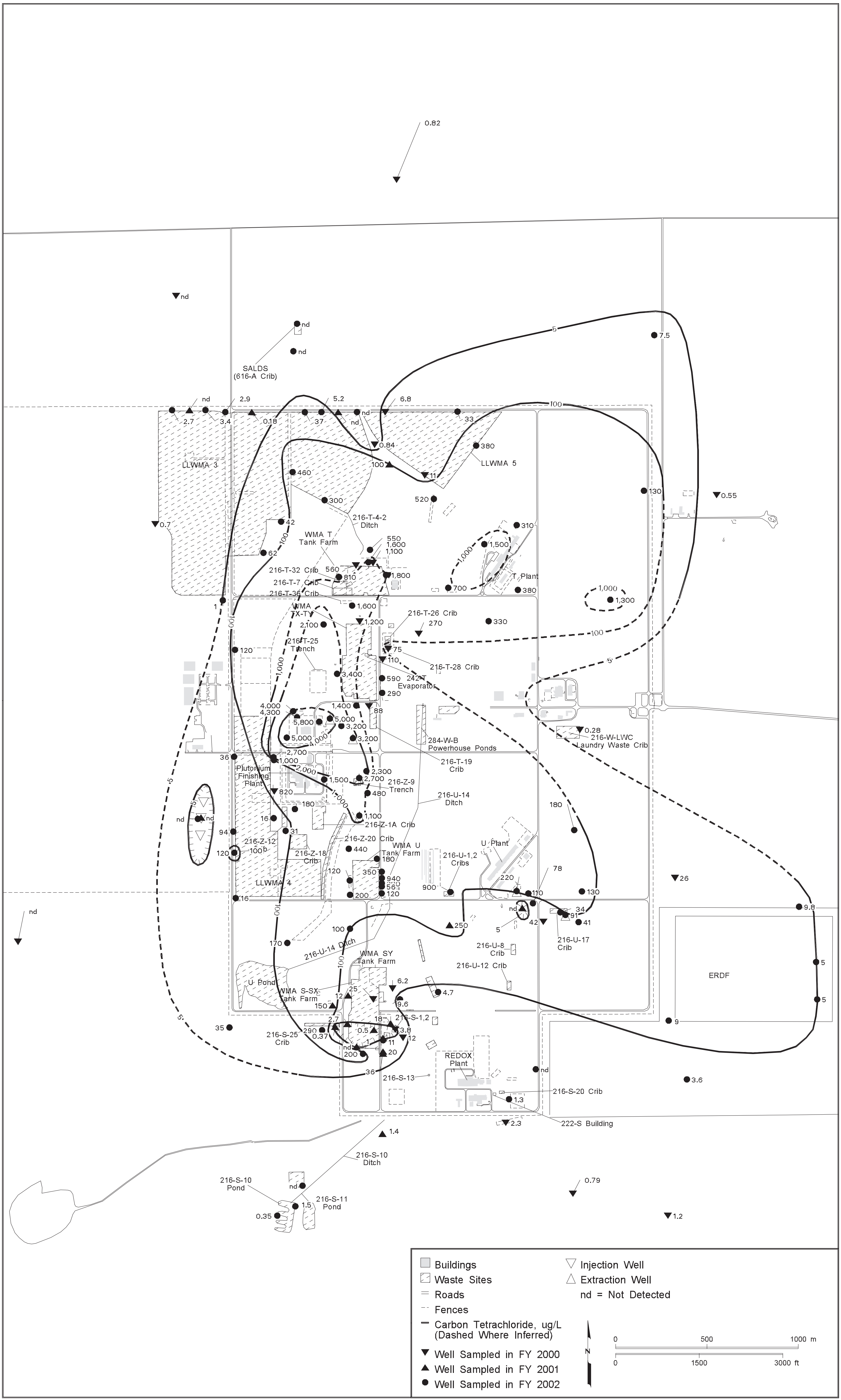
can_gw02_2 February 17, 2003 2:28 PM

Figure 2.8-1. Groundwater Monitoring Wells in the 200 West Area



can_gwf02_271 February 17, 2003 9:03 AM

Figure 2.8-2. Water-Table Contours in the 200 West Area



can_gw02_36 February 10, 2003 9:40 AM

Figure 2.8-3. Average Carbon Tetrachloride Concentrations in 200 West Area, Top of Unconfined Aquifer

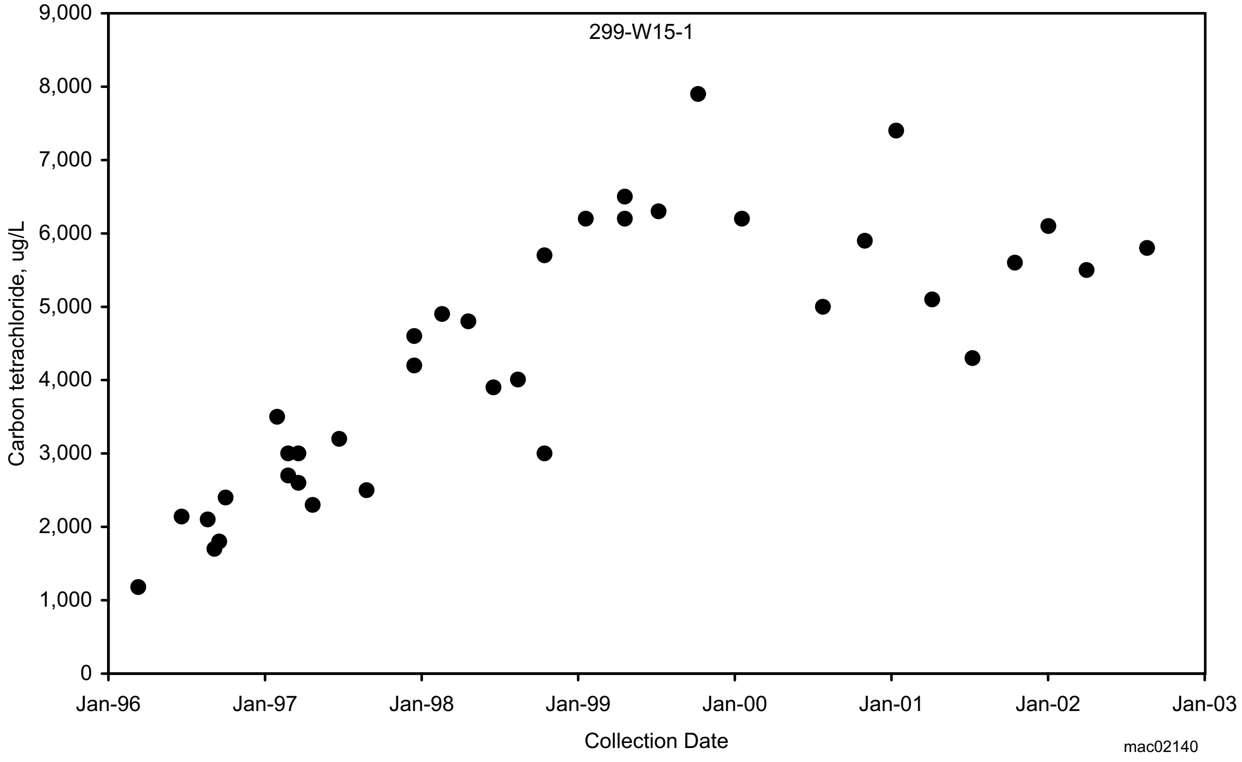


Figure 2.8-4. Carbon Tetrachloride Concentrations Near the North Extraction Wells

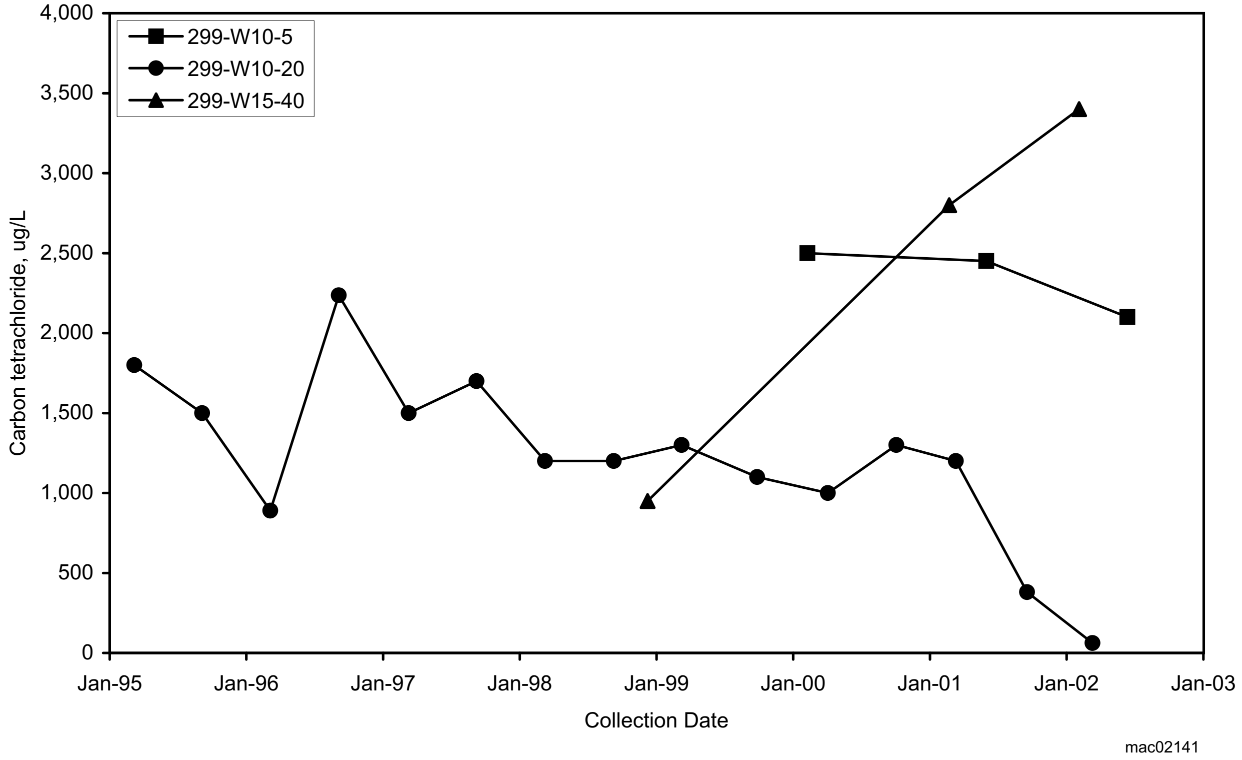
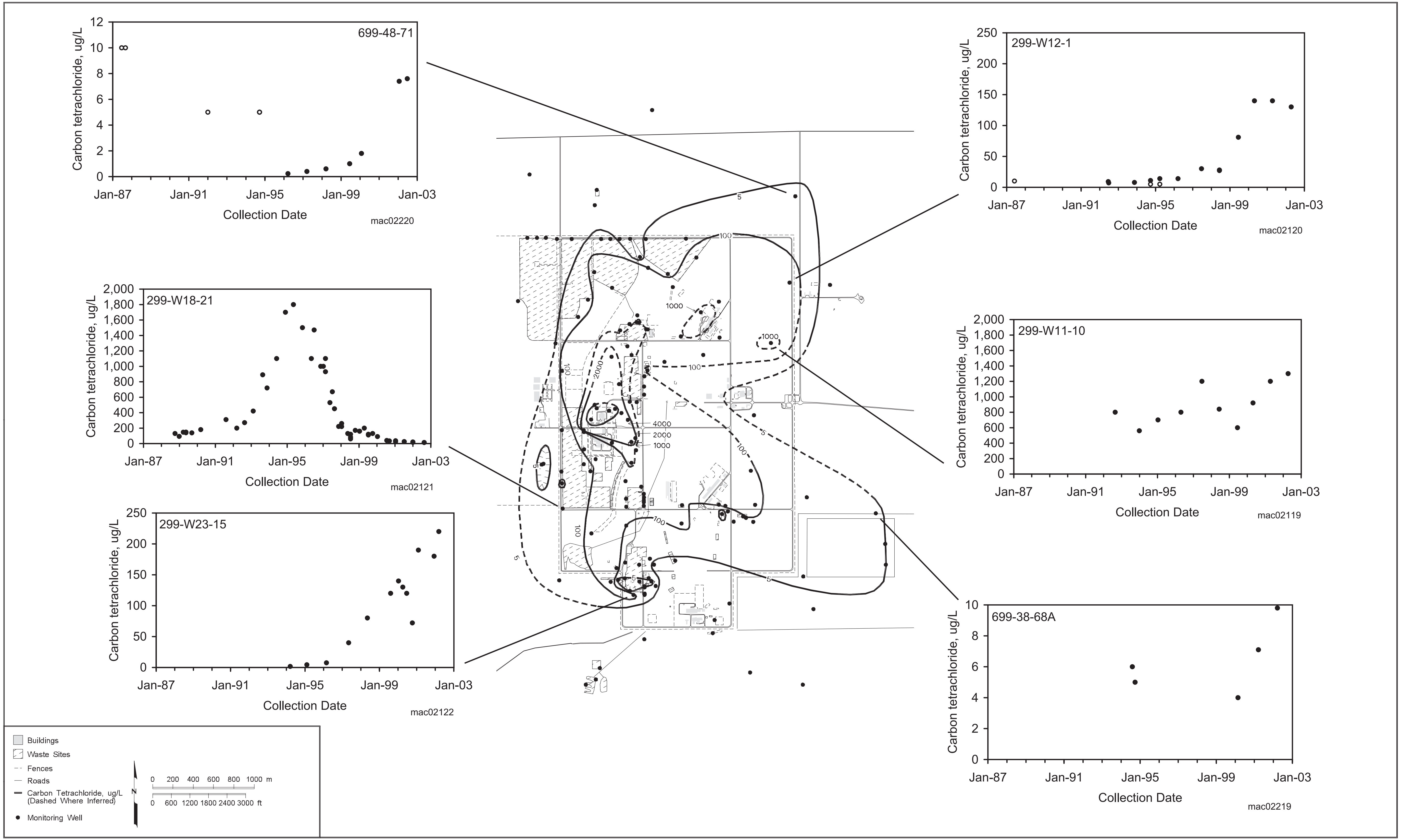


Figure 2.8-5. Carbon Tetrachloride Concentrations North of the 200-ZP-1 Remediation System



can_gw02_37 February 07, 2003 4:43 P

Figure 2.8-6. Carbon Tetrachloride Concentrations in Wells Monitoring 200 West Area, Top of Unconfined Aquifer

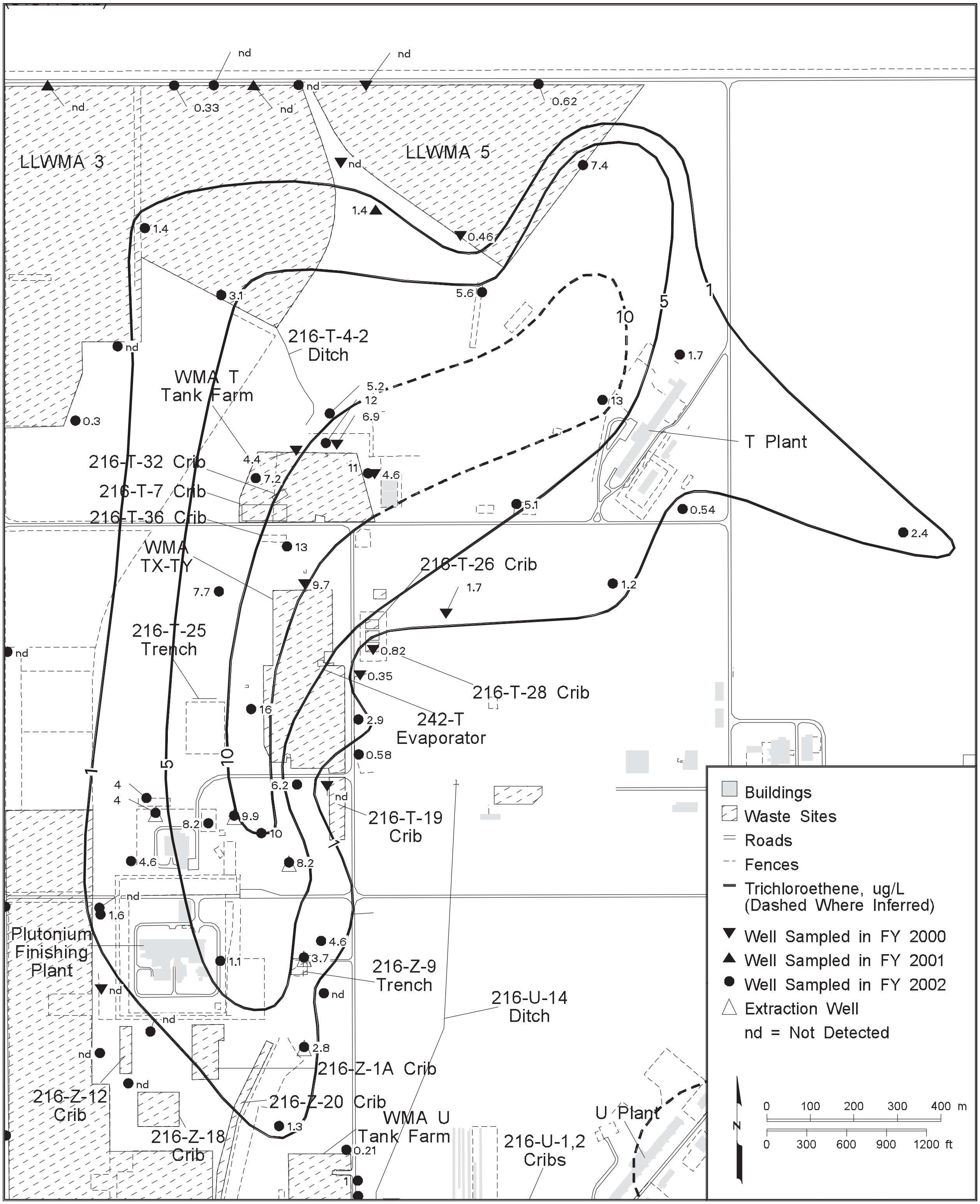


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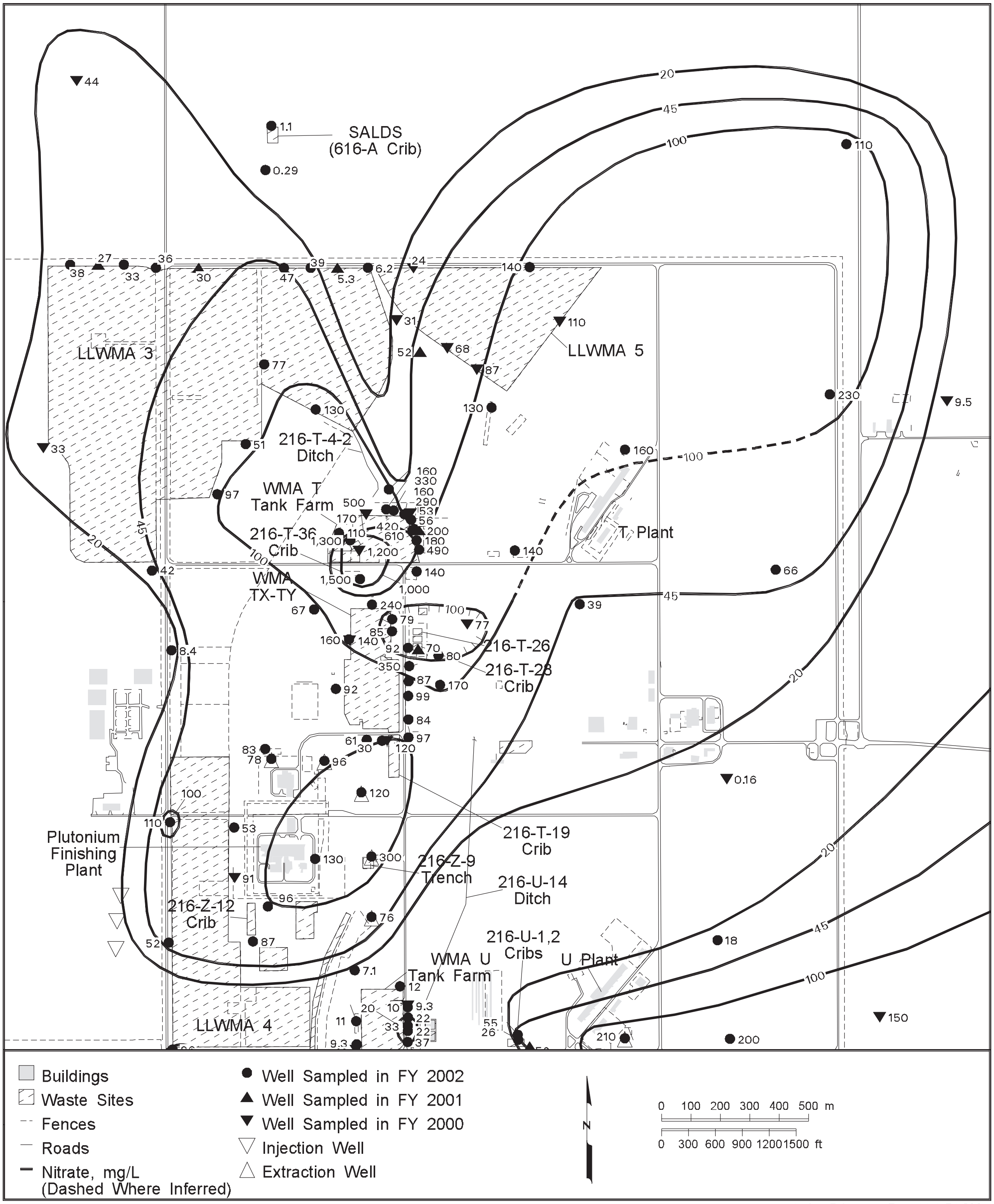
Figure 2.8-7. Average Trichloroethene Concentrations in Central and North 200 West Area, Top of Unconfined Aquifer



can_gw02_40a February 07, 2003 3:52 PM

Figure 2.8-8. Average Nitrate Concentrations in the Central and North 200 West Area, Top of Unconfined Aquifer

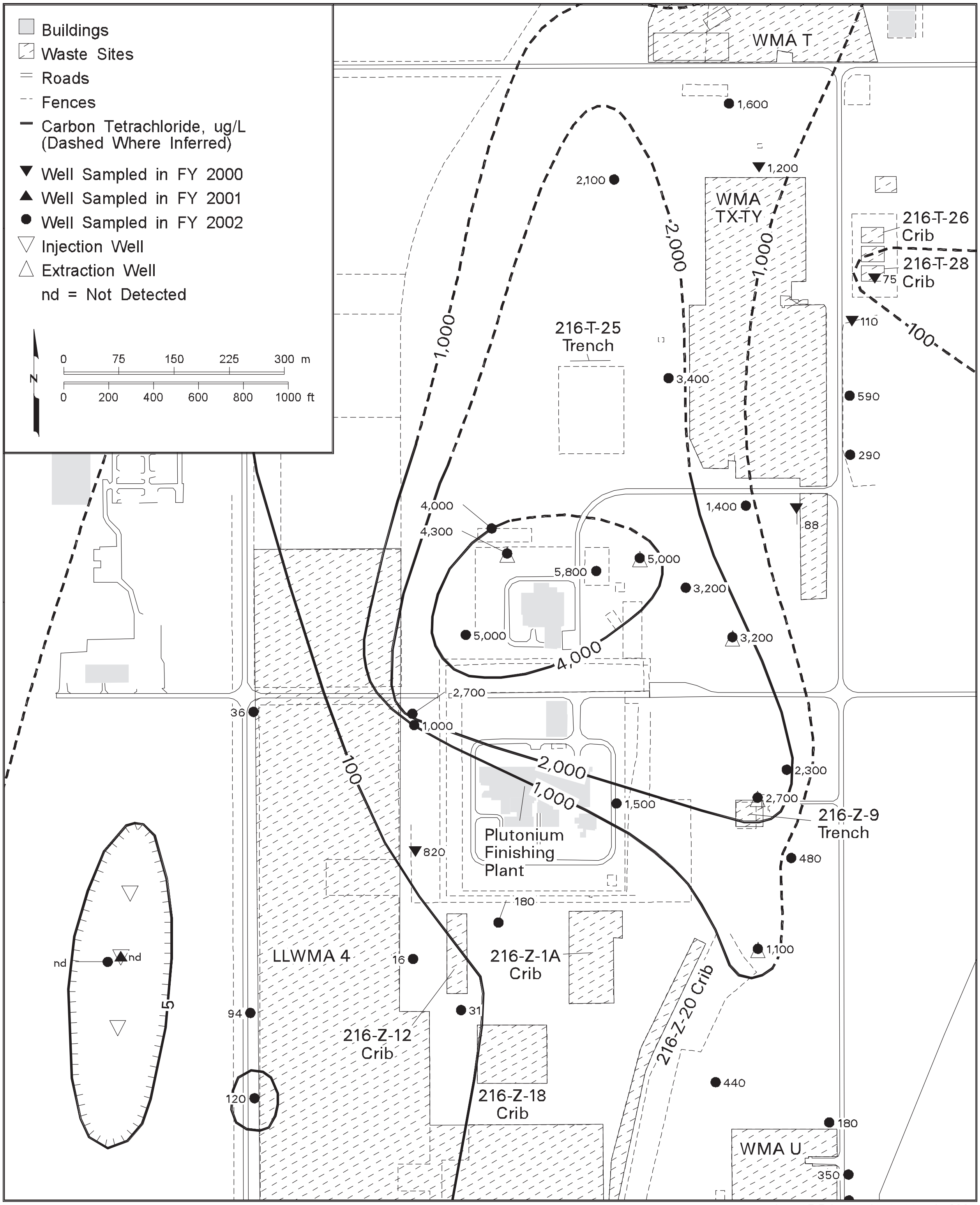


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Figure 2.8-9. Carbon Tetrachloride Plume at the 200-ZP-1 Operable Unit Remediation Area, Top of Unconfined Aquifer

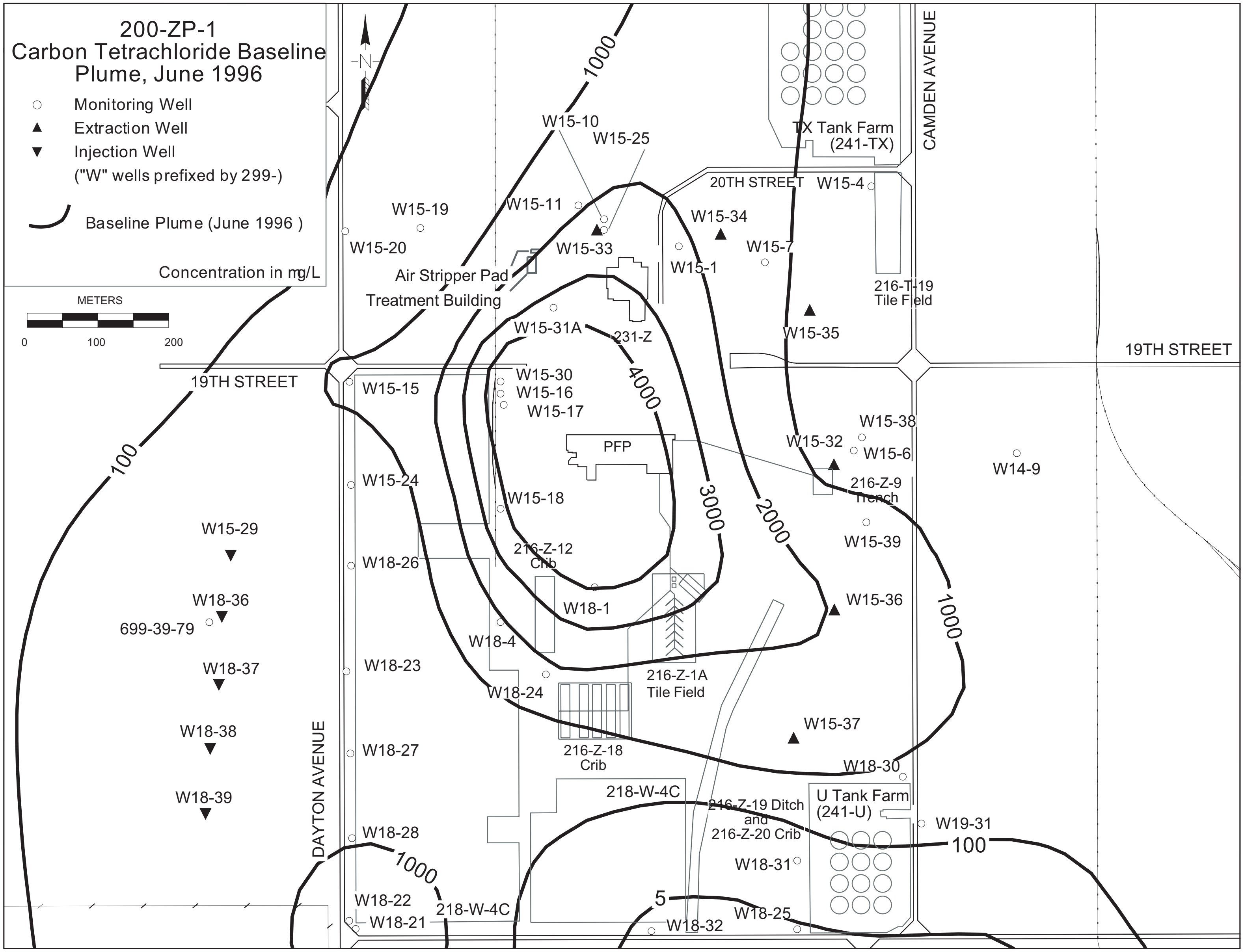


Figure 2.8-10. Carbon Tetrachloride Plume at the 200-ZP-1 Operable Unit Remediation Area, June 1996 (DOE/RL-2000-71)

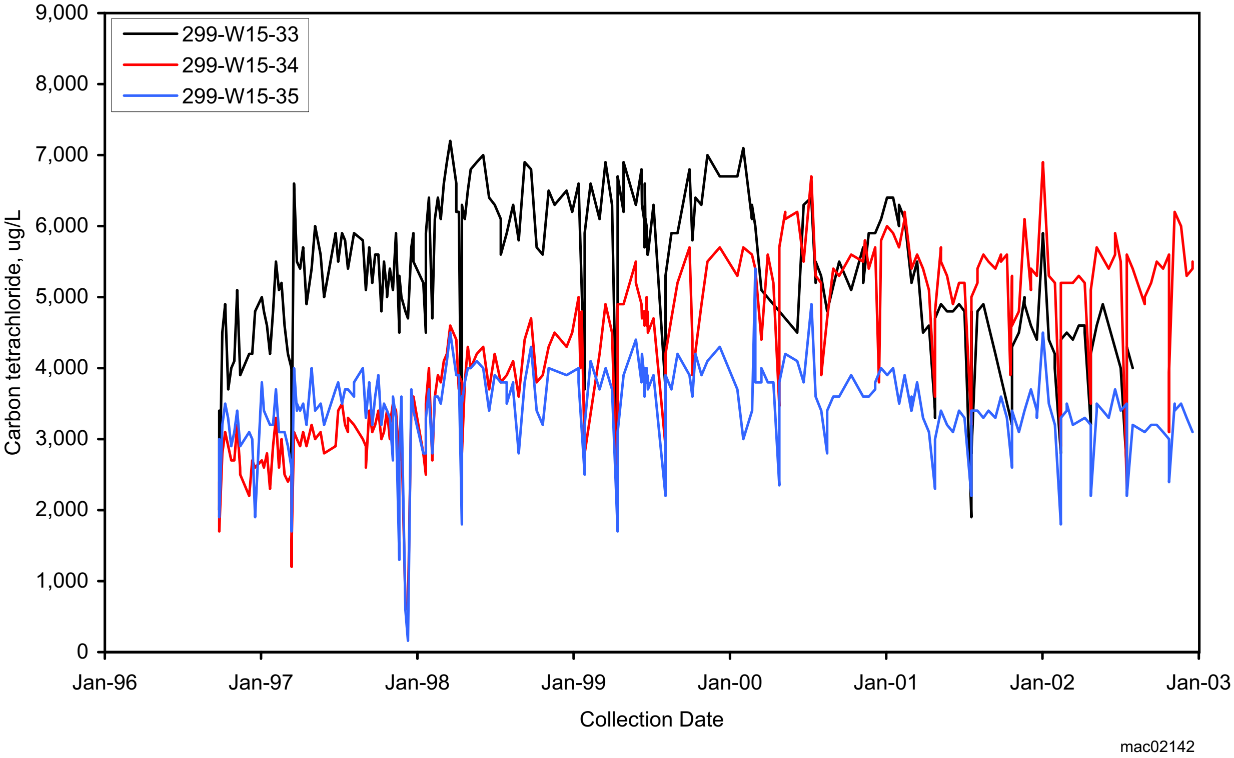


Figure 2.8-11. Carbon Tetrachloride Concentrations in North Extraction Wells for the 200-ZP-1 Pump-and-Treat System

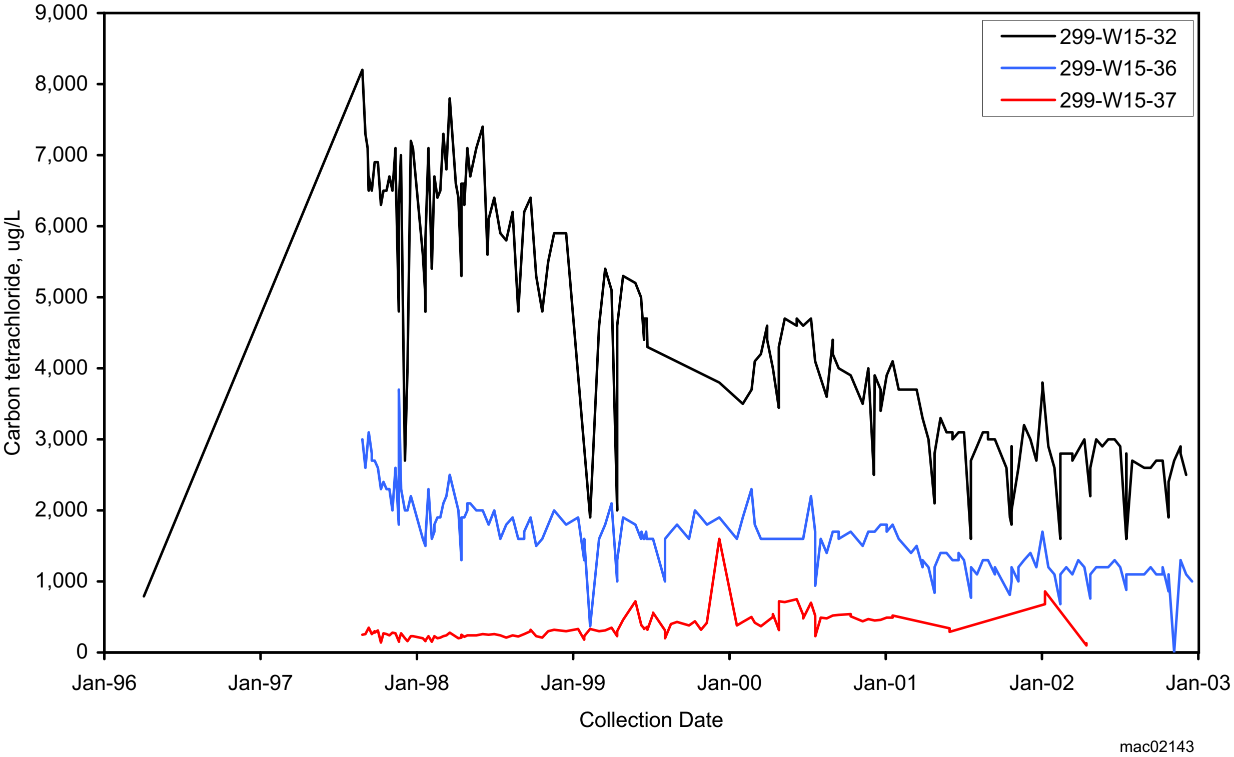


Figure 2.8-12. Carbon Tetrachloride Concentrations in South Extraction Wells for the 200-ZP-1 Pump-and-Treat System

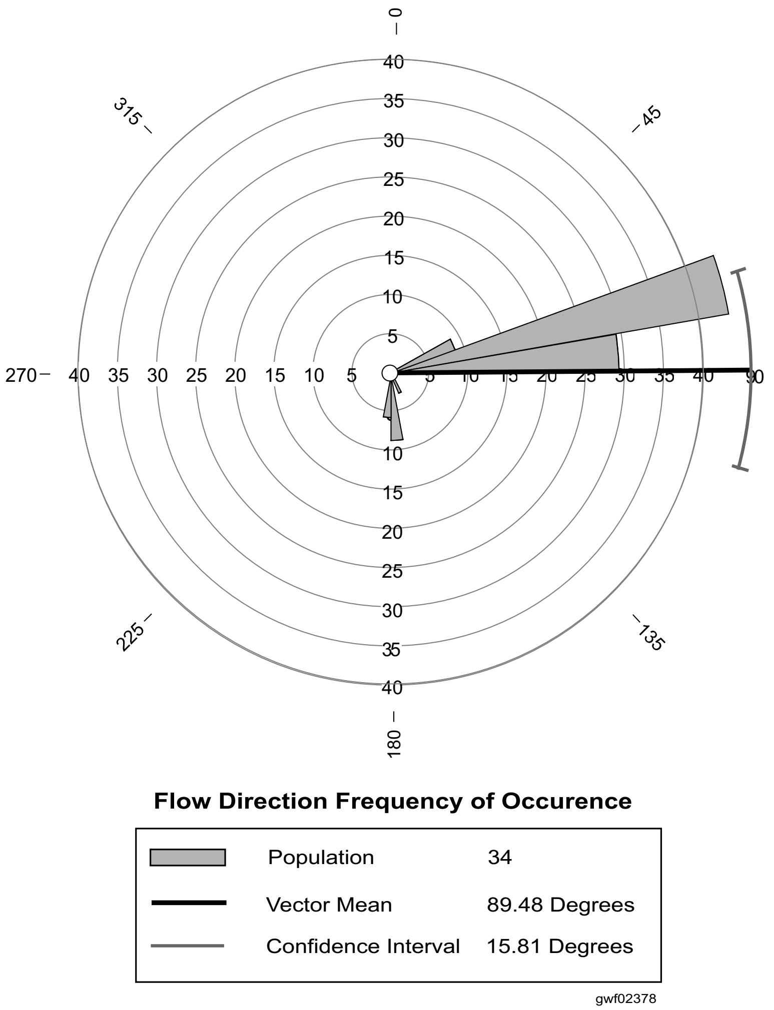
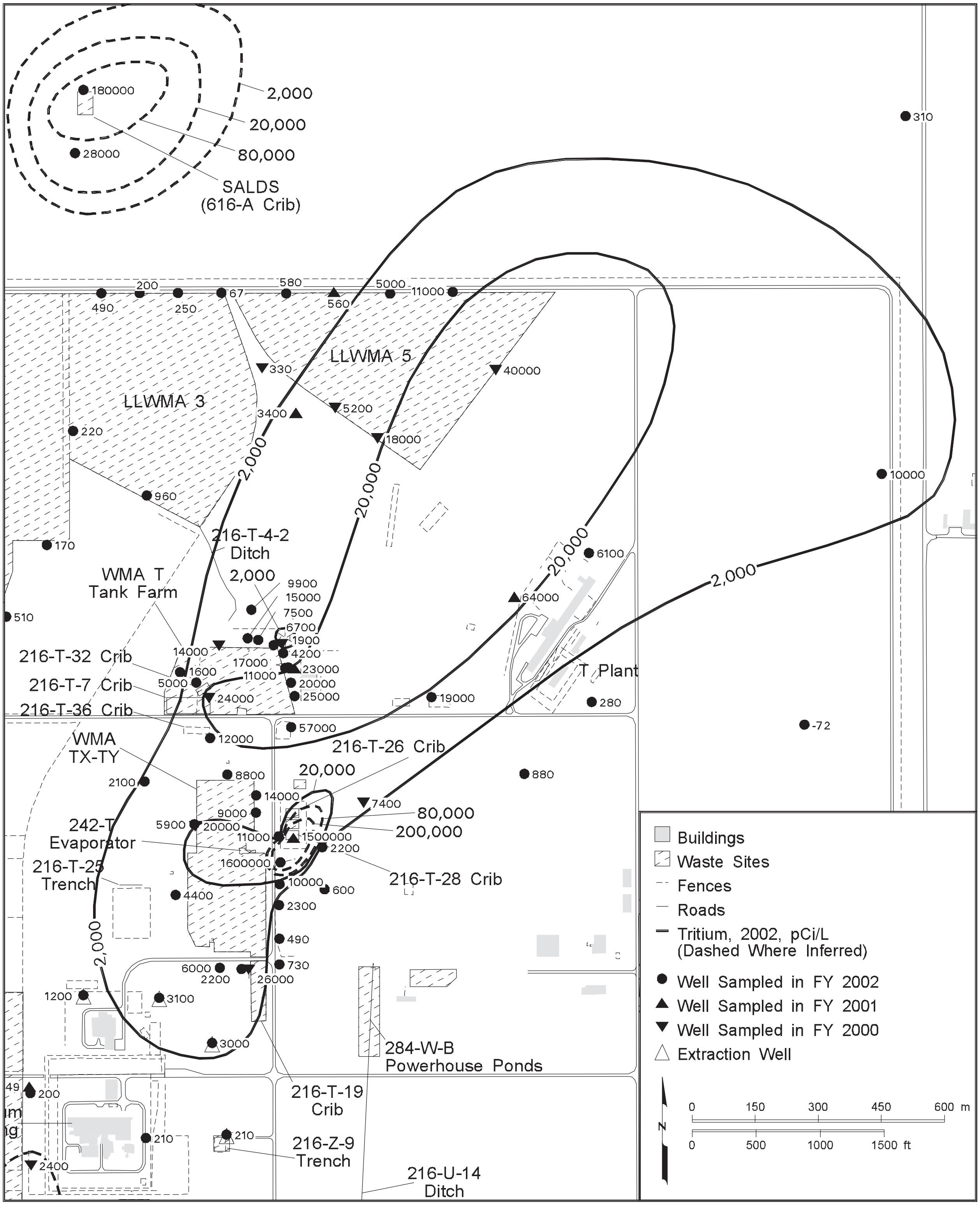


Figure 2.8-13. Distribution of Calculated Gradient Directions for Low-Level Waste Management Area 4



can_gw02_96a December 27, 2002 4:00 PM

Figure 2.8-14. Average Tritium Concentrations in the North 200 West Area, Top of Unconfined Aquifer

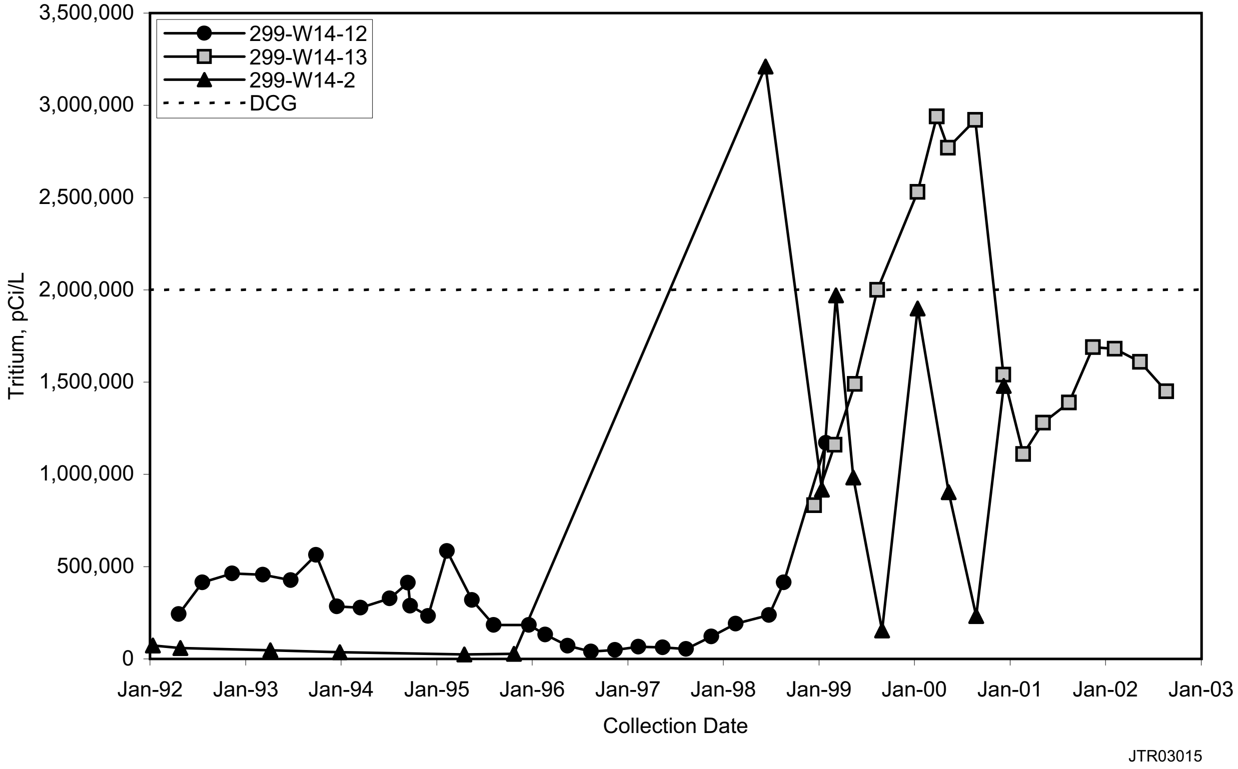
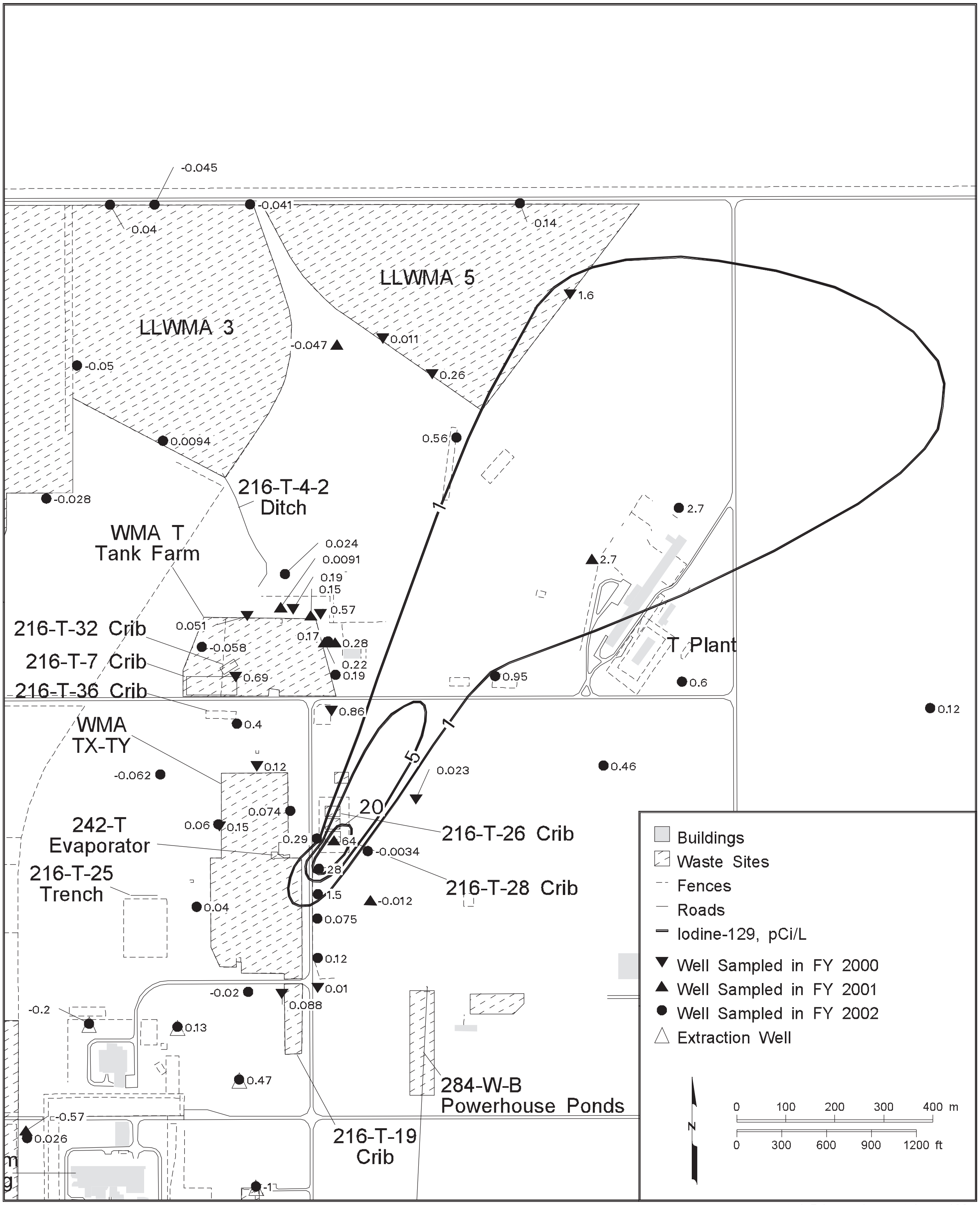
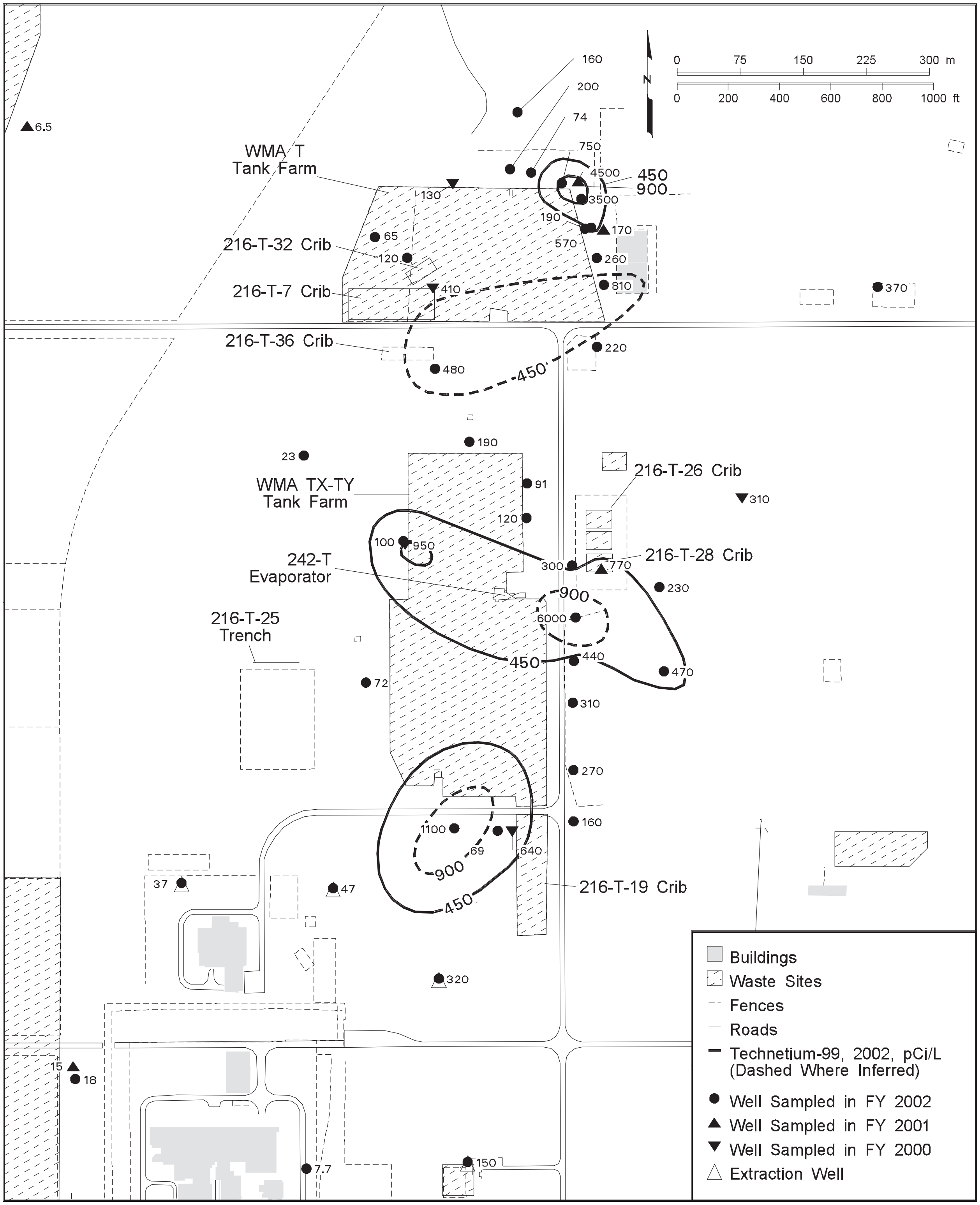


Figure 2.8-15. Tritium Concentrations in Wells East of TY Tank Farm



can_gw02_96b February 10, 2003 10:36 AM

Figure 2.8-16. Average Iodine-129 Concentrations in the North 200 West Area, Top of Unconfined Aquifer



can_gw02_78 January 03, 2003 9:37 AM

Figure 2.8-17. Average Technetium-99 Concentrations in the North 200 West Area, Top of Unconfined Aquifer

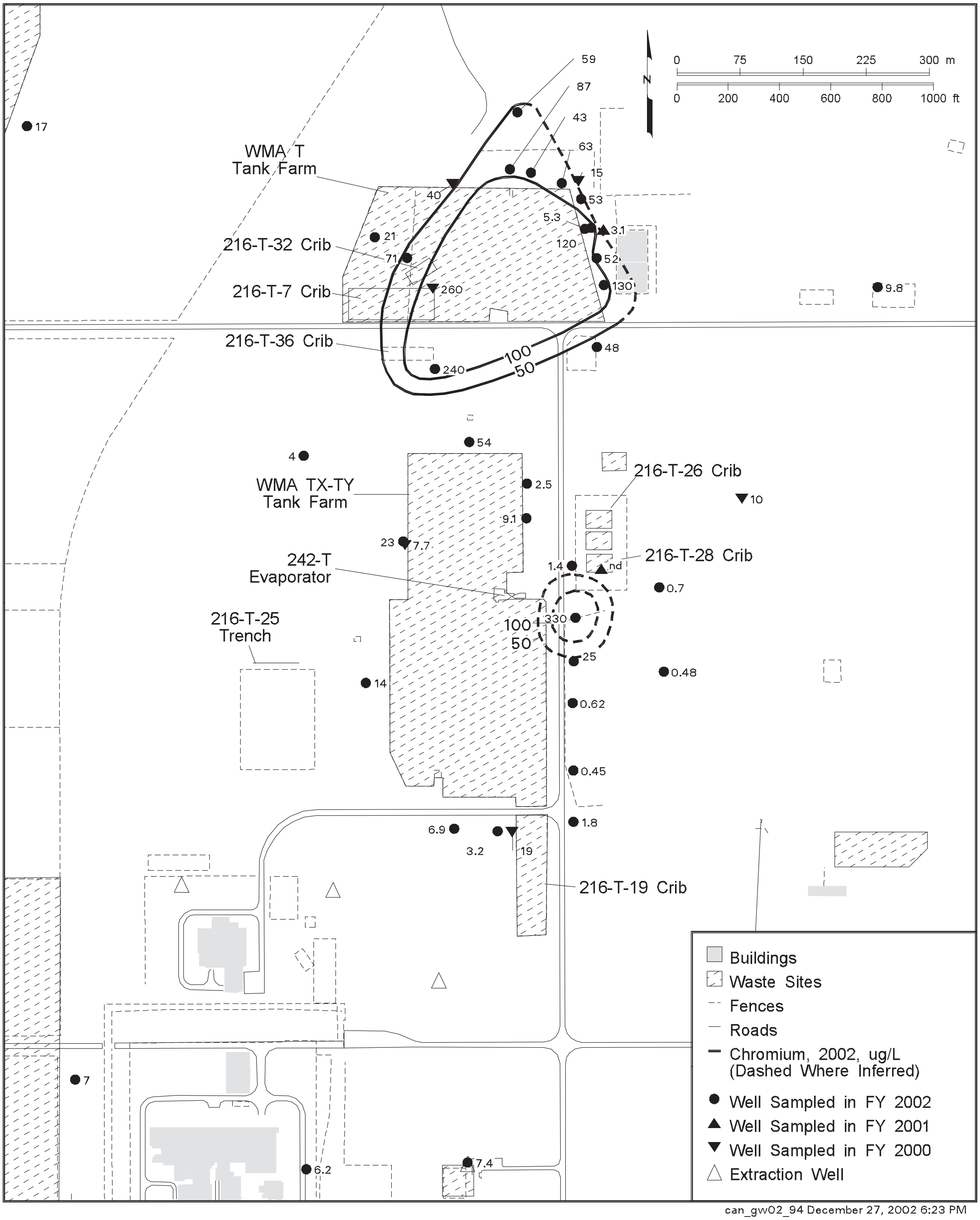


Figure 2.8-18. Average Dissolved Chromium Concentrations Near Waste Management Areas T and TX-TY, Top of Unconfined Aquifer

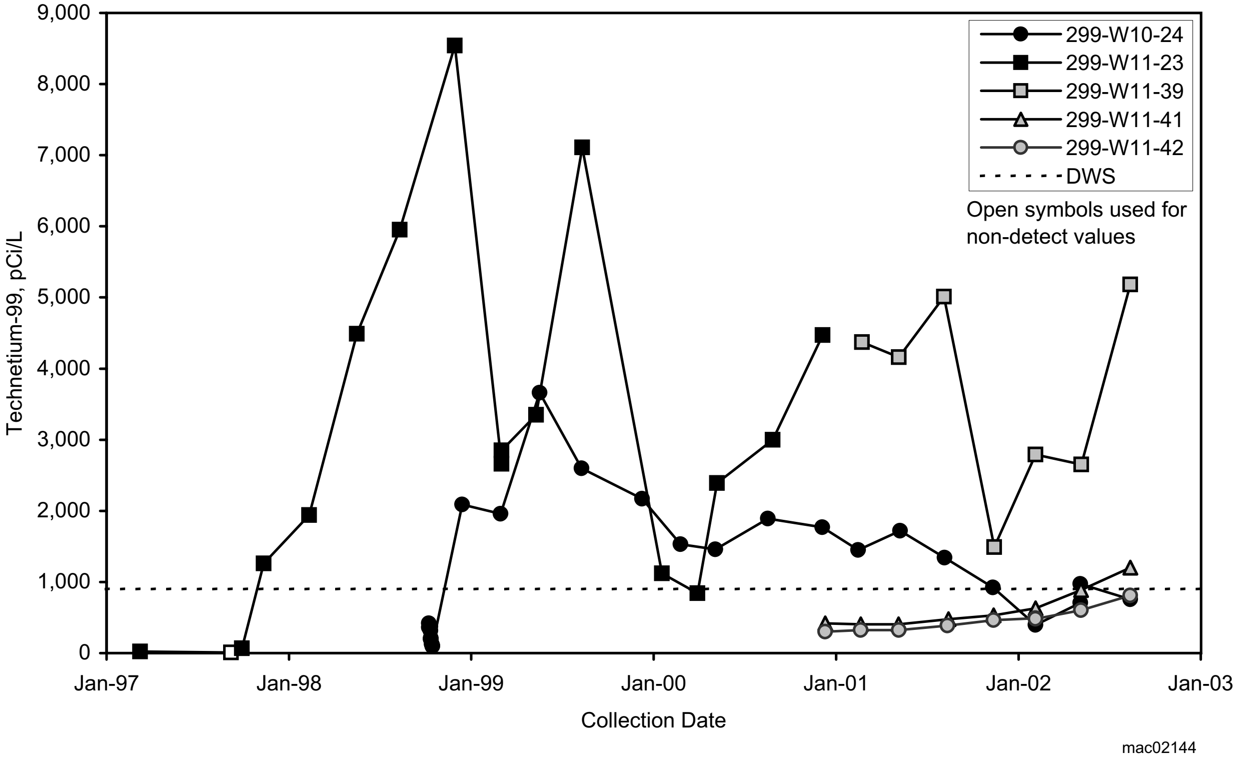


Figure 2.8-19. Technetium-99 Concentrations in Selected Wells at Waste Management Area T

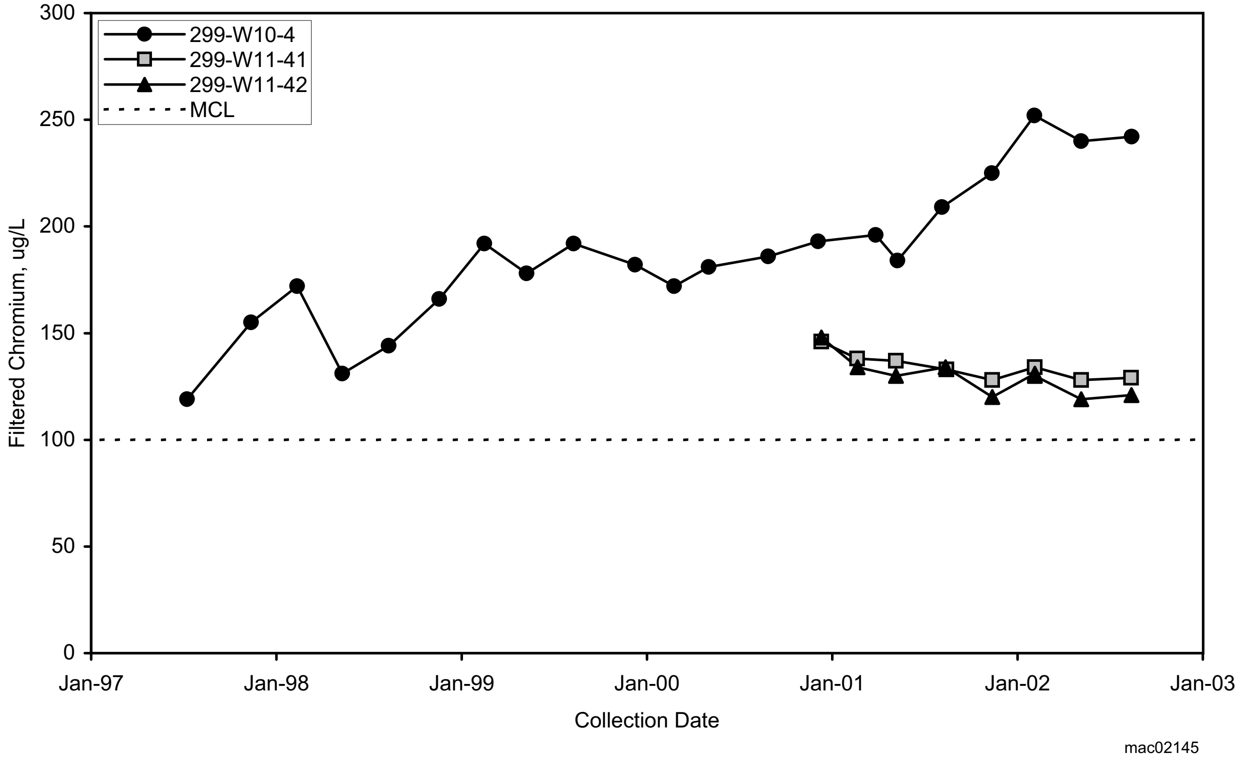


Figure 2.8-20. Chromium Concentrations in Filtered Groundwater Samples in Selected Wells at Waste Management Area T

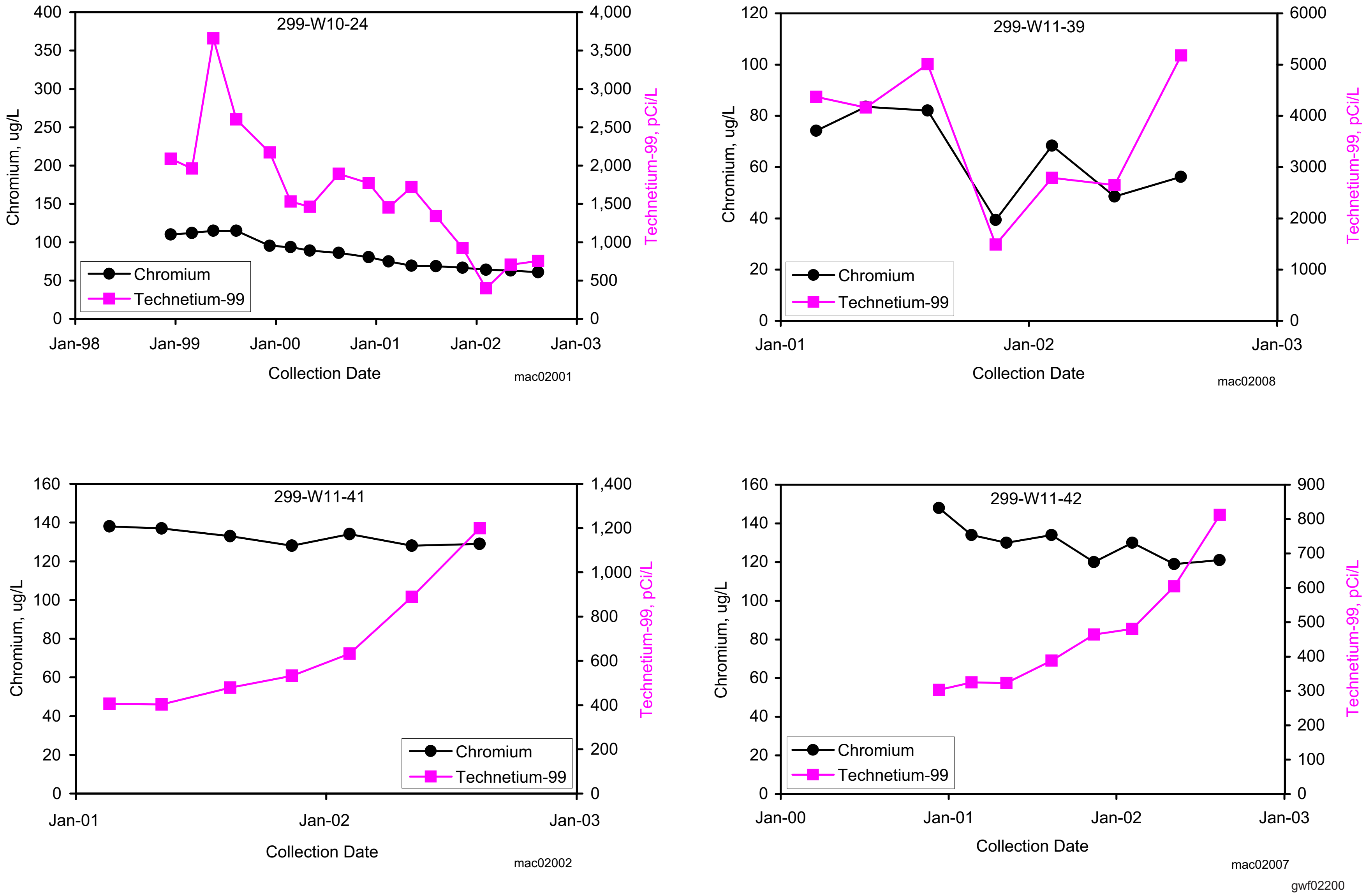


Figure 2.8-21. Representative Chromium Concentrations (filtered samples) and Technetium-99 Concentrations in Selected Wells at Waste Management Area T

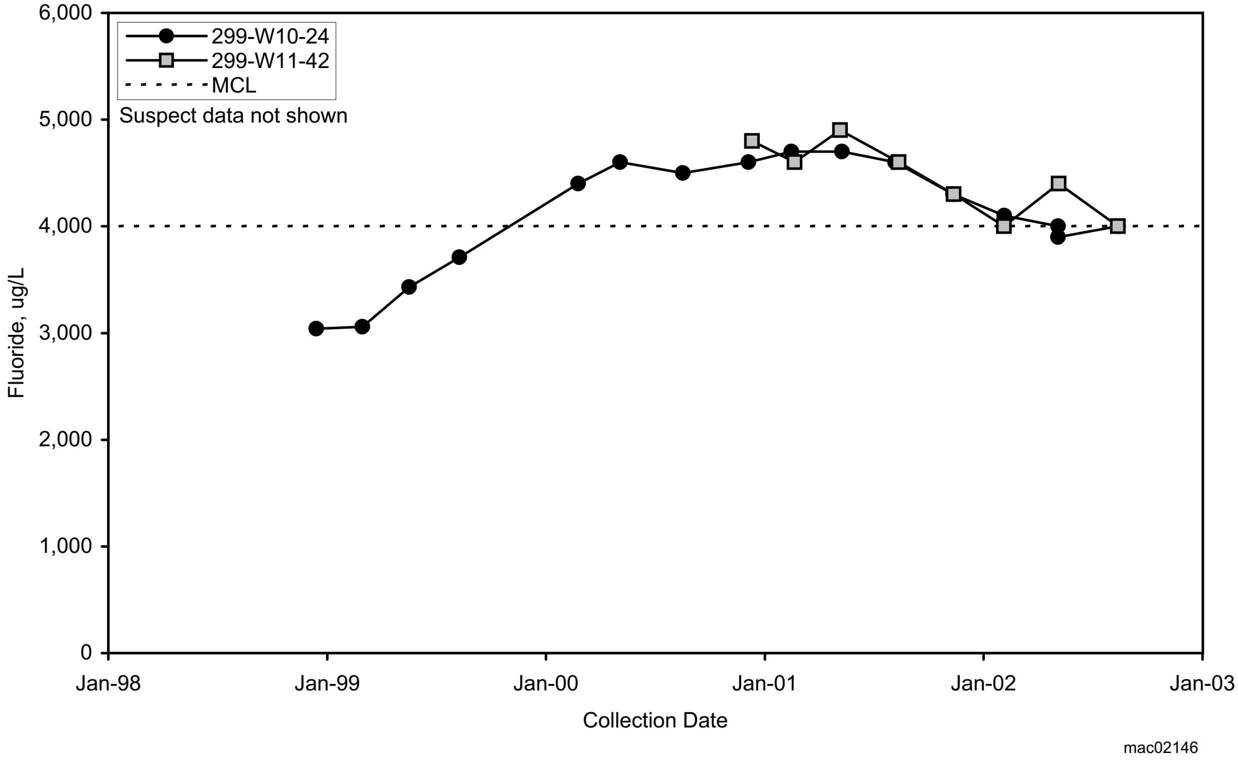


Figure 2.8-22. Fluoride Concentrations Versus Time in Selected Wells at Waste Management Area T

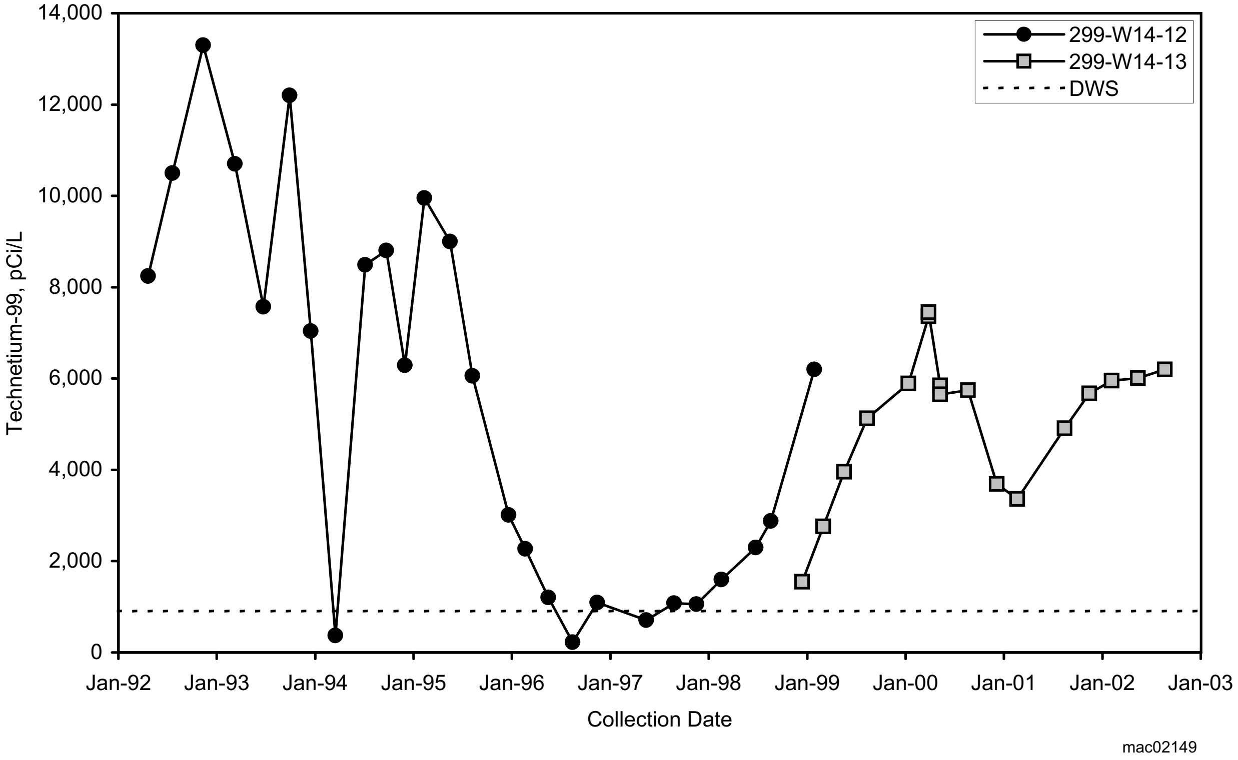


Figure 2.8-23. Technetium-99 Concentrations Versus Time in Wells 299-W14-12 and 299-W14-13 at Waste Management Area TX-TY

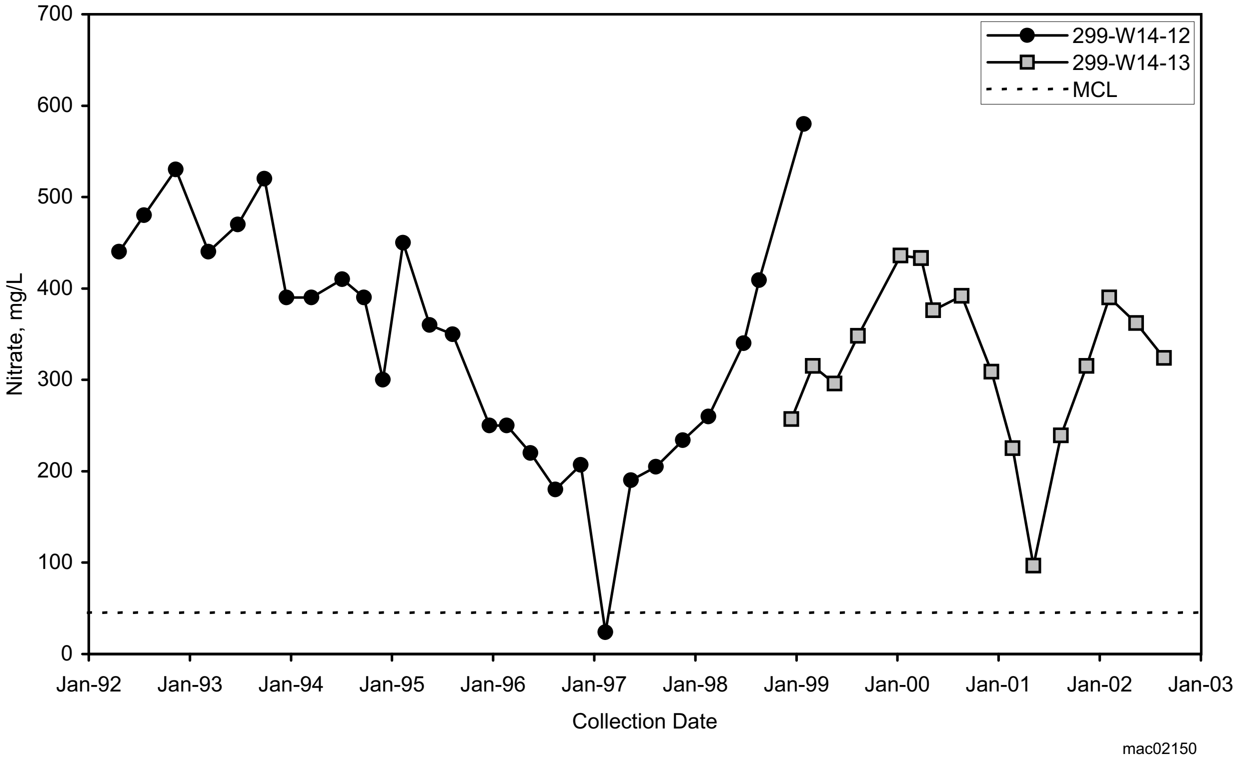


Figure 2.8-24. Nitrate Concentrations Versus Time in Wells 299-W14-12 and 299-W14-13 at Waste Management Area TX-TY

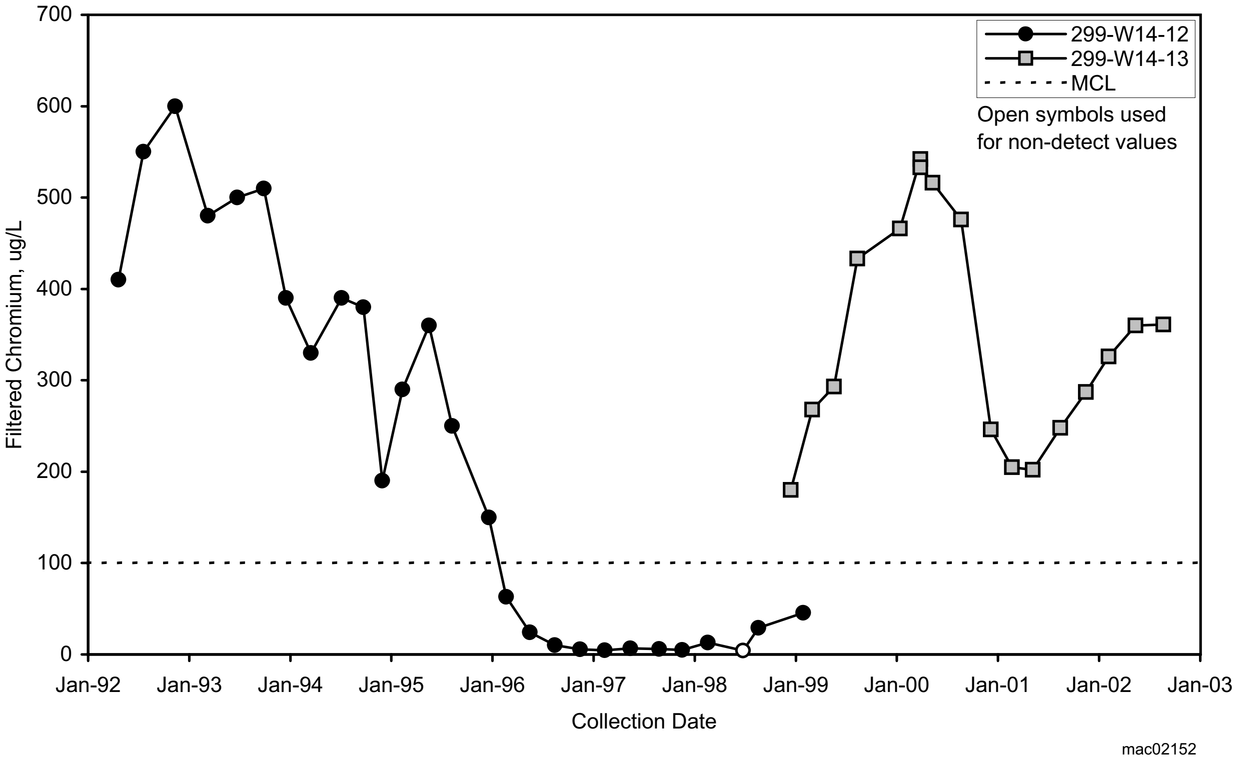


Figure 2.8-25. Chromium Concentrations Versus Time in Wells 299-W14-12 and 299-W14-13 at Waste Management Area TX-TY

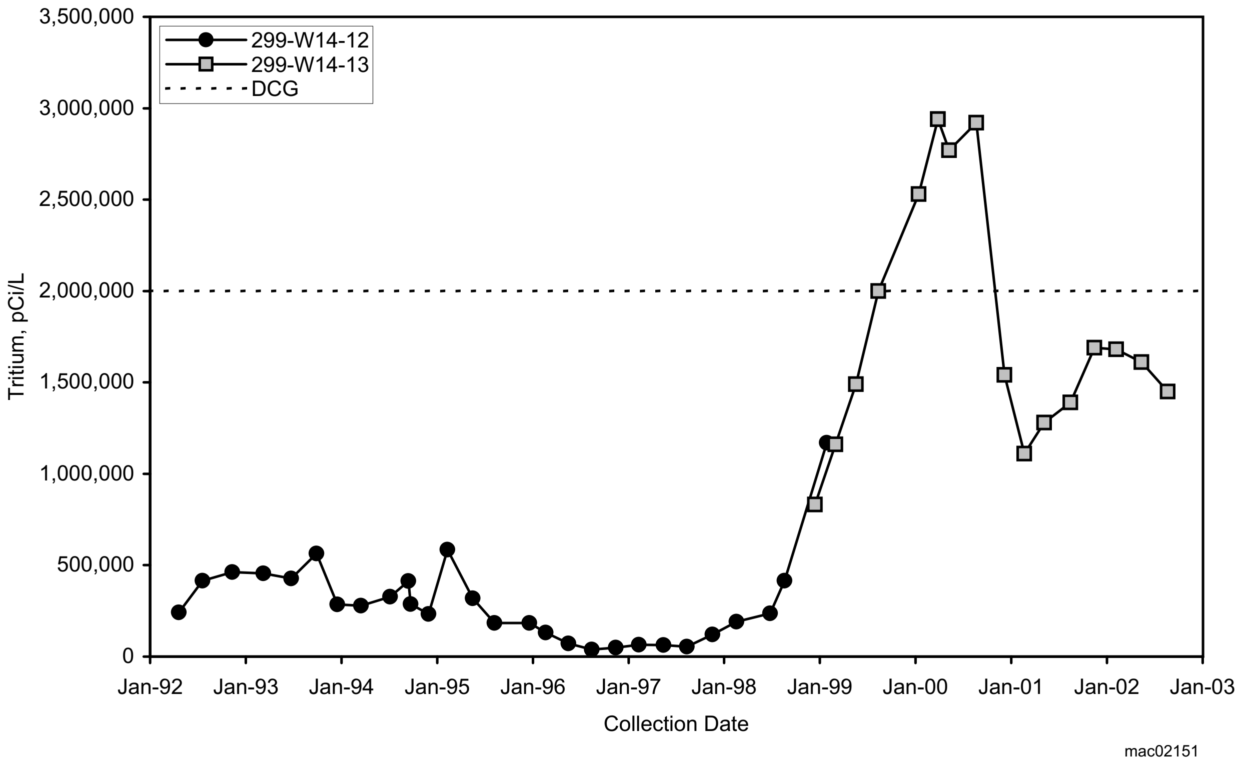


Figure 2.8-26. Tritium Concentrations Versus Time in Wells 299-W14-12 and 299-W14-13 at Waste Management Area TX-TY

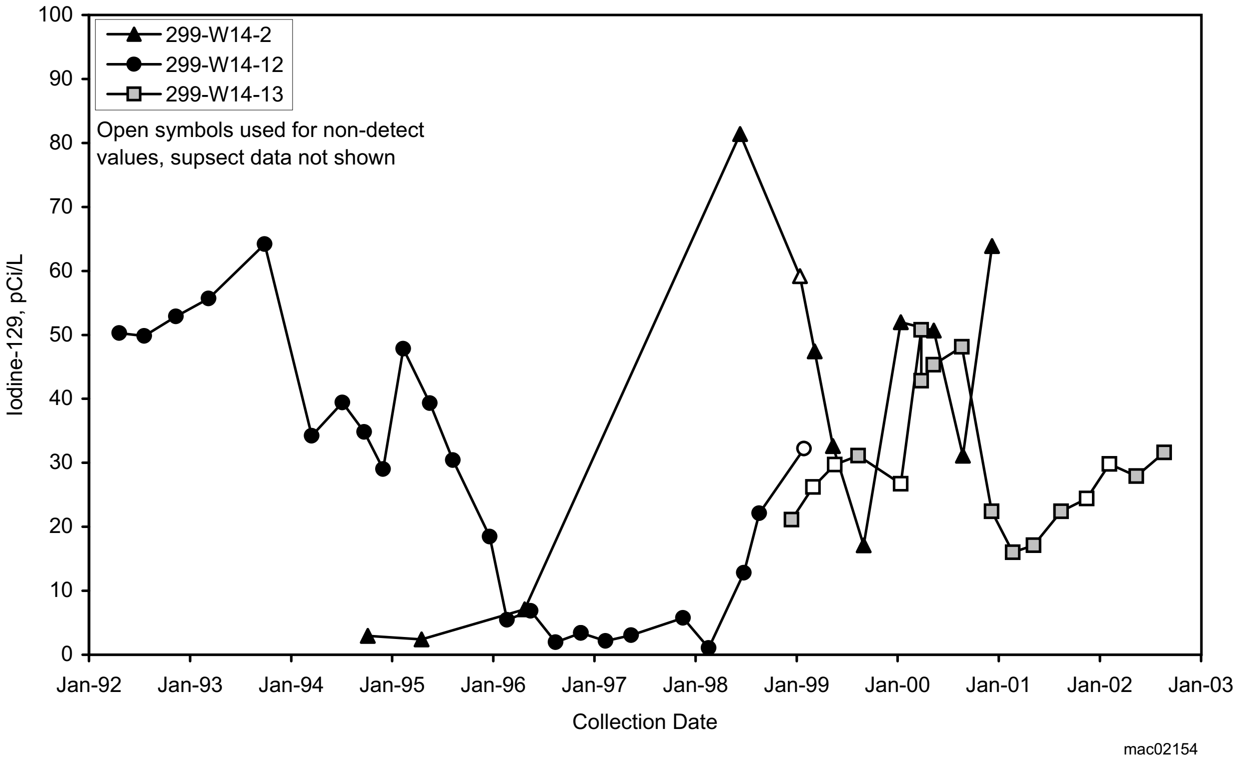


Figure 2.8-27. Iodine-129 Concentrations in Selected Wells at Waste Management Area TX-TY

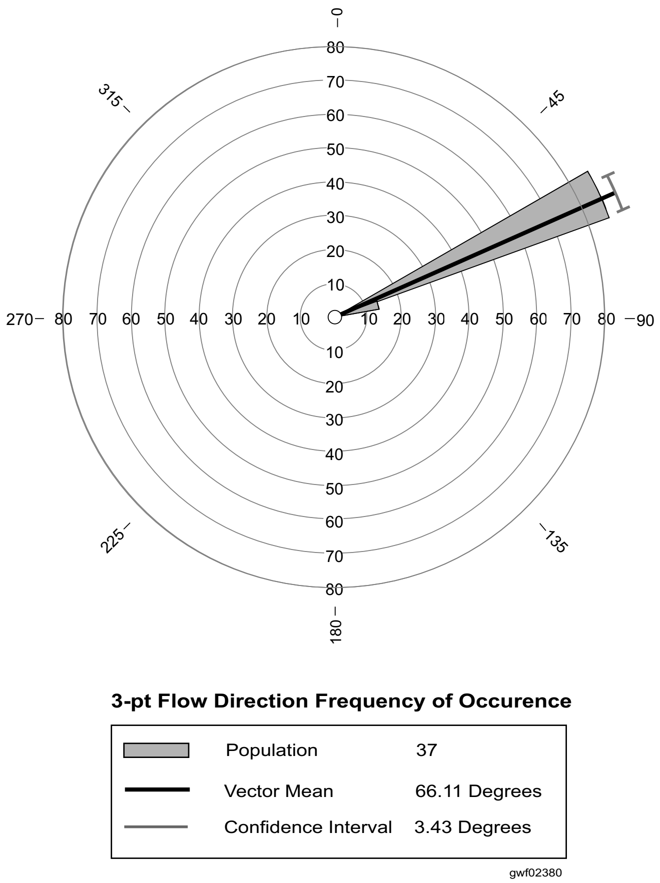


Figure 2.8-28. Distribution of Calculated Gradient Directions for Low-Level Waste Management Area 3

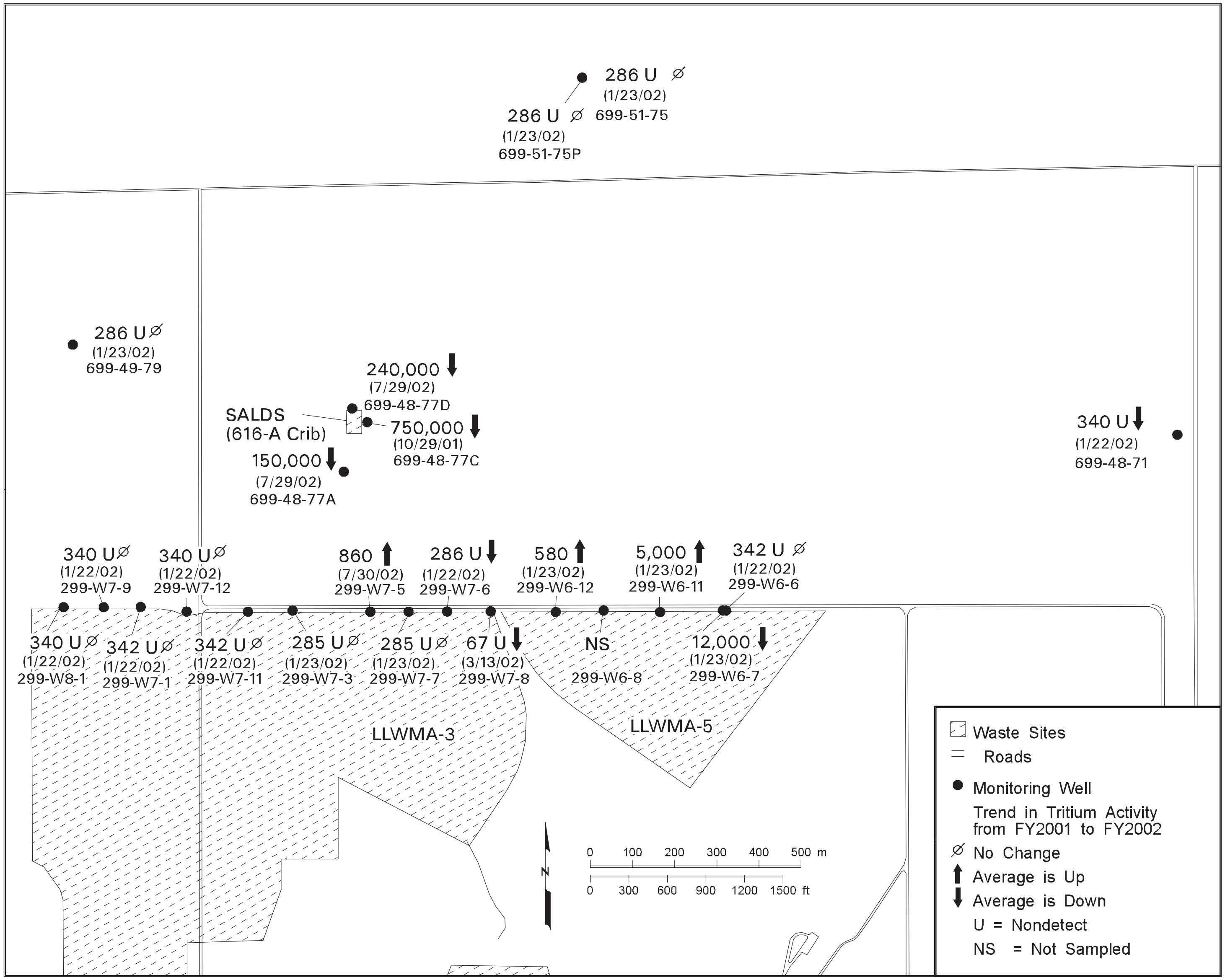


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Figure 2.8-29. Groundwater Monitoring Wells at the State-Approved Land Disposal Site Showing Maximum Tritium Concentrations for Fiscal Year 2002, Indicating Date of Measurement and Change from Fiscal Year 2001

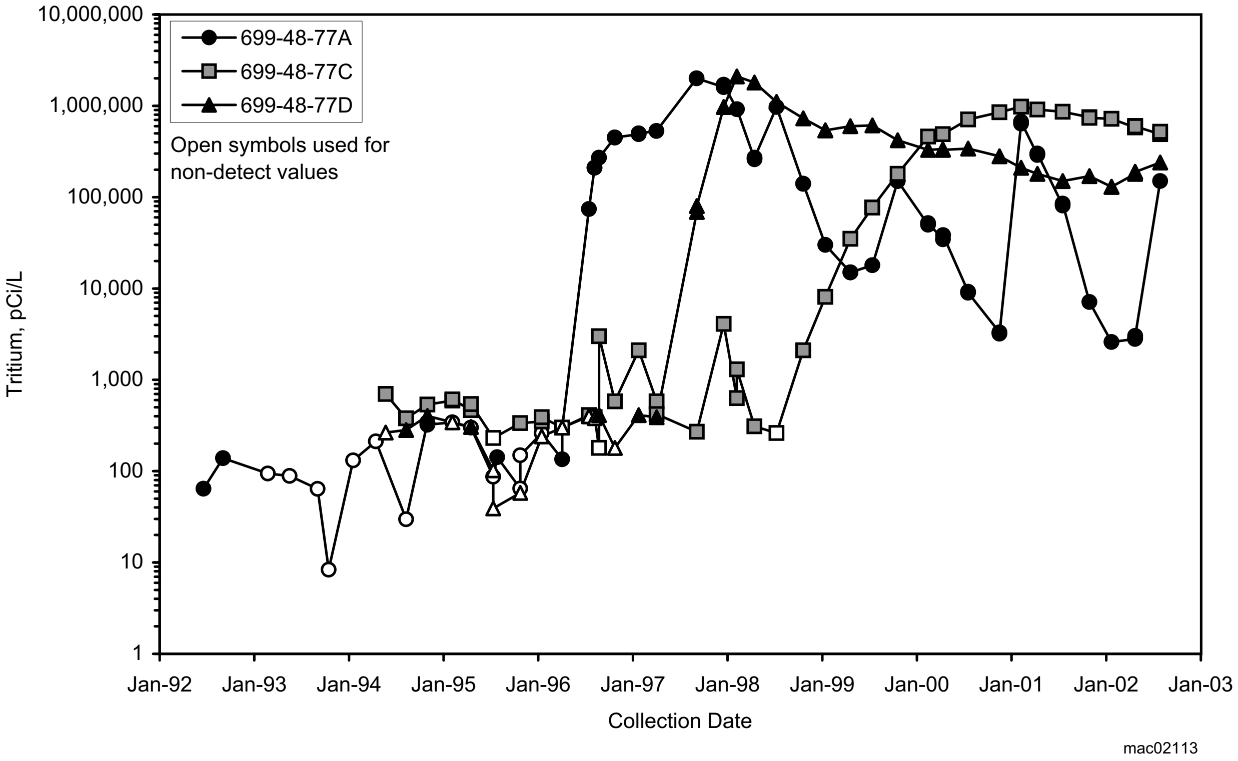
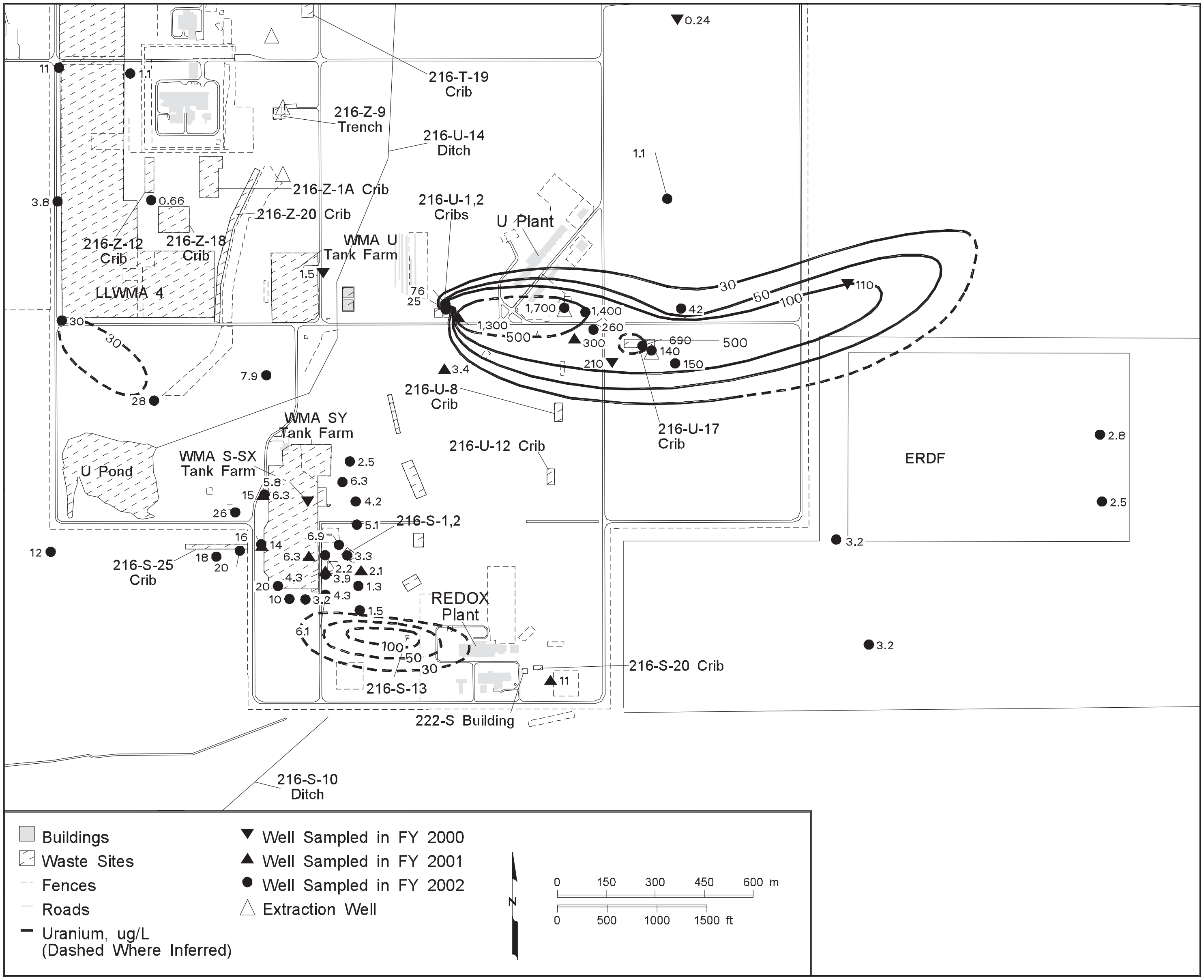


Figure 2.8-30. Tritium Concentration Trends in Wells Nearest to the State-Approved Land Disposal Site Through August 2001. Well 699-48-77C is completed ~20 meters deeper in the aquifer than wells 699-48-77A and 699-48-77D.



can_gw02_97 February 15, 2003 12:12 PM

Figure 2.8-31. Average Uranium Concentrations in the South 200 West Area, Top of Unconfined Aquifer

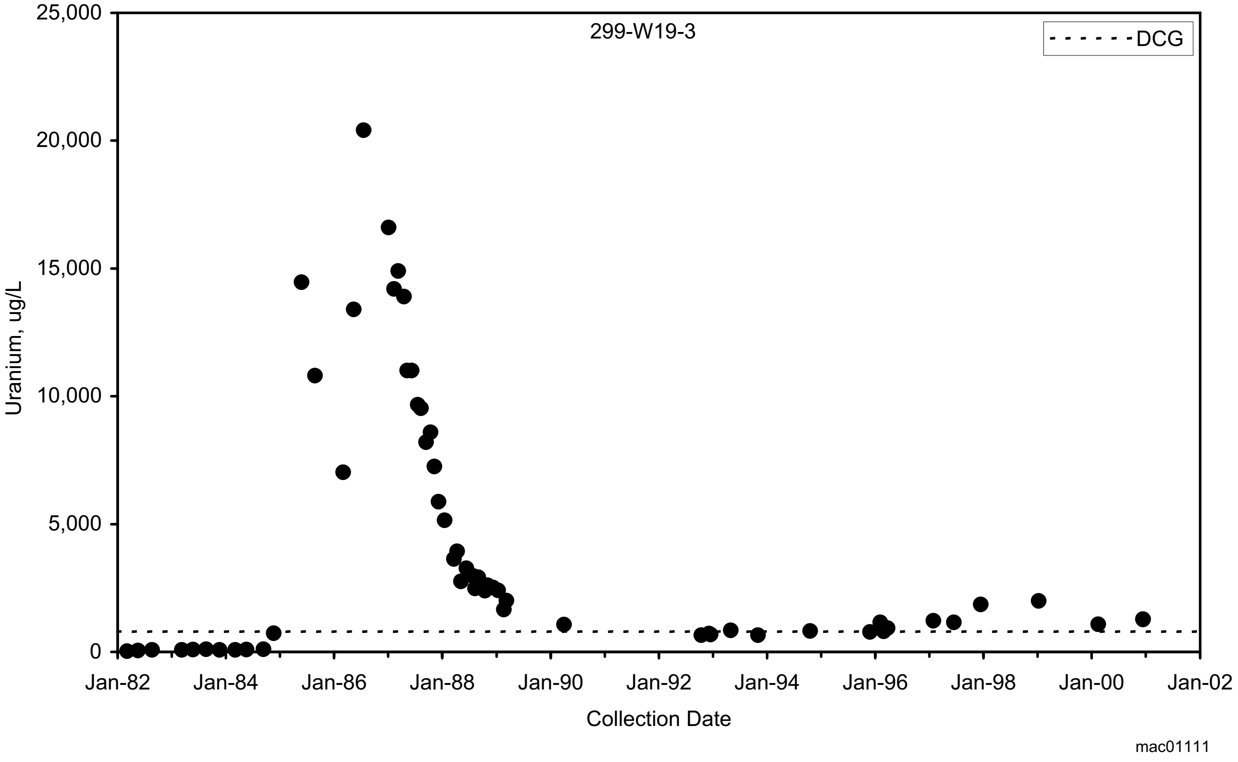


Figure 2.8-32. Uranium Concentrations Near the 216-U-1 and 216-U-2 Cribs

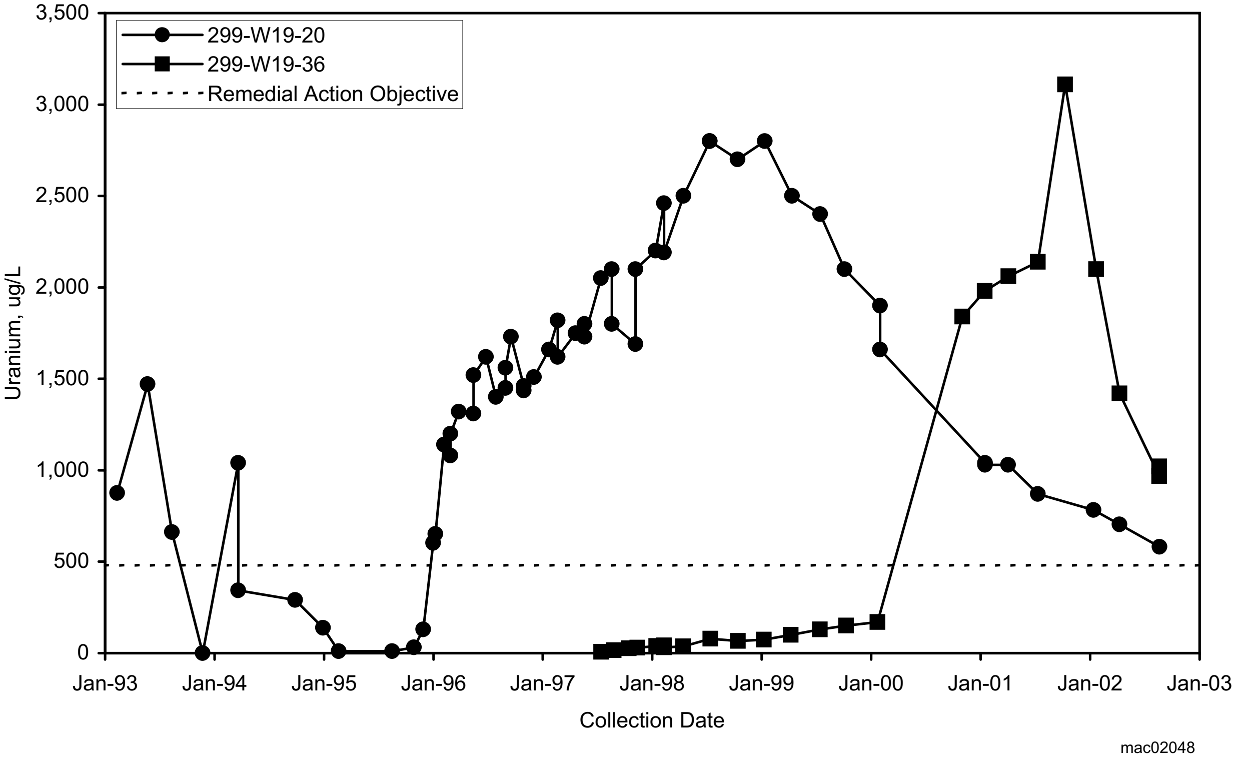
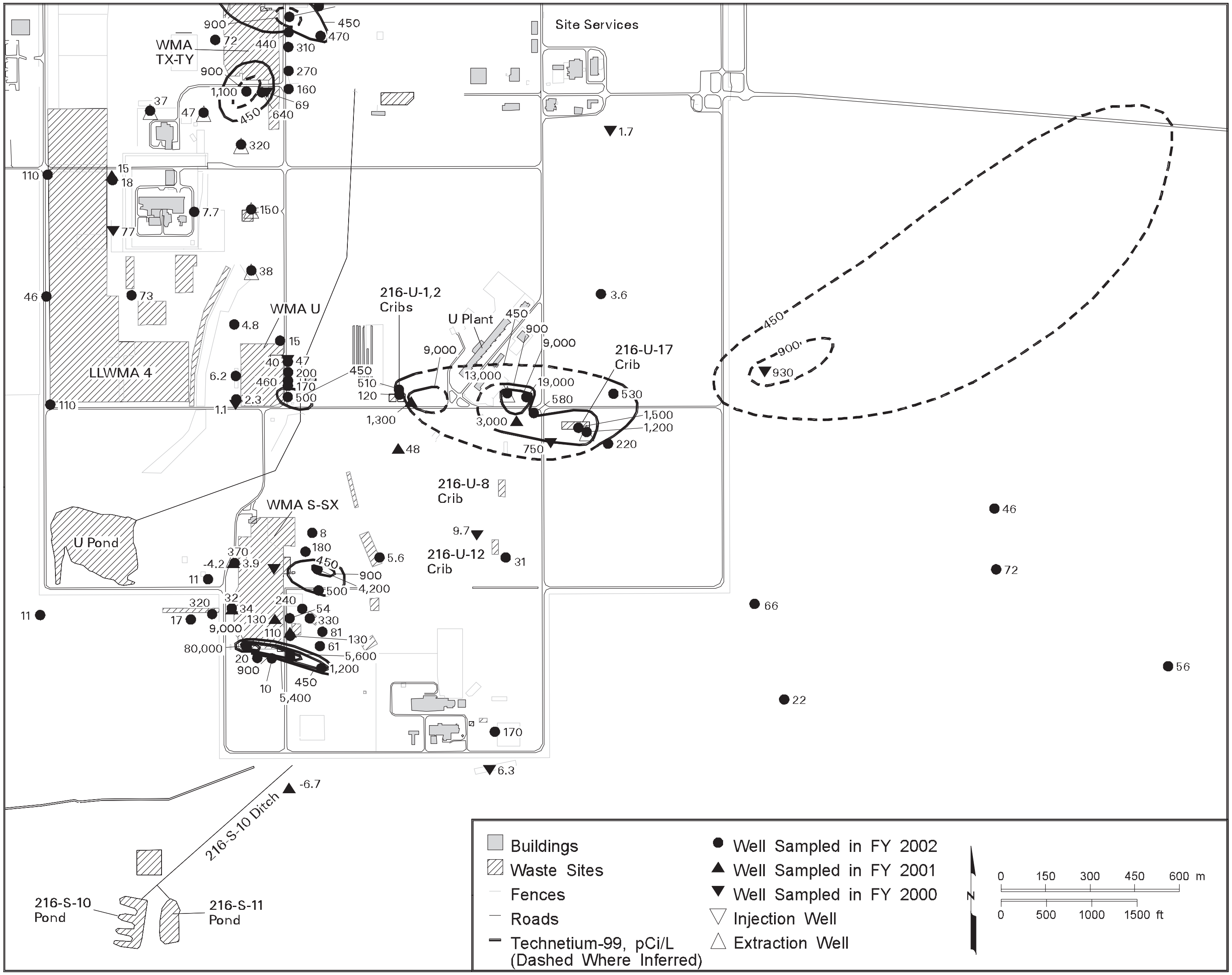


Figure 2.8-33. Uranium Concentrations at the 200-UP-1 Pump-and-Treat Area



can_gw02_39 February 14, 2003 4:52 PM

Figure 2.8-34. Average Technetium-99 Concentrations in the South 200 West Area, Top of Unconfined Aquifer

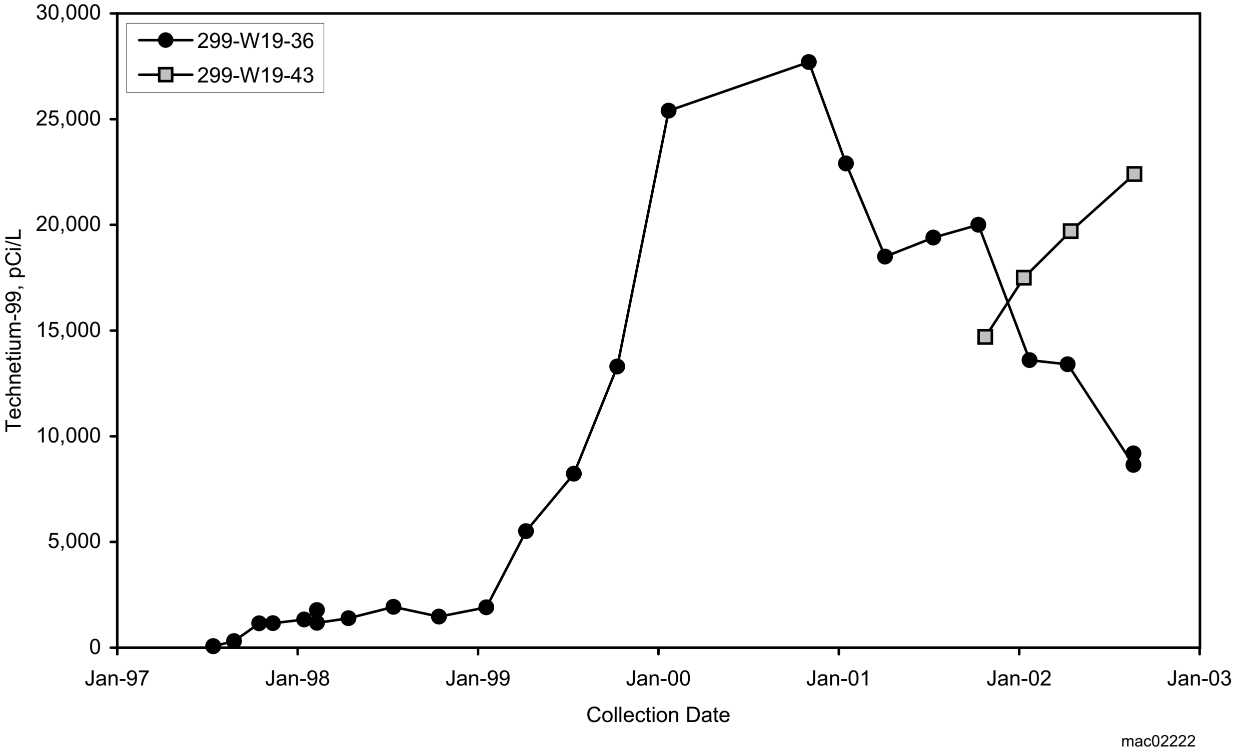


Figure 2.8-35. Technetium-99 Concentrations in Wells Monitoring the 216-U-1, 216-U-2, and 216-U-17 Cribs

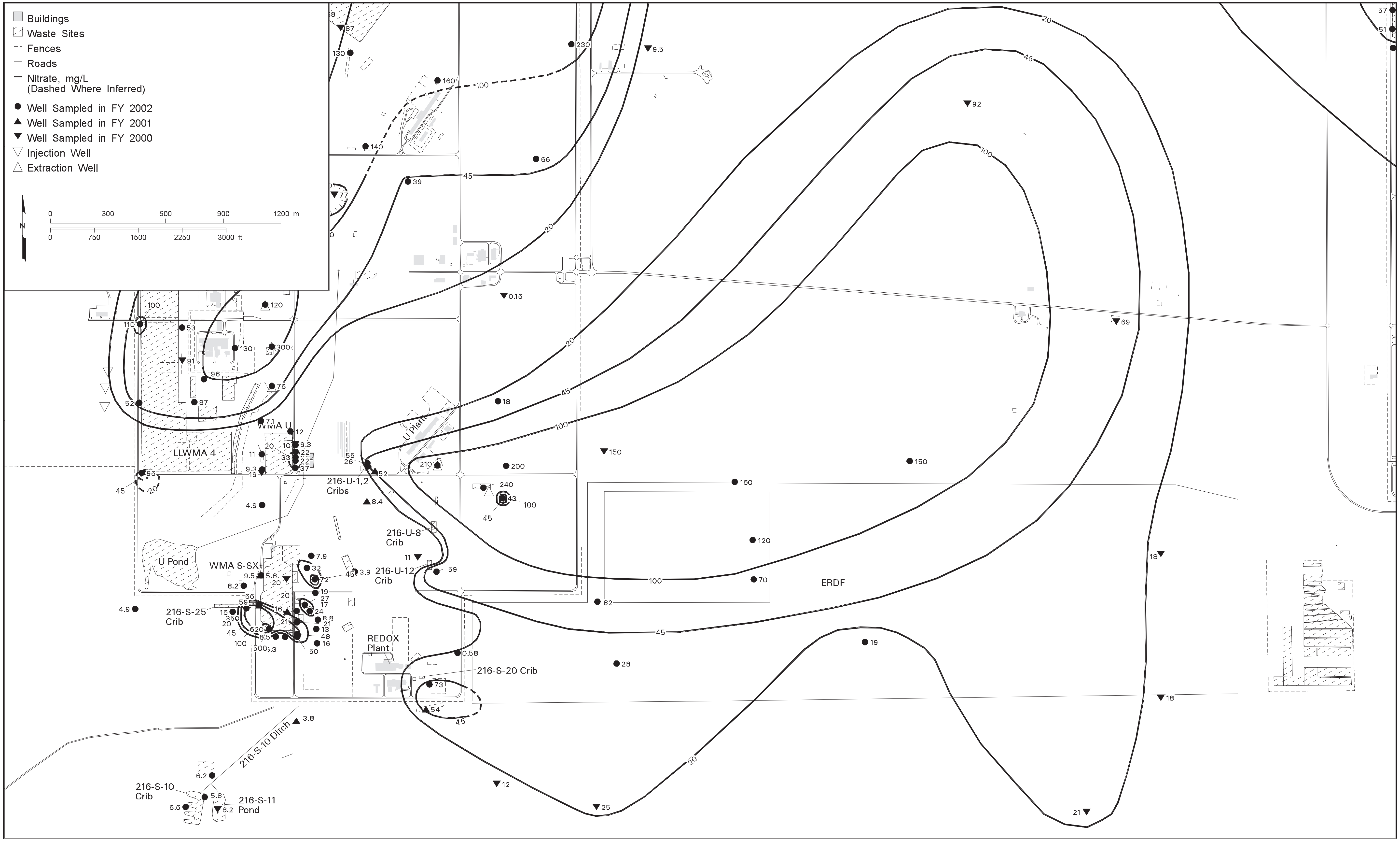


Figure 2.8.36. Nitrate Concentrations in the U Plant and REDOX Plant Areas, Top of Unconfined Aquifer

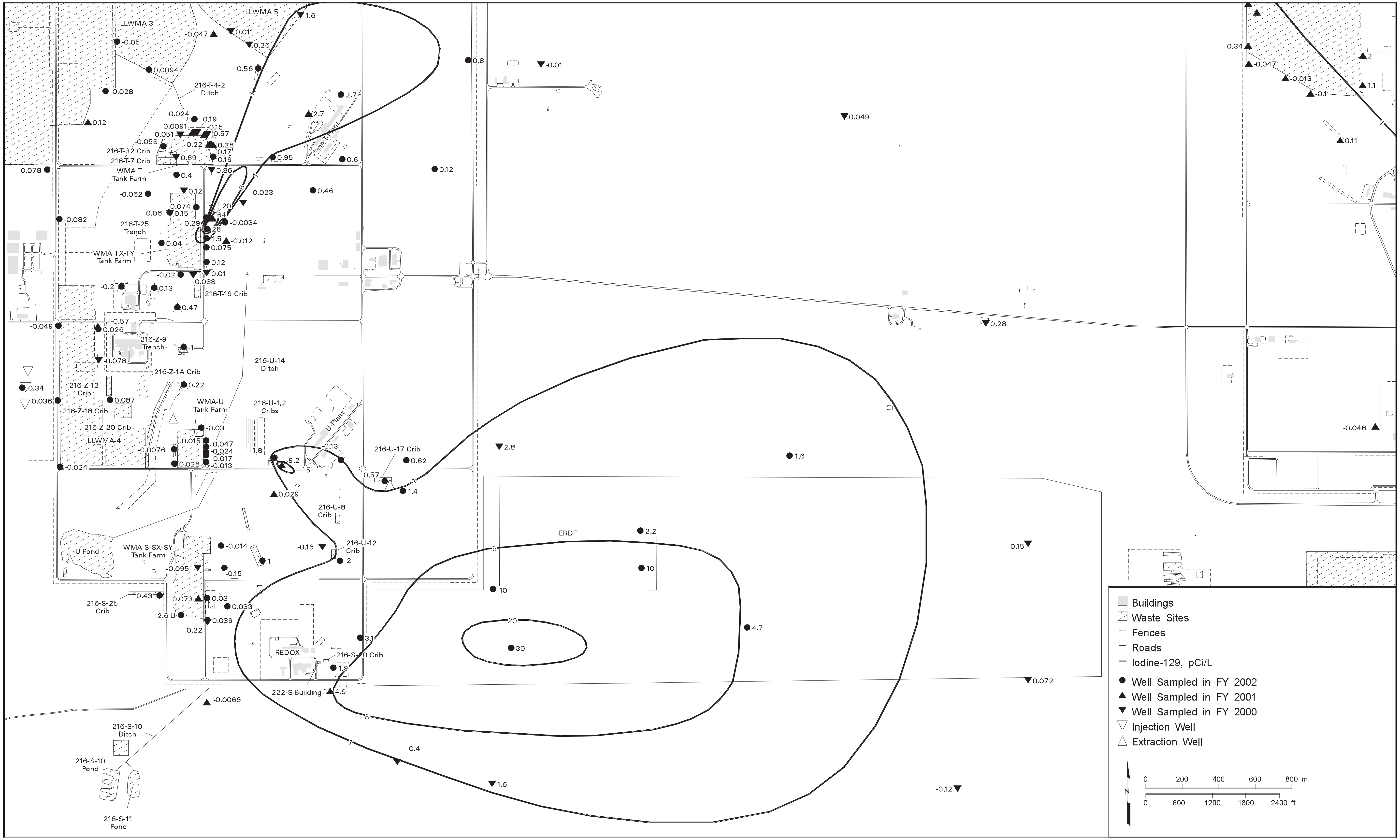


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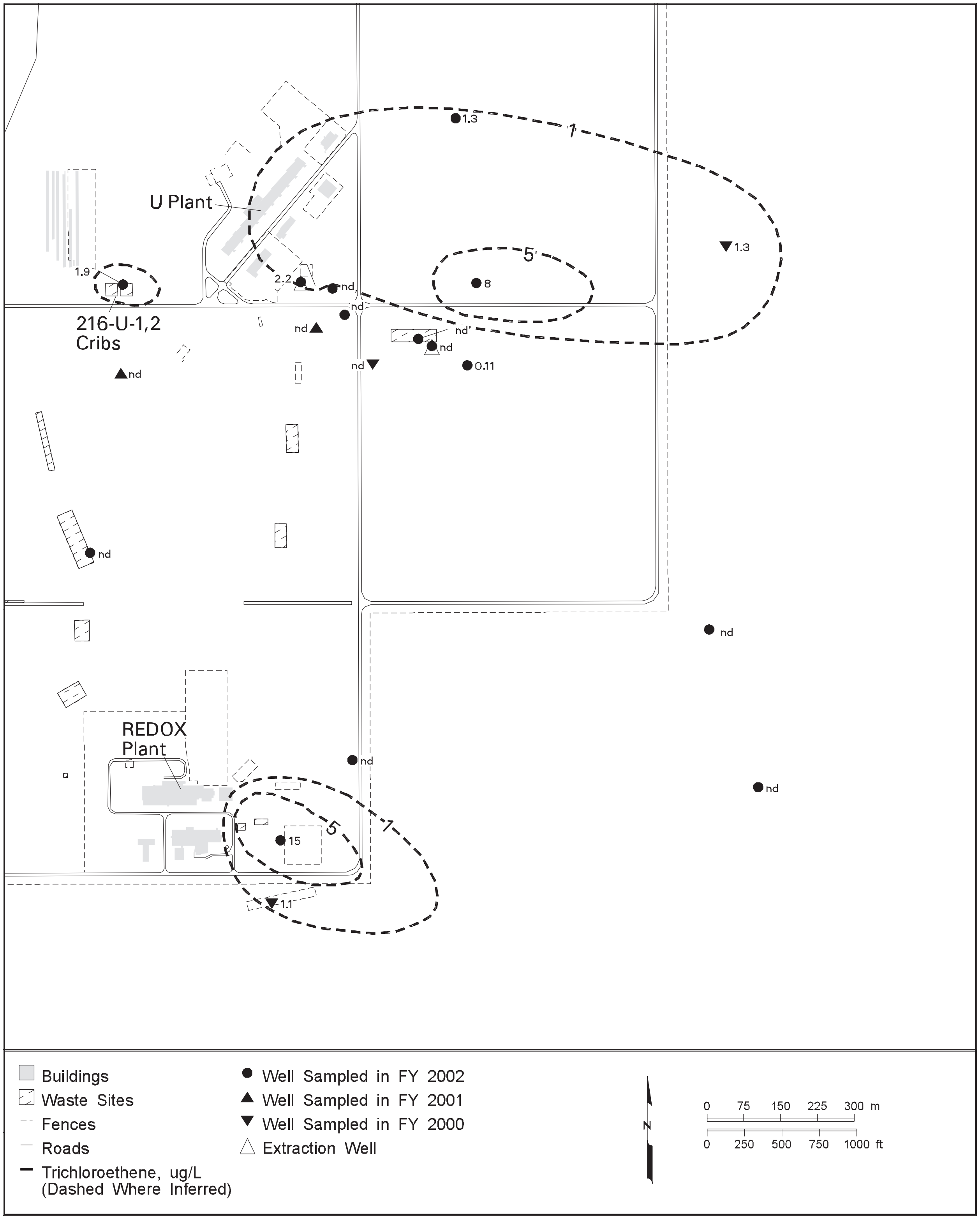
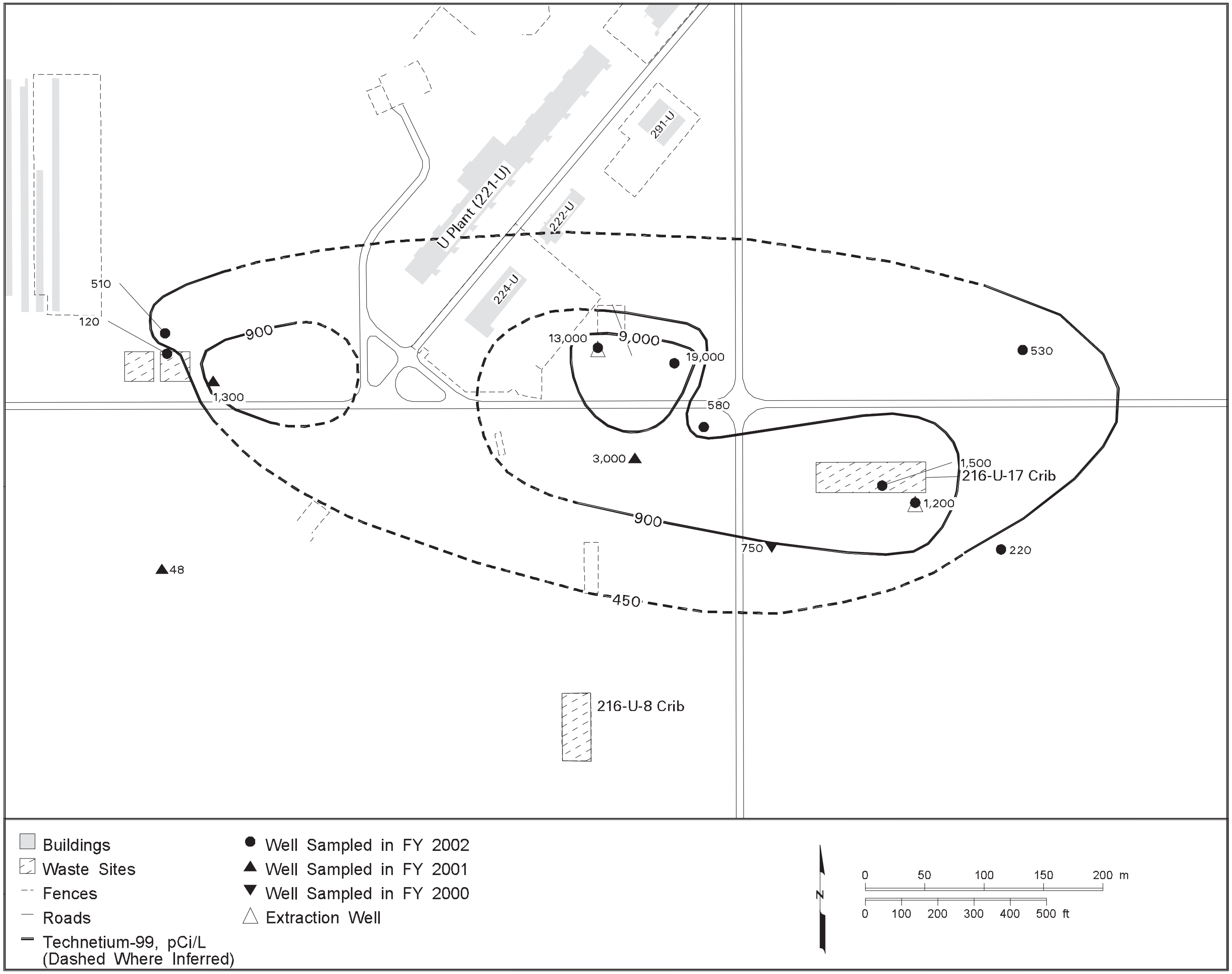
Figure 2.8-37. Average Iodine-129 Concentrations in the South and East 200 West Area, Top of Unconfined Aquifer



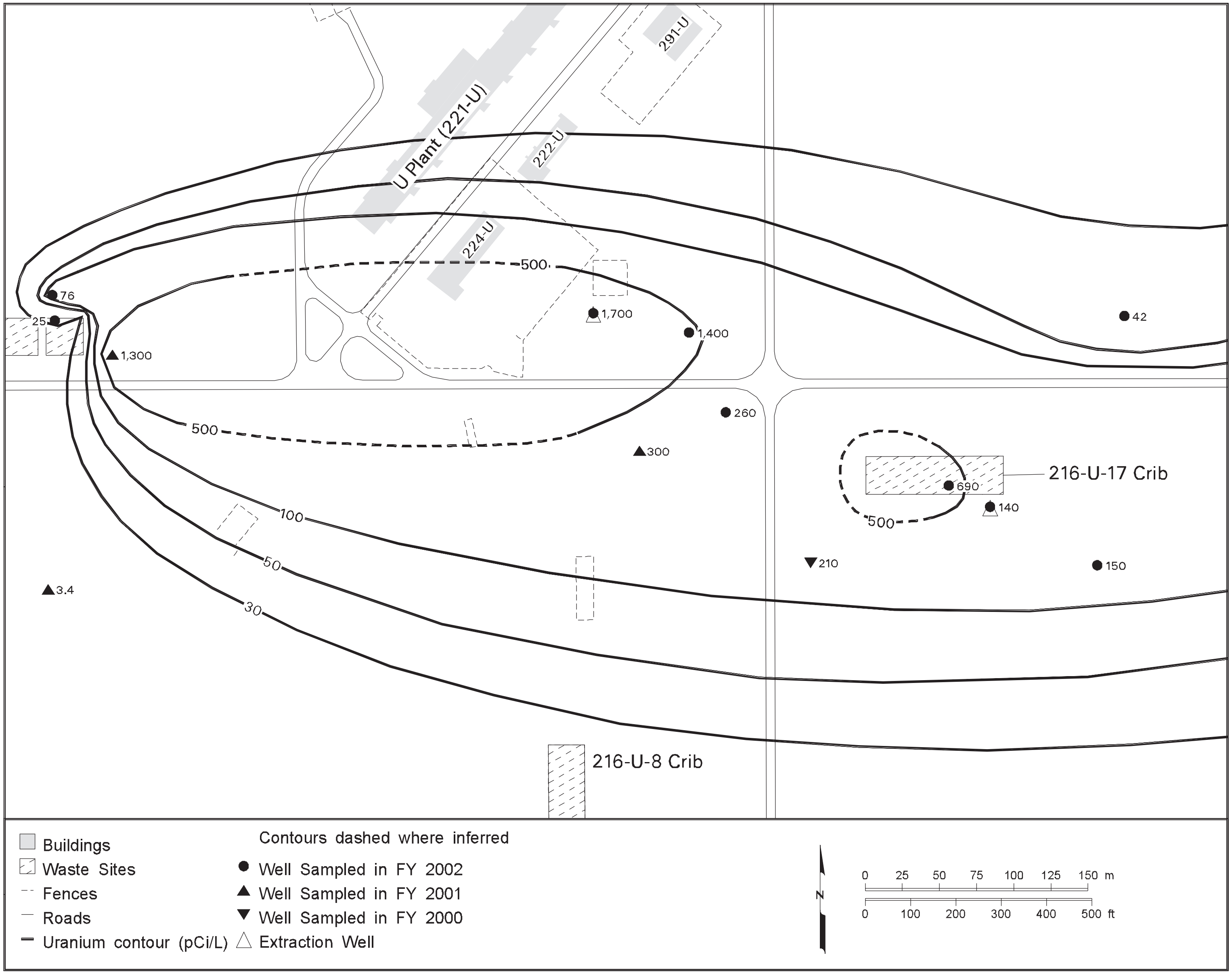
can_gwf02_281 February 14, 2003 4:53 PM

Figure 2.8-38. Trichloroethene Concentrations in the U Plant and REDOX Plant Areas, Top of Unconfined Aquifer



can_gw02_39a February 15, 2003 12:13 PM

Figure 2.8-39. Technetium-99 Plume at 200-UP-1 Pump-and-Treat Area, Top of Unconfined Aquifer



can_gw02_43 February 14, 2003 4:53 PM

Figure 2.8-40. Uranium Plume at 200-UP-1 Pump-and-Treat Area, Top of Unconfined Aquifer

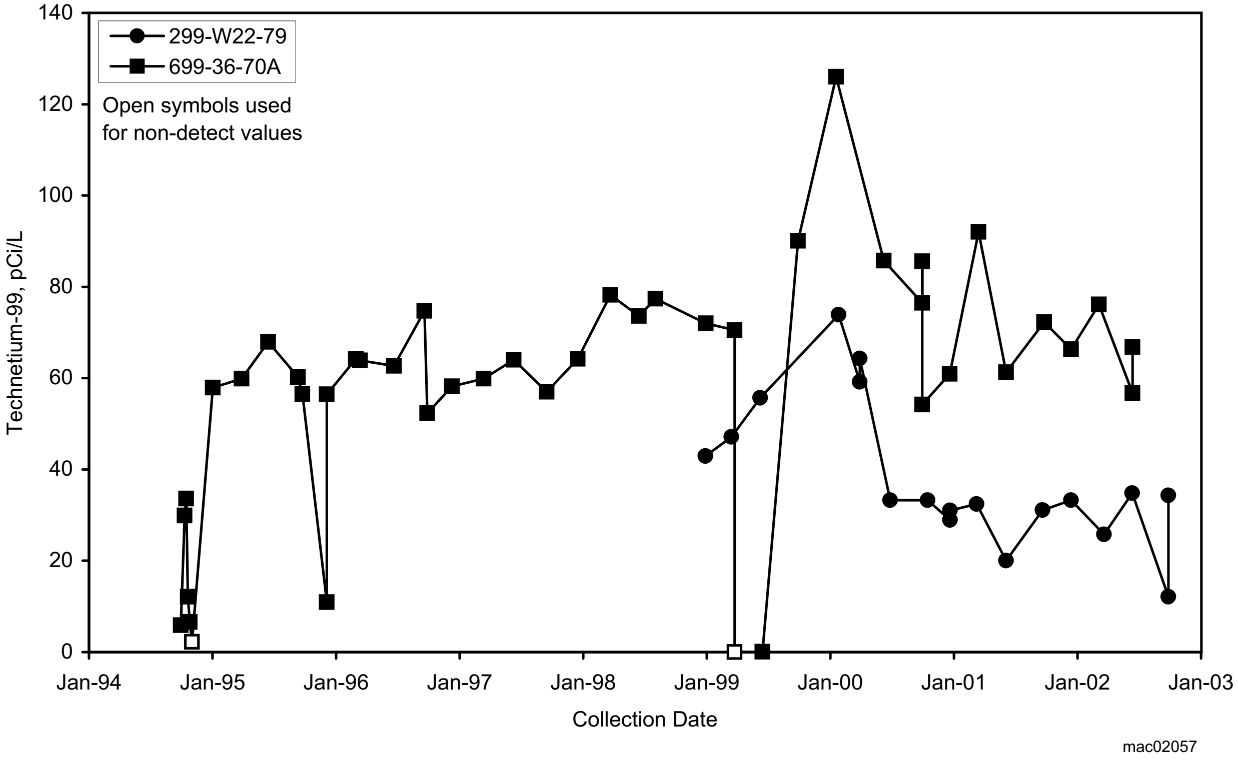


Figure 2.8-41. Technetium-99 Concentrations in Wells Near the 216-U-12 Crib

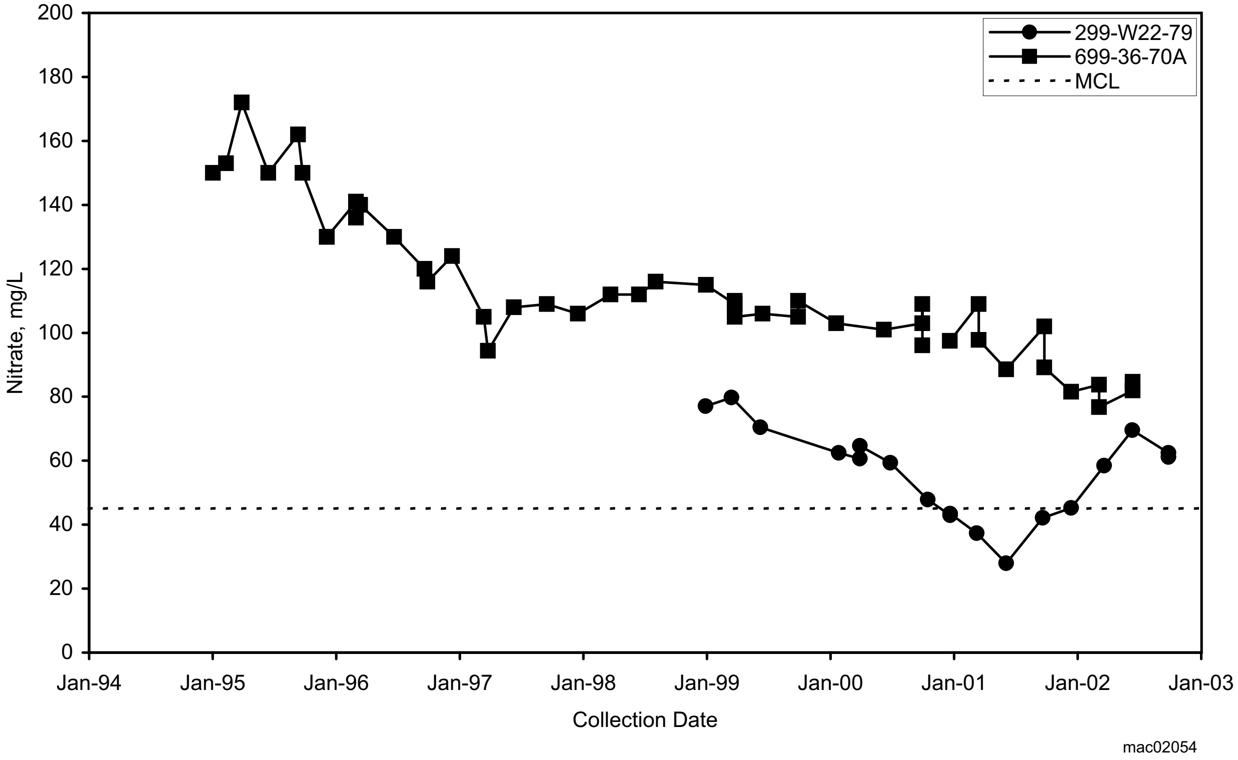


Figure 2.8-42. Nitrate Concentrations in Wells Near the 216-U-12 Crib

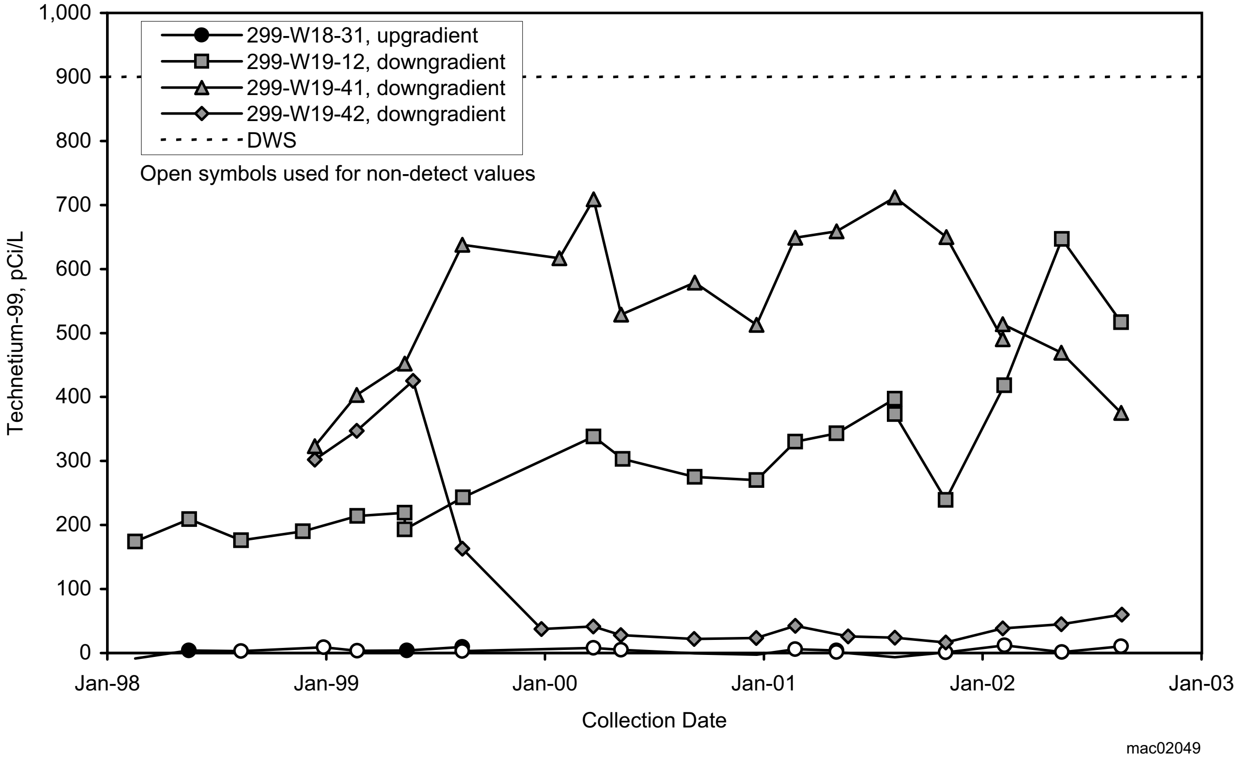


Figure 2.8-43. Technetium-99 Concentrations in Wells at Waste Management Area U

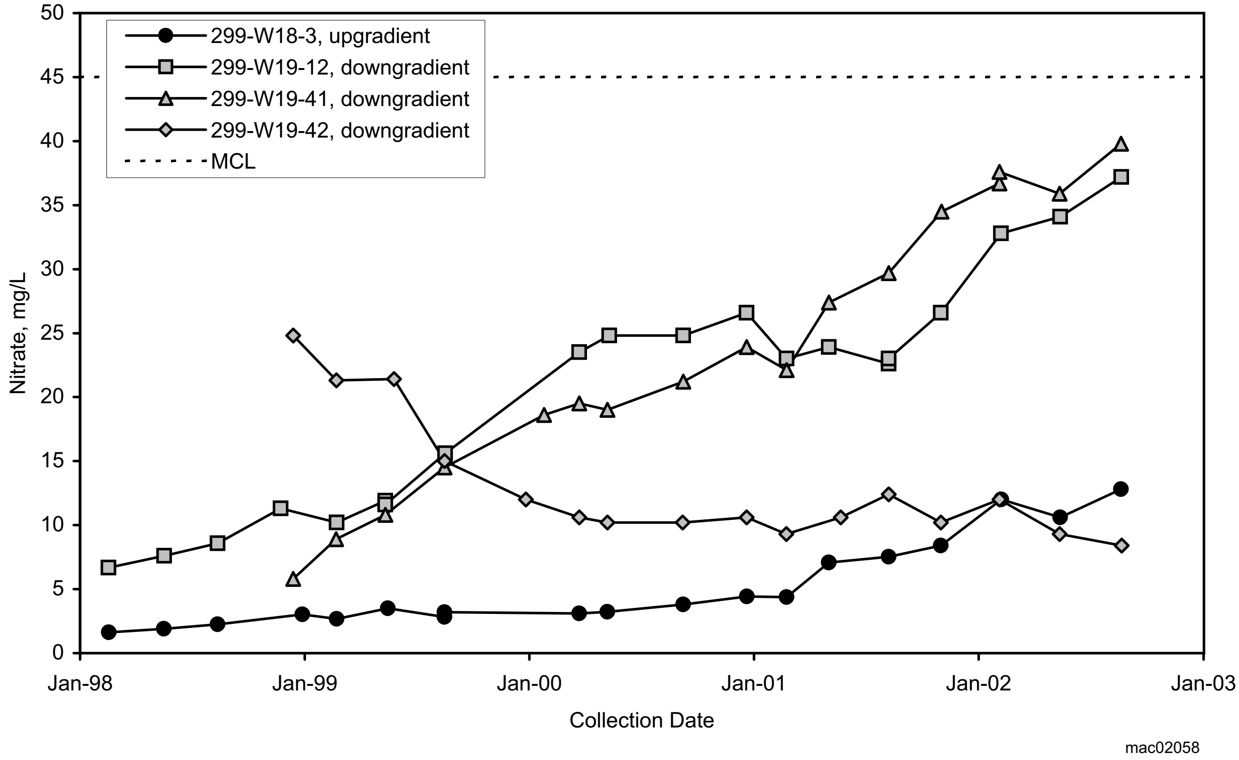


Figure 2.8-44. Nitrate Concentrations in Wells at Waste Management Area U

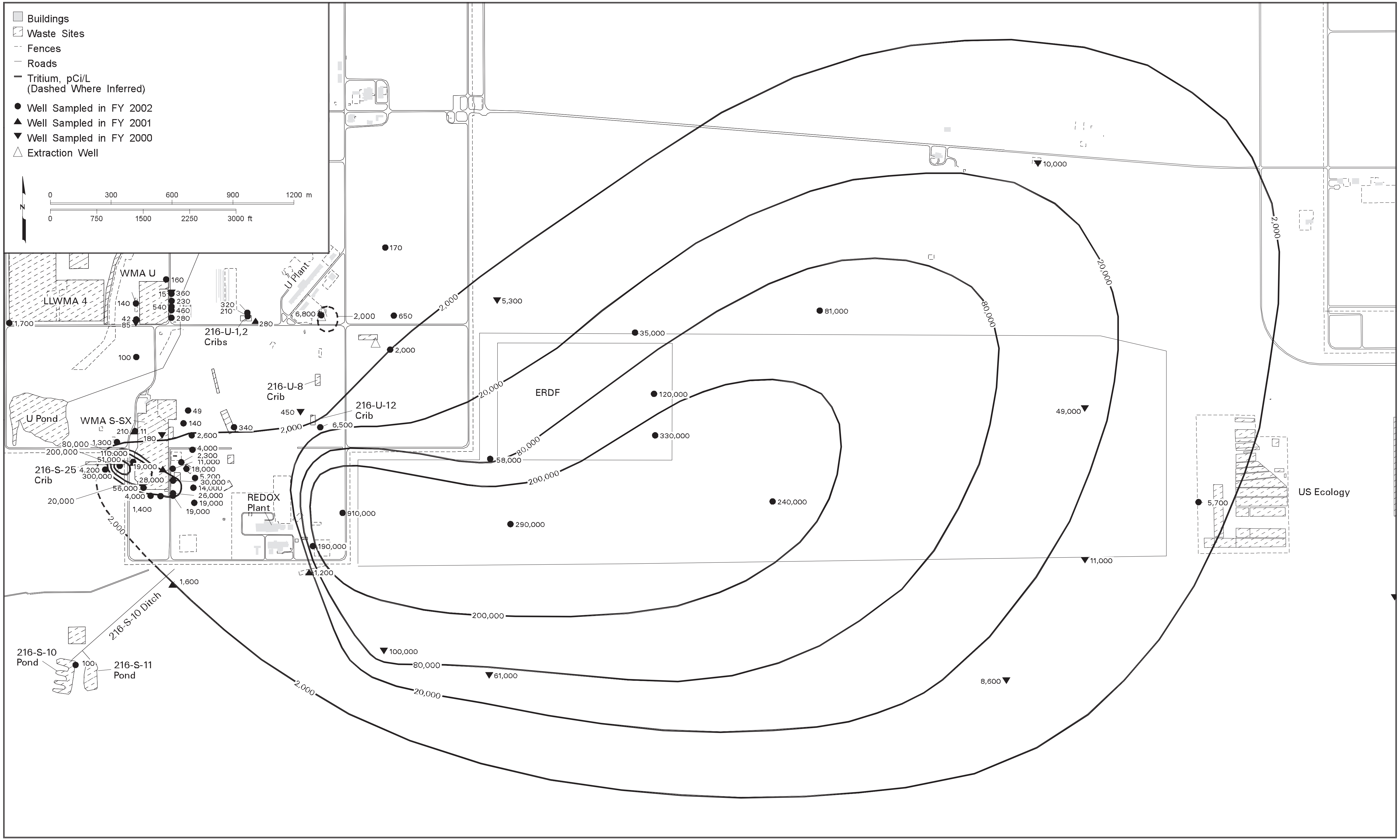


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Figure 2.8-45. Tritium Plume in the 200 West Area Near REDOX Plant, Top of Unconfined Aquifer

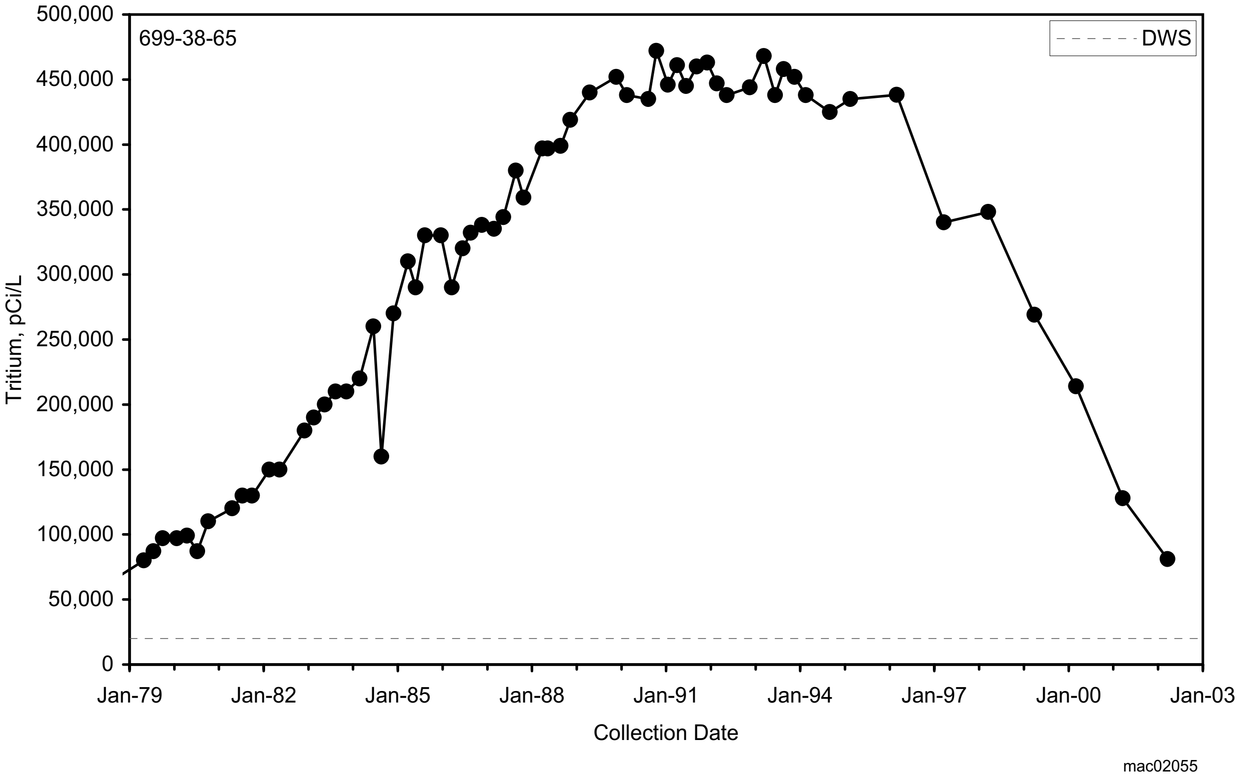
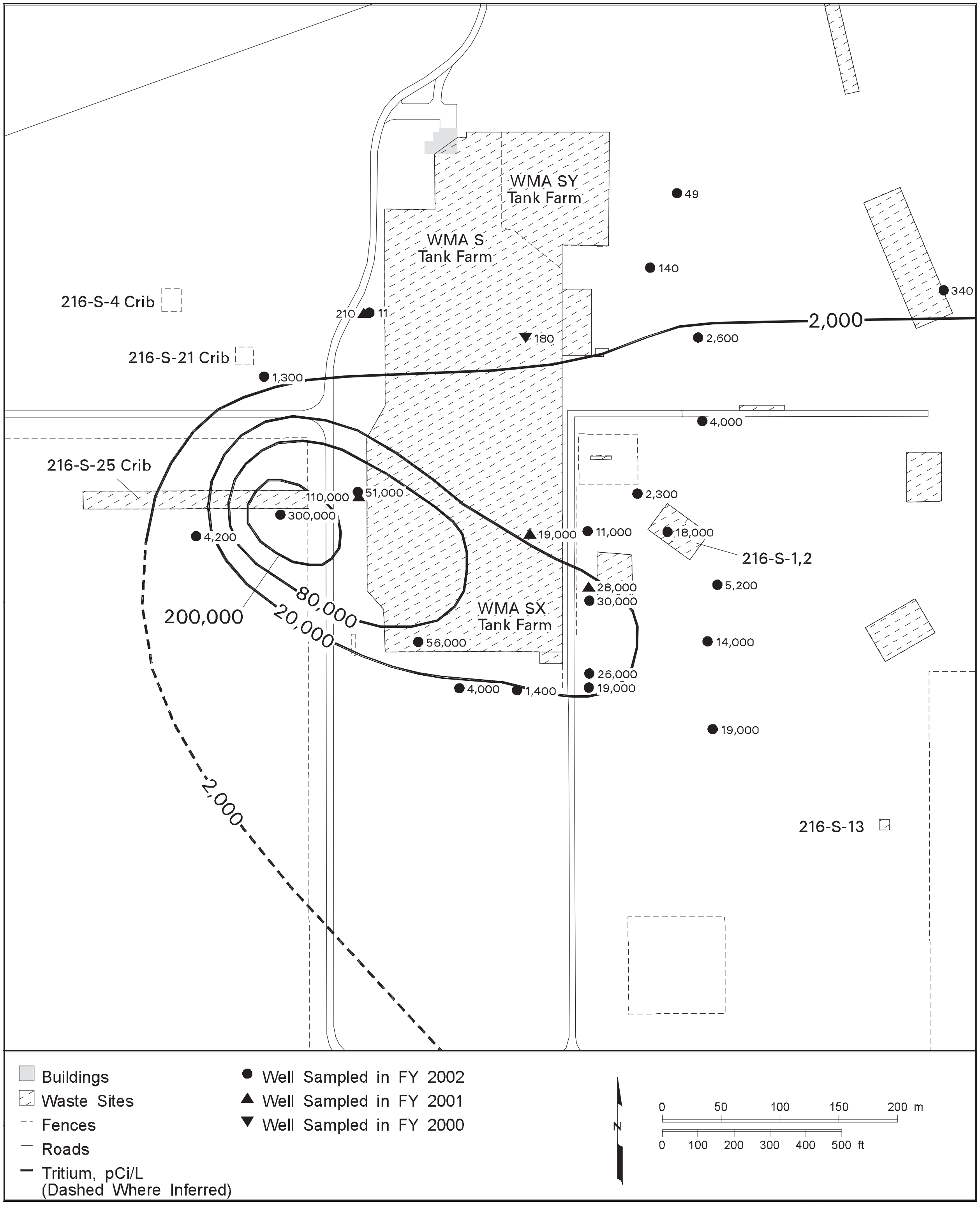
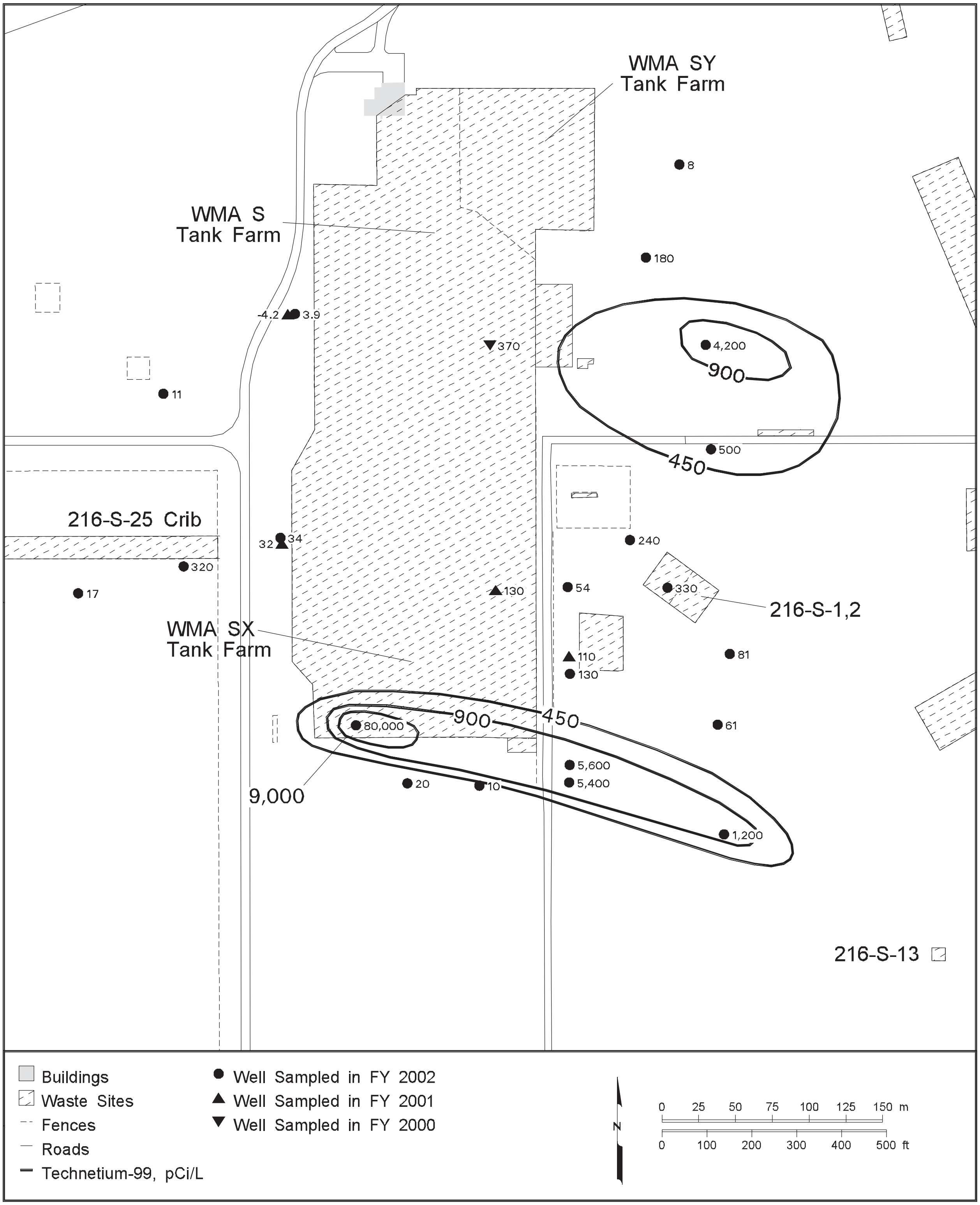


Figure 2.8-46. Tritium Concentrations East of 200 West Area REDOX Plant



can_gw02_72 February 14, 2003 4:54 PM

Figure 2.8-47. Tritium Concentrations in Wells Near the 216-S-25 Crib and Waste Management Area S-SX, Top of Unconfined Aquifer



can_gw02_95 February 14, 2003 4:54 PM

Figure 2.8-48. Average Technetium-99 Concentrations in Wells Near Waste Management Area S-SX, Top of Unconfined Aquifer

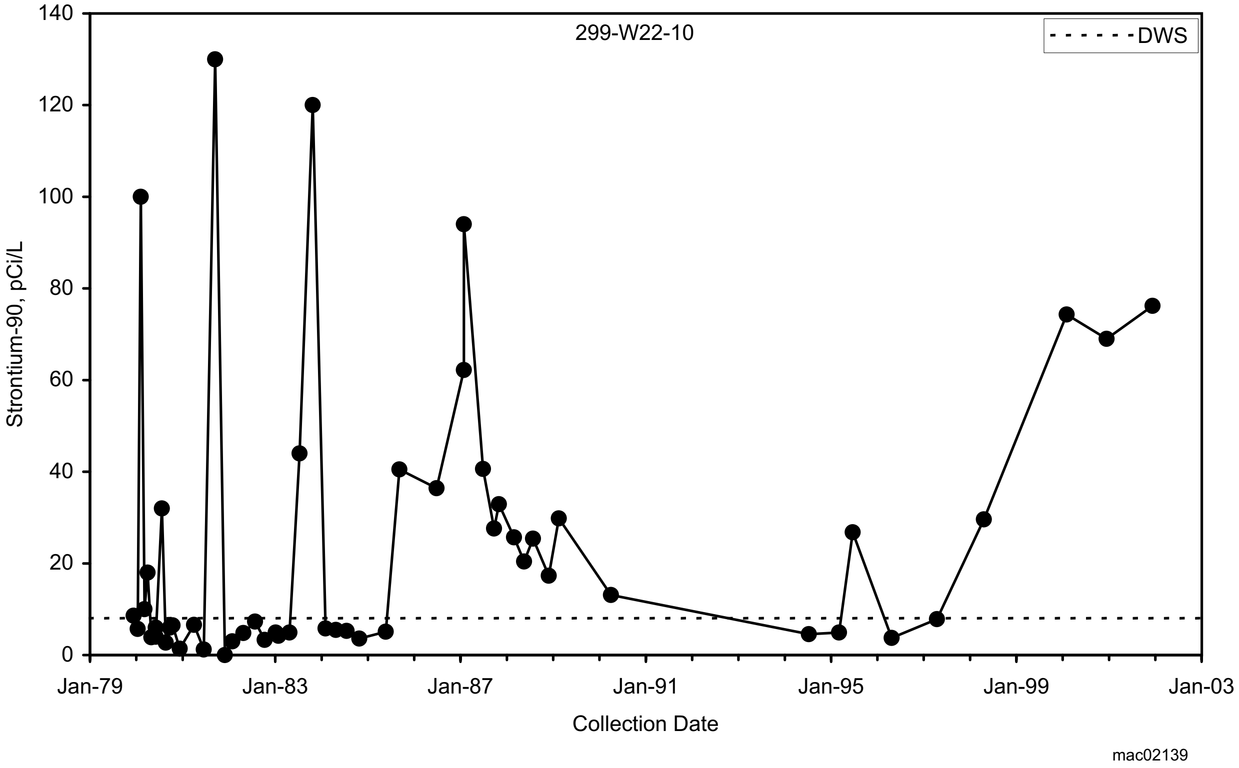


Figure 2.8-49. Strontium-90 Concentrations Southeast of the 216-S-1 and 216-S-2 Cribs

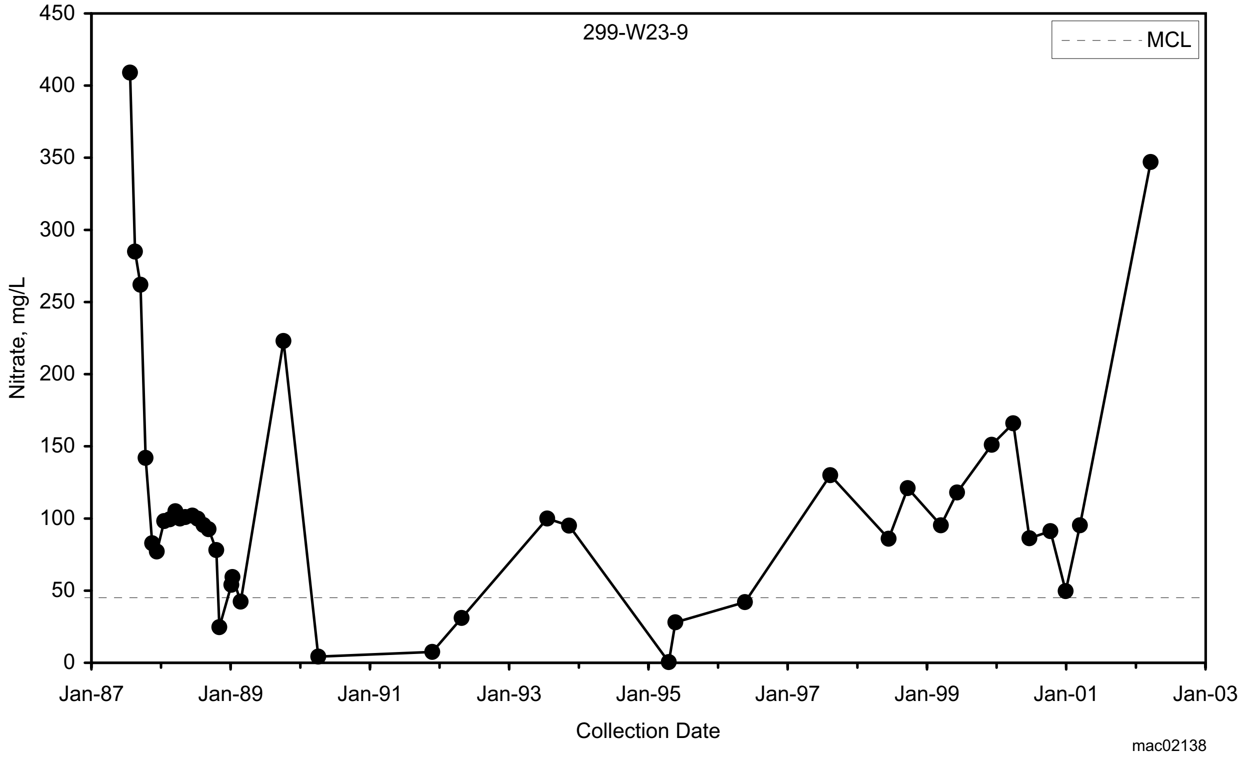


Figure 2.8-50. Nitrate Concentrations at the 216-S-25 Crib

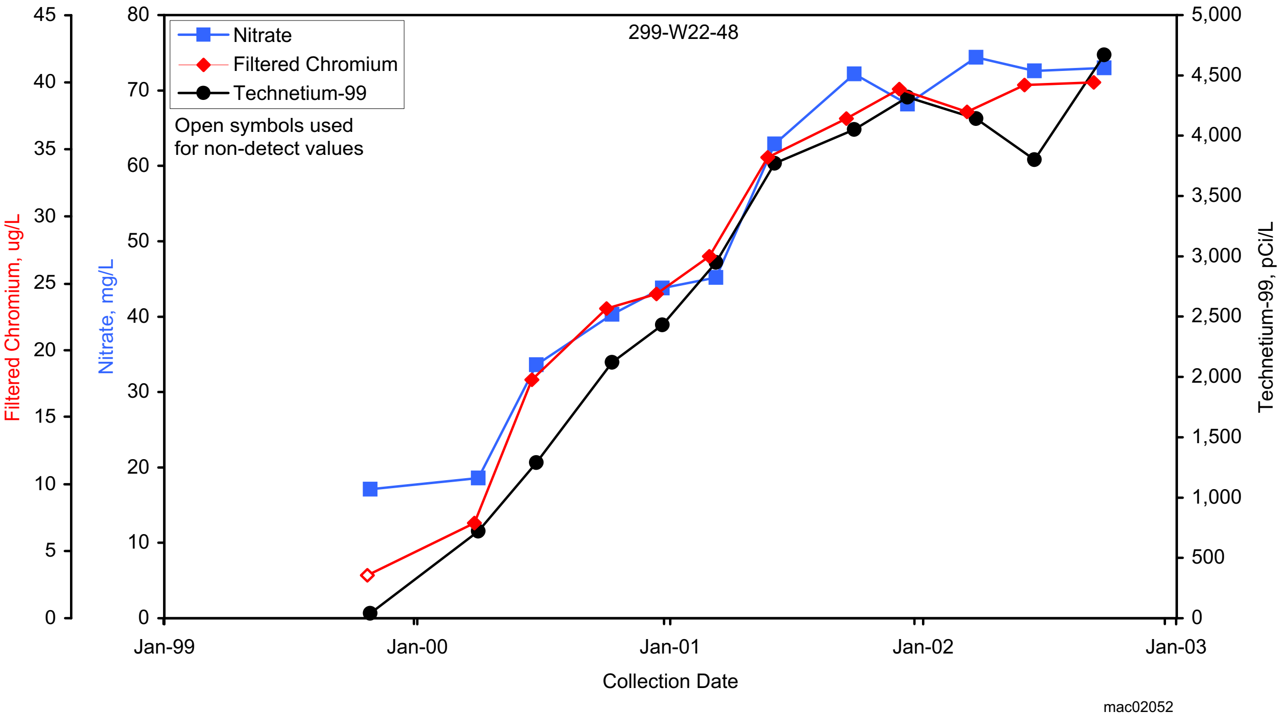


Figure 2.8-51. Technetium-99, Chromium, and Nitrate Concentrations East of the S Tank Farm

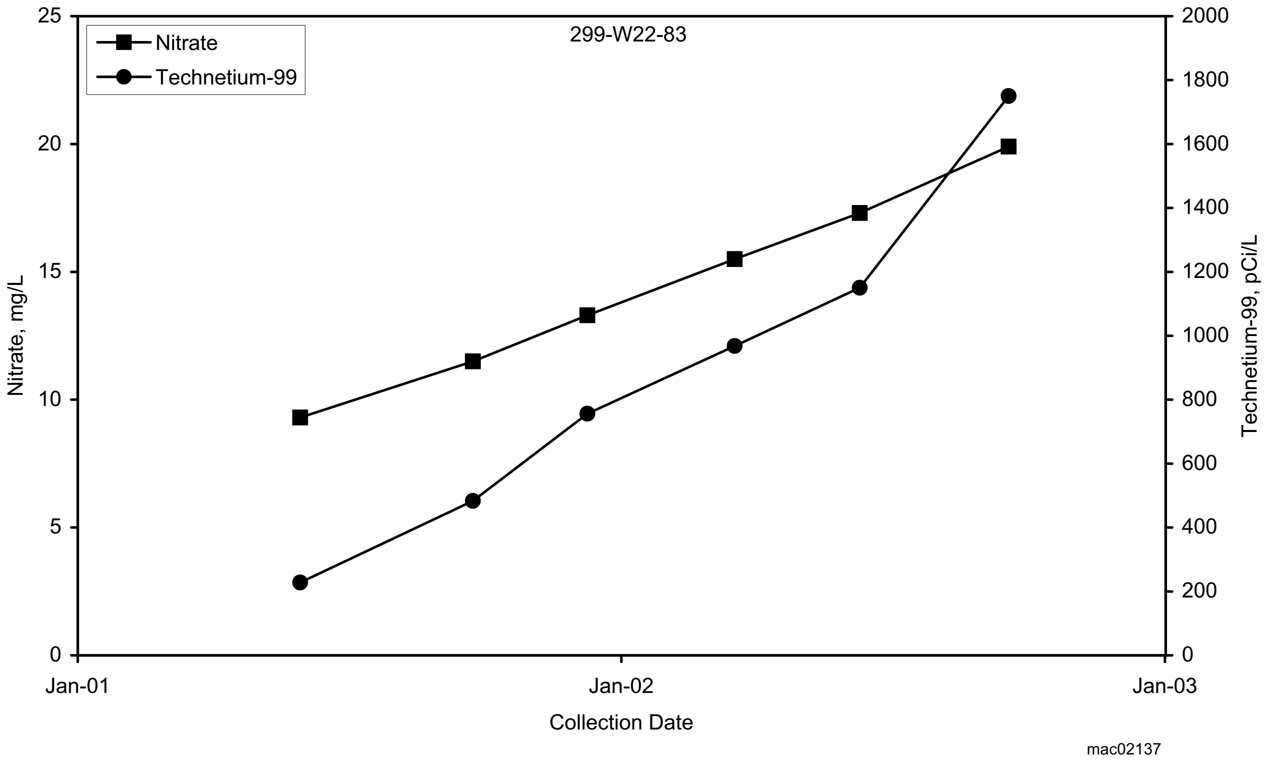


Figure 2.8-52. Technetium-99 and Nitrate Concentrations East of the SX Tank Farm

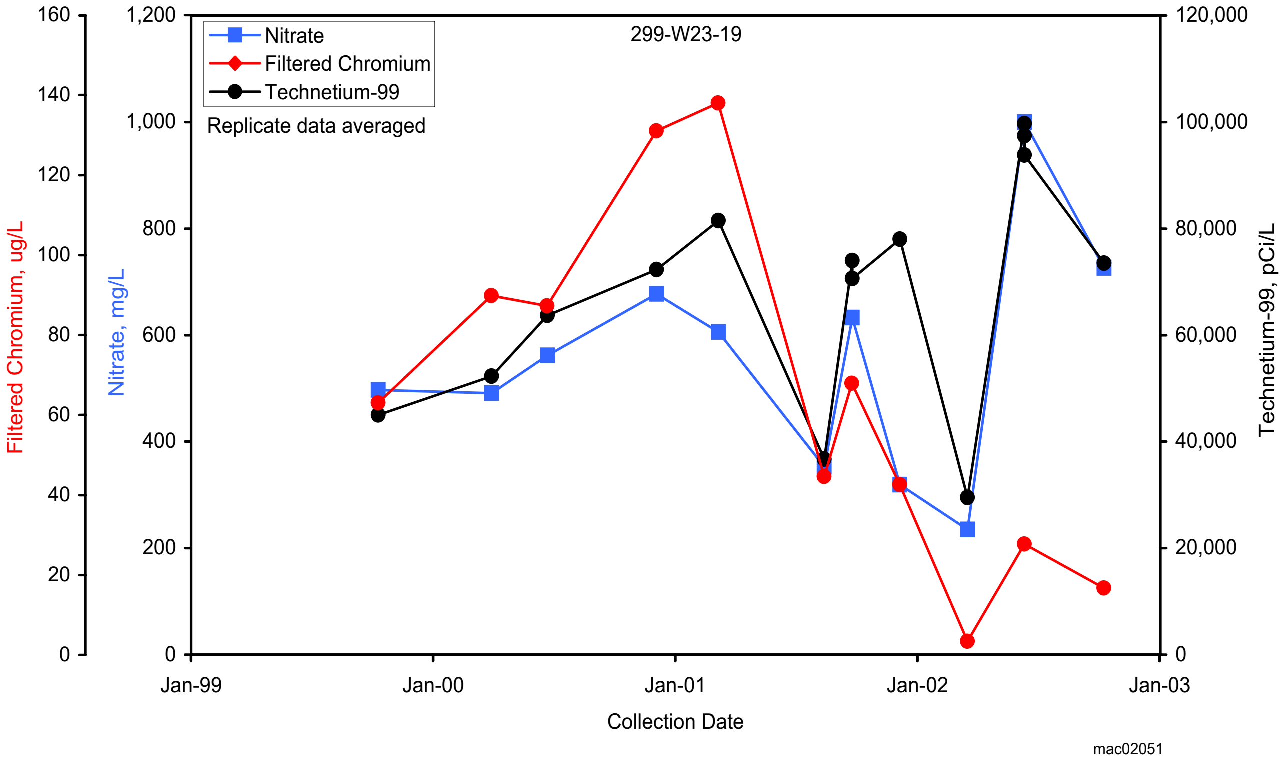


Figure 2.8-53. Technetium-99, Chromium, and Nitrate Concentrations Inside the Southwest Corner of the SX Tank Farm

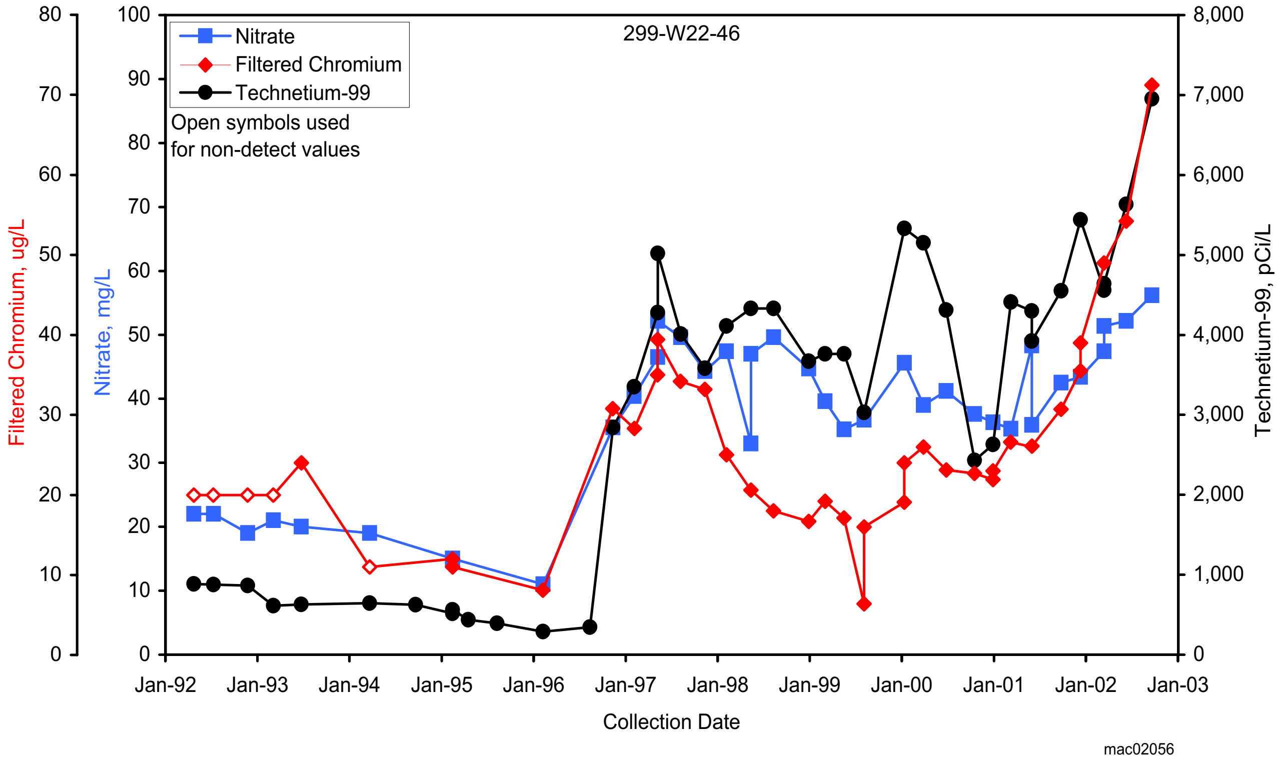


Figure 2.8-54. Technetium-99, Chromium, and Nitrate Concentrations in Well 299-W22-46 Southeast of Waste Management Area SX

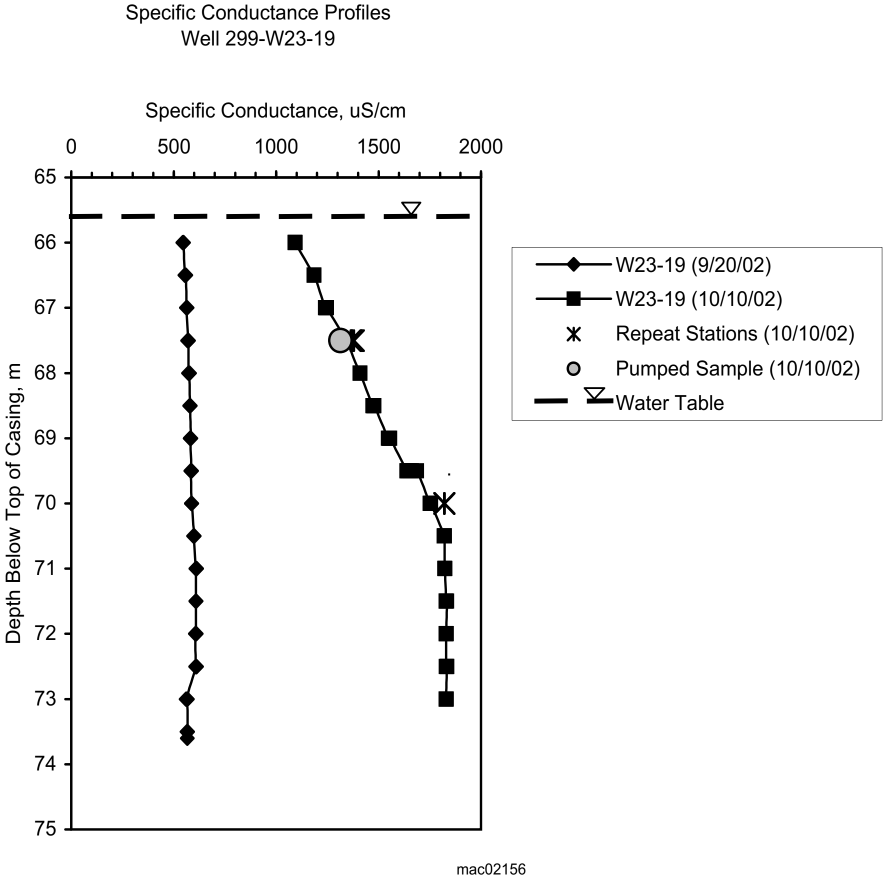


Figure 2.8-55. Specific Conductance in Well 299-W23-19 at Waste Management Area S-SX

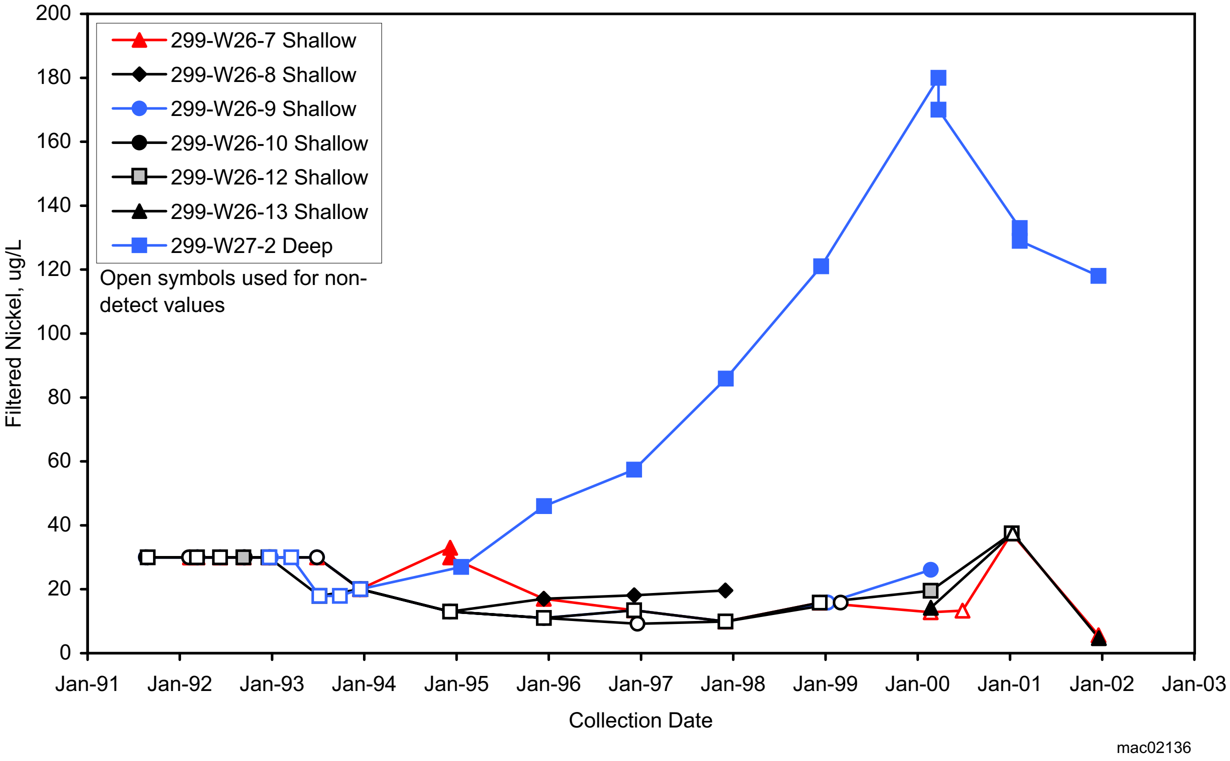


Figure 2.8-56. Nickel Concentrations Near the 216-S-10 Pond and Ditch

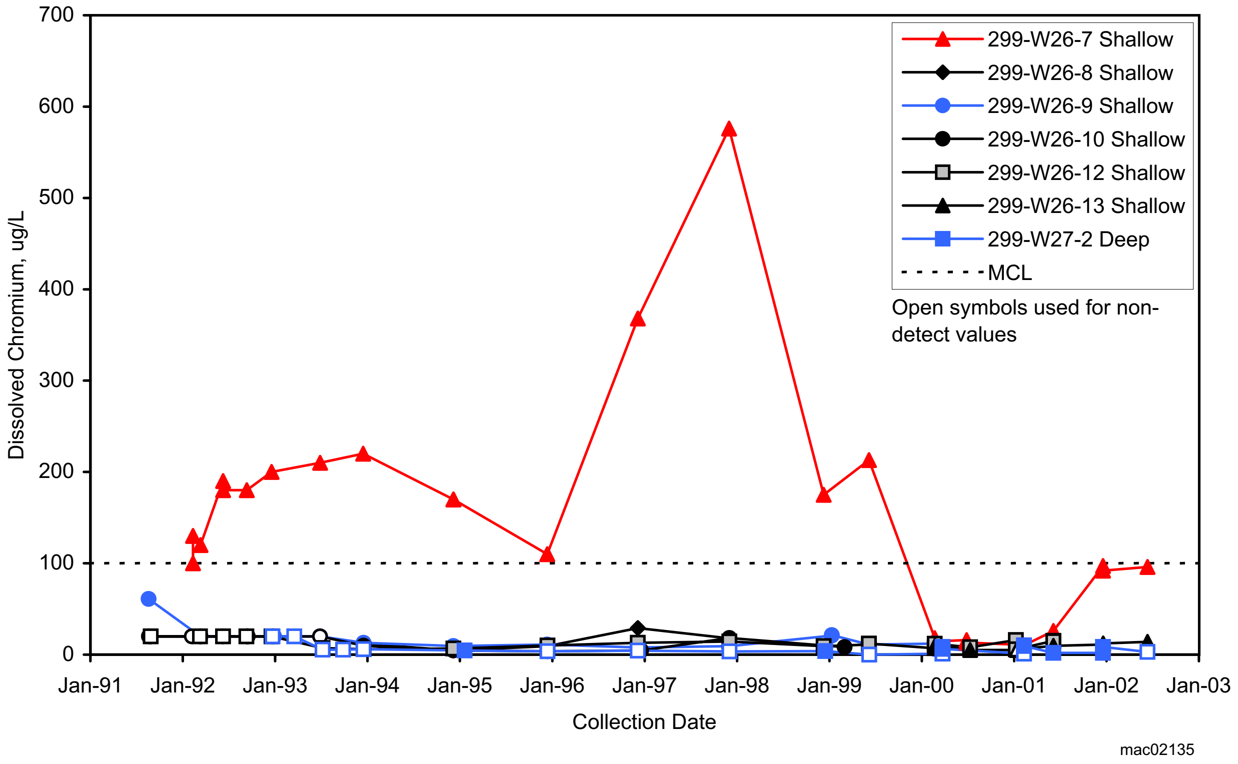


Figure 2.8-57. Chromium Concentrations Near the 216-S-10 Pond and Ditch

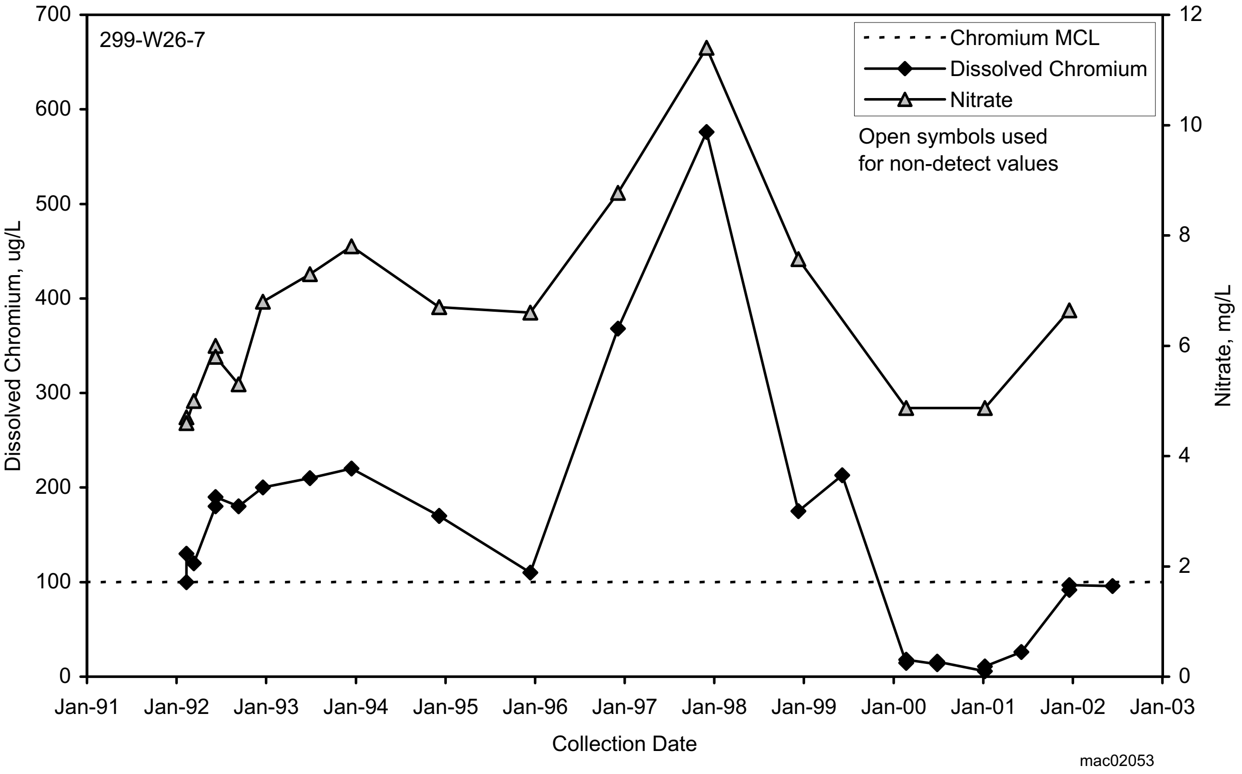


Figure 2.8-58. Covariance Between Chromium and Nitrate Concentrations in Well 299-W26-7 Near the 216-S-10 Pond and Ditch

2.9 200 East Area

J. W. Lindberg, E. C. Thornton, D. B. Barnett, J. P. McDonald, P. E. Dresel, S. M. Narbutovskih, and M. D. Sweeney

The 200 East Area, located on the Central Plateau of the Hanford Site, was used to process irradiated reactor fuel to extract plutonium between 1944 and 1990. The extraction took place at the B Plant and later at the Plutonium-Uranium Extraction (PUREX) Plant. Currently, the 200 East Area is used for waste management, storage, and disposal. Further details are provided in PNNL-13080.

For the purpose of describing groundwater contamination, the 200 East Area is divided into two parts:

- the B Plant area in the northwest and north parts of the 200 East Area (generally the *Comprehensive Environmental Response, Compensation, and Liability Act* [CERCLA] 200-BP-5 Operable Unit)
- the PUREX Plant area in the southeast and east parts of the 200 East Area (generally the *Resource Conservation and Recovery Act* [RCRA] Past-Practice 200-PO-1 Operable Unit)

Most of the 200 East Area groundwater contamination has its source in these two operable units (see Figure 2.1-6). A data quality objectives study was completed in fiscal year 2002 to identify specific groundwater monitoring needs in the

101_0156_IMG

A groundwater monitoring well is prepared for sampling: the well cap is being removed and the hose is being positioned to handle purgewater.

200-BP-5 and 200-PO-1 Operable Units (PNNL-14049). Sampling and analysis plans are also being prepared that update the operable unit monitoring networks.

This chapter includes a discussion of the regional contaminant plumes that extend northwest and southeast of the 200 East Area. These plumes have sources within the 200 East Area. Shoreline monitoring at the Hanford town site for tritium and other constituents from the 200 East Area also are discussed in this section. Under CERCLA regulations, contamination at Gable Mountain Pond and the 216-B-3 pond (B Pond) is considered part of a 200 East Area operable unit. Consequently, they also are discussed here. Strontium-90 and nitrate are significant contaminants around Gable Mountain Pond. A section on contamination in the confined aquifer in the Ringold Formation near B Pond also is included.

The discussion in this section is divided into two parts representing these two areas within the overall 200 East Area. Within each section, the general groundwater flow, major contaminants, and specific RCRA facility monitoring are discussed. The major groundwater contaminants of the 200 East Area are tritium, iodine-129, technetium-99, and nitrate. Also discussed is uranium, strontium-90, and other radionuclide contamination, which is less extensive.

2.9.1 B Plant

Monitoring Objectives at B Plant

Groundwater monitoring is conducted near B Plant:

- triennially to annually to describe the nature and extent of regional contamination
- semiannually to monitor trends in various constituents/wells
- semiannually to detect possible impact of six RCRA waste management areas
- quarterly to assess contamination from one RCRA waste management area

This section describes the area surrounding B Plant including waste storage and disposal facilities north of the plant (Figure 2.9-1). B Plant was used to recover plutonium from irradiated fuel using the bismuth phosphate process from 1945 to 1956. Contamination in the B Plant area is the result of waste disposal to the soil at a variety of locations. Throughout the active life of B Plant, the waste that was disposed to these facilities included effluent from process streams, chemicals, cooling water, and condensate. Due to similarity in the chemical makeup of some of the waste, it is difficult to assign regional groundwater contaminants to individual waste sites. However, there are instances where contaminants sources can be assigned to specific waste facilities. The broadly distributed groundwater plumes throughout the east Central Plateau, however, are the result of disposal to unspecified waste units within the B Plant area and adjacent PUREX complex (see Section 2.9.2). Monitoring wells within the 200 East Area are shown in Figure 2.9-1.

Groundwater in this vicinity is considered part of the 200-BP-5 Operable Unit. Waste sites include past-practice disposal facilities regulated under CERCLA or RCRA. The BY cribs, the 216-B-5 injection well, and Gable Mountain Pond are included in the 200-BP-5 Operable Unit. RCRA facilities include low-level burial grounds Waste Management Areas 1 and 2, the 216-B-63 ditch, the Liquid Effluent Treatment Facility, and the tank farms in Waste Management Areas B-BX-BY and C. Of the RCRA facilities associated with B Plant, only the tank farm in Waste Management Area B-BX-BY is monitored under a groundwater assessment plan because it is believed to have contaminated groundwater with hazardous constituents. Much of the detailed information on contaminant distributions in this area was collected as part of the RCRA assessment for the tank farms. Section 2.9.1.11 on Waste Management Area B-BX-BY is written to support the annual reporting requirements of RCRA regulations. Because of the multiple sources in the area, several of which have affected the groundwater in the immediate vicinity of the tank farm, the groundwater flow and contaminant distributions will be discussed in a general sense first. Then specific conclusions related to the tank farm assessment and other RCRA detection monitoring will be discussed.

2.9.1.1 Groundwater Flow

The small differences in water-table elevation across the B Plant area make it difficult to determine the direction of groundwater flow from water-table maps (Figure 2.9-2). Therefore, several other techniques are used to examine groundwater flow in this region. The results based on these techniques are compared for consistency with each other and with groundwater flow theory. The techniques used to determine groundwater flow within the B Plant area consist of plume maps and contaminant trend plots, water-level trend surface analysis, water-level hydrographs for multiple wells, and in situ flow measurements at groundwater wells.

In pre-Hanford times, groundwater in the B Plant area is believed to have flowed toward the southeast. Currently, groundwater entering the 200 East Area from the west divides and flows to the Columbia River along two separate paths: one to the southeast and one to the northwest across a buried anticline and through the gap between Gable Butte and Gable Mountain (i.e., Gable Gap). The pre-Hanford water-table elevation in the 200 East Area vicinity was ~120 meters in the North American Vertical Datum of 1988 (NAVD88). Wells drilled to basalt in the vicinity of the buried anticline show basalt elevations from 119 to 122 meters (NAVD88). Therefore, it is likely that a significant portion of the buried anticline was present above the water table in pre-Hanford times and blocked the northwest flow pathway resulting in southeasterly flow beneath the B Plant area.

During Hanford operations, a significant quantity of liquid effluent was discharged to the soil column in the 200 East Area. This caused the water table to rise and groundwater beneath the B Plant area to flow toward the northwest. The decline in liquid effluent discharges to the soil in the 200 East Area, and the resulting decline in the water table, is expected to cause groundwater flow in the B Plant area to reverse direction and resume its pre-Hanford flow toward the southeast. This interpretation is generally consistent with recent three-dimensional transient modeling results.

Groundwater flow moved contaminants to the north and northwest in the B Plant area during the period of effluent disposal. Current flow direction in this area has not been determined with certainty because the water table is flat.

An in situ flow meter (the colloidal borescope) was used during fiscal year 2000 to determine local groundwater flow directions. The results indicate a generally south to southeast flow direction across the study area; however, considerable variation was observed in flow direction between wells (see PNNL-13404 for a full discussion). Also during fiscal year 2000, a water-level trend surface analysis was conducted for both the 216-B-63 trench and Low-Level Waste Management Area 1. This technique fits a plane to a set of water-level measurements using least squares regression. The results indicate that groundwater flow is to the southwest beneath the 216-B-63 trench, while groundwater flow beneath Low-Level Waste Management Area 1 is toward the northwest (which appears inconsistent with results of the borescope study). The March 2002 water-level data collected at Low-Level Waste Management Areas 1 and 2 were analyzed using a 3-point solver on multiple groups of three wells. The results for Low-Level Waste Management Area 1 indicate northwest flow, where the results for Low-Level Waste Management Area 2 were inconclusive (see Section 2.9.1.13).

Constituents typically used to track groundwater flow in the B Plant region are tritium, technetium-99, iodine-129, and nitrate because they are not significantly affected by interactions with the aquifer matrix. Contamination from the B Plant area is known to occur to the north and northwest of the 200 East Area, which means that groundwater at some time in the past moved in this direction. A recent analysis of nitrate/technetium-99 ratios and the local tritium plume at Waste Management Area B-BX-BY suggest flow in a southward direction (see Section 2.9.1.11). The movement of contaminants beneath Low-Level Waste Management Area 1, especially tritium, is generally interpreted as supporting northwest flow. To date, the direction of groundwater flow beneath the 216-B-63 trench cannot be determined using groundwater chemistry, since this area has no significant contamination.

Considering the available information on groundwater flow in the B Plant area, the following conceptual model was developed. The generally south flow beneath Waste Management Area B-BX-BY (based on borescope data, hydrographs, and contaminant movement) and flow to the southwest at the 216-B-63 trench (based on trend surface analysis) is a direct result of the declining water table, as groundwater flows in a perpendicular direction away from the southeast-northwest buried anticline. Farther from the anticline, the saturated thickness and, thus, the transmissivity, increases sharply and flow becomes southeasterly. The flow divide between the southeast and northwest pathways, which was present to the southeast of the B Plant area during Hanford Site operations, is migrating to the northwest in response to the declining water table because less water is being transmitted through Gable Gap. Currently, this flow divide occurs within the B Plant area somewhere between Waste Management Area B-BX-BY and Low-Level Waste Management Area 1, or perhaps within the southeast half of Low-Level Waste Management Area 1.

This conceptual model is preliminary and uncertain. The elevation of the basalt across the buried anticline is not well known because wells drilled to basalt in this area are sparse. It is possible that a significant gap was eroded into this anticline, and its presence remains undiscovered. If this were the case, the northwest flow pathway would be much more transmissive than is currently recognized, so the flow divide would not be expected to migrate very far to the northwest. Further, determining the direction of groundwater flow in the 200 East Area using constituent sampling data is difficult because of the many potential contaminant source areas and the widespread distribution of contaminants in groundwater. There may be other explanations for this data that are inconsistent with the conceptual model, such as other sources affecting the groundwater or overlapping plumes. In particular, water-line leaks, sanitary septic systems, and leakage from the potable water storage basin may locally affect flow direction and contaminant distribution. Therefore, efforts to verify this conceptual model and better understand groundwater flow in the B Plant area will continue. For a more complete discussion of groundwater flow in the B Plant area, see PNNL-13404.

2.9.1.2 Tritium

Tritium contamination is widespread throughout the northwest part of the 200 East Area. The contamination extends north through the gap between Gable Mountain and Gable Butte toward the Columbia River. Tritium contamination from B Plant has declined greatly because of natural decay and dilution.

Tritium contamination is widespread throughout the northwest part of the 200 East Area. The contamination extends north through the gap between Gable Mountain and Gable Butte toward the Columbia River and southeast toward the PUREX Plant (see Figure 2.1-3). Tritium contamination from B Plant has declined greatly because of natural decay and dilution. The highest concentrations are in the south part of the 200 East Area and represent contamination from the PUREX Plant that moved to the northwest under past flow conditions. Given the widespread, low-level nature of the contamination, it is likely that a number of waste disposal facilities contributed to the plume.

Tritium concentrations in the B Plant area have declined since 1990. No new data were collected in fiscal year 2002 in the vicinity of the 216-B-5 injection well owing to waste control issues.

Tritium at levels above the drinking water standard can be found between Gable Mountain and Gable Butte and extends to the northwest (see Figure 2.1-3). Concentrations in monitoring well 699-61-62 in Gable Gap continued to decline with a measured concentration for fiscal year 2002 of 28,000 pCi/L. Wells 699-60-60 and 699-64-62 are at fairly constant levels of 31,000 and 24,000 pCi/L, respectively.

Well 699-72-73, between the 100-B/C and 100-K Areas, exceeded the drinking water standard for the first time in fiscal year 2001 but declined to 14,000 pCi/L in fiscal year 2002.

Tritium values have increased recently at the south end of Waste Management Area B-BX-BY. The maximum average tritium value in this region in fiscal year 2002 was 17,000 pCi/L in well 299-E33-334.

2.9.1.3 Iodine-129

Contamination from iodine-129 is present throughout the B Plant area. Like the tritium plume, the iodine-129 plume extends to the northwest toward the Gable Mountain/Gable Butte gap and southeast toward the PUREX Plant (Figures 2.9-3 and 2.1-5). Unlike tritium, levels greater than the iodine-129 drinking water standard (1 pCi/L) have not passed the Gable Mountain/Gable Butte gap. Iodine-129 concentrations range up to 6 pCi/L in well 299-E33-34. Iodine-129 concentrations have increased slowly in that well but appear to have stabilized in the last several years. A band of elevated iodine-129 concentrations (~5 pCi/L) extends from the vicinity of the 216-B-63 trench, through Waste Management Area B-BX-BY, to the northeast corner of Low-Level Waste Management Area 1. Interpretation of the iodine-129 configuration in this area is complicated by elevated detection limits that result from interference of technetium-99. In addition, the current laboratory reporting system produced some values reported as not detected at levels greater than the 1 pCi/L-drinking water standard.

2.9.1.4 Technetium-99

A plume of technetium-99 extends from the area of the BY cribs and Waste Management Area B-BX-BY to beyond the 200 East Area boundary to the northwest (Figure 2.9-4). The larger part of the plume is to the north and is interpreted to represent early releases of technetium-99 from the BY cribs. Detection of technetium-99 at levels lower than the 900-pCi/L drinking water standard north of the Gable Mountain/Gable Butte gap indicates that in the past, technetium-99 moved north, into, and through the gap. See Figure 2.2-2 for locations of wells in the 600 Area.

A plume of technetium-99 extends from the area of the BY cribs to beyond the 200 East Area boundary to the northwest

Interpretation of the exact configuration and extent of the technetium-99 plume north of the 200 East Area is complicated by the variable concentrations seen in wells that are relatively close together. For example, concentrations of technetium-99 less than the drinking water standard were consistently detected in well 699-49-55A since the early 1990s (16 pCi/L in fiscal year 2001). This well was used as the injection well in 1995 for pump-and-treat activities and has had very low technetium-99 values since then. Well 699-49-57A has higher and increasing concentrations (3,200 pCi/L in fiscal year 2001). Well 699-52-57, located north of well 699-49-57A, had consistently low technetium-99 concentrations (<90 pCi/L) throughout the 1990s; however, the water table fell below the screen in 1999 so the well can no longer be sampled. The data from well 699-52-57 remains somewhat suspect due to the shallow penetration into the aquifer. Technetium-99 was not routinely measured in groundwater prior to the late 1980s, limiting the information on the historical trends. Thus, there is considerable uncertainty in the extent of technetium-99 contamination north of the 200 East Area.

Very high levels of technetium-99, along with cobalt-60, cyanide, and nitrate were found north of the 200 East Area in well 699-50-53A in the late 1980s (Figure 2.9-5). As the water table began to drop in 1988 (Figure 2.9-6), contaminant levels decreased, indicating that the plume had moved out of this area. Technetium-99 levels rose again to almost 10,000 pCi/L during pump-and-treat operations, which were conducted in 1994 to 1995. Since that time, technetium-99 concentrations in this well have been low as the aquifer has become thinner. In fact, the aquifer above the basalt surface in this area is presently only a few centimeters thick and the well was not sampled in fiscal year 2002.

In the early 1990s, rising technetium-99 concentrations were seen at the BY crib area in wells 299-E33-7 and 299-E33-38 (see Figure 2.9-5). During late 1997 and 1998, the technetium-99 concentration was higher in well 299-E33-7 than in well 299-E33-38. In early 1999, the trends for both wells began to track together. Possible explanations for this increase include movement of the contaminant plume back into the 200 East Area from the north and/or uniform and pervasive transport of contamination from the vadose zone. The relatively high concentrations in well 299-E33-38 suggests a continuing source of contamination from the BY cribs to groundwater.

2.9.1.5 Uranium

Uranium contamination in the B Plant area is limited to three isolated areas:

- wells monitoring Waste Management Area B-BX-BY and surrounding cribs
- wells near the 216-B-5 injection well
- wells 299-E28-21 and 299-E28-18 at the 216-B-62 crib

Many wells in all three of these areas exceeded the 30-µg/L drinking water standard during fiscal years 2001 and 2002.

The highest uranium concentrations in the B Plant area are found within and to the east of the BY Tank Farm.

Waste Management Area B-BX-BY and Surrounding Cribs. The largest uranium plume in the 200 East Area may have sources at the BY cribs and/or Waste Management Area B-BX-BY. Currently, the highest uranium concentrations in the B Plant area are found within and to the east of the BY Tank Farm (Figure 2.9-7). The contamination is present in a narrow northwest-southeast band, but is increasing to the south along the west side of Waste Management Area B-BX-BY. In fiscal year 2002, the highest concentrations were detected in wells 299-E33-9 and 299-E33-44, with annual average concentrations of 360 and 310 µg/L, respectively. Section 2.9.1.11 includes additional discussion of uranium at Waste Management Area B-BX-BY.

216-B-5 Injection Well. Uranium contamination is associated with the cesium-137, plutonium, and strontium-90 contamination found at the former 216-B-5 injection well. The wells at this site were not sampled in fiscal year 2002 pending publication of a revised sampling and analysis plan and a plan for disposal of derived waste such as gloves and paper wipes. The highest uranium concentration detected in fiscal year 2001 was 220 µg/L in well 299-E28-23, located only ~1 meter from the injection well. A uranium value of 30.3 µg/L also was reported for well 299-E28-25, which is the first time since 1989 a sample from this well has exceeded the maximum contaminant level of 30 µg/L.

216-B-62 Crib. Uranium was detected consistently at levels slightly above the drinking water standard in wells monitoring the 216-B-62 crib, located west of B Plant. Uranium concentrations were over 200 µg/L in the mid-1980s, but declined to current levels by the early 1990s. The maximum uranium at the 216-B-62 crib, which was last sampled in fiscal year 2000, was 32 µg/L in well 299-E28-18. Uranium also has been found along the west side of Low-Level Waste Management Area 1, but no wells exceeded the maximum contaminant level in fiscal year 2002. The uranium detected near Low-Level Waste Management Area 1 probably originated at the 216-B-62 crib.

2.9.1.6 Nitrate

A nitrate plume originating in the 200 East Area extends beyond the boundary fence line, extending northwest to the Columbia River (Figures 2.9-8 and 2.1-4). The plume within the 200 East Area has two parts: (1) a west plume that extends from B Plant to the northwest and (2) an east plume extending from the BY and surrounding cribs toward the southeast and the northwest. The two plumes join northwest of the 200 East Area and extend through the gap between Gable Butte and Gable Mountain to the Columbia River at levels less than the allowable maximum contaminant level for drinking water (45 mg/L).

A nitrate plume originating in the 200 East Area extends beyond the boundary fence line, extending northwest to the Columbia River.

The west part of the nitrate plume, extending from B Plant, appears to be a portion of a larger plume extending from the PUREX Plant. This plume apparently moved to the northwest under past flow conditions during the period of high discharge to 200 East Area facilities and B Pond.

The highest nitrate concentrations are in the vicinity of the BY and 216-B-8 cribs. High concentrations of nitrate are associated with the cobalt-60, cyanide, and technetium-99 plume originating from the BY cribs. The highest nitrate concentrations measured in fiscal year 2002, however, were found in well 299-E33-16, near the 216-B-8 crib, where the fiscal year 2002 average concentration was 589 mg/L (Figure 2.9-9). The ratio of nitrate to technetium-99 in well 299-E33-16 is high compared to the ratio of nitrate to technetium-99 in wells near the BY cribs, indicating an additional nitrate source in the area (see Section 2.9.1.11).

2.9.1.7 Sulfate

Sulfate levels have been increasing in a number of wells in the north portion of the 200 East Area in the last several years, especially in the east portion of Low-Level Waste Management Area 2 (e.g., wells 299-E34-7 and 299-E34-3; see Figure 2.9-10 and Section 2.9.1.13). This distribution pattern suggests that sulfate is derived from sediment along or above the basalt subcrop and is transported outward from the subcrop as water level declines in the area. Sulfate enrichment in groundwater has been observed in other parts of the Hanford Site, where it appears to be related to infiltration of water from the vadose zone in response to irrigation or release of water to surface facilities (PNNL-14107; PNNL-11633).

2.9.1.8 Cobalt-60 and Cyanide

Cobalt-60 and cyanide continue to be detected in a number of wells in the vicinity of B Plant. Cobalt-60 has a relatively short half-life (5.3 years), and is currently only found at levels less than the 100-pCi/L drinking water standard. Cyanide is also a minor contaminant but is found at levels above the 200-μg/L allowable maximum contaminant level for drinking water. These species are useful, however, in distinguishing contaminant groups and contaminant sources. Cyanide and cobalt-60 are generally found together in this area.

Cobalt-60 and cyanide continue to be detected in a number of wells in the vicinity of B Plant. These species are useful in distinguishing contaminant groups and contaminant sources.

The maximum cyanide concentrations in this area in fiscal year 2002 were 263 μg/L from well 299-E33-38 and 321 μg/L from well 299-E33-7, both located in the BY cribs. Cyanide contamination in these wells is increasing along with the technetium-99 and nitrate. Thus, the cyanide appears to be related to past discharges of ferrocyanide waste to the BY cribs.

The highest cobalt-60 values in fiscal year 2002 also were detected in wells monitoring the BY cribs, and the cribs are believed to be the source of this contamination. The highest cobalt-60 concentration was in well 299-E33-7, located in the north part of the BY cribs, where the November 2001 result was 48.5 pCi/L.

2.9.1.9 Cesium-137 and Strontium-90

Cesium and strontium have relatively low mobility and are generally found near their source. Several wells near the 216-B-5 injection well have had elevated concentrations of strontium-90. The wells at this site were not sampled in fiscal year 2002 owing to the need to develop a waste control plan in support of CERCLA sampling activities. Four wells (299-E28-2, 299-E28-23, 299-E28-24, and 299-E28-25) had concentrations of strontium-90 above the drinking water standard (8.0 pCi/L) in fiscal year 1999. Two of the wells have had concentrations greater than the U.S. Department of Energy (DOE) derived concentration guide (1,000 pCi/L) in past years and in fiscal year 2001. The highest strontium-90 concentration was reported for well 299-E28-23, which averaged 11,900 pCi/L in fiscal year 2001.

Well 299-E28-23 near the 216-B-5 injection well has concentrations of cesium-137 greater than the drinking water standard (200 pCi/L). In fiscal year 2001, a value of 1,910 pCi/L was reported for this well, which is similar to previous years.

2.9.1.10 Plutonium

Plutonium-239 and -240 were detected in past years in samples taken from several wells near the 216-B-5 injection well. Plutonium contamination is relatively immobile and, therefore, is found only near the source, which was the injection well. The wells at this site were not sampled in fiscal year 2002 pending publication of a waste plan in support of CERCLA sampling activities. The highest value reported for plutonium in fiscal year 2001 was 63 pCi/L in a sample collected from well 299-E28-23.

2.9.1.11 Single-Shell Tank Waste Management Area B-BX-BY

Single-shell tank farms B, BX, and BY, located in the northwest part of the 200 East Area, comprise Waste Management Area B-BX-BY (see Appendix A, Figure A.16). The following discussion describes the local hydrogeology of the waste management area and the current state of groundwater contamination associated with Waste Management Area B-BX-BY. A summary of assessment monitoring specific to RCRA-regulated constituents is presented at the end of this section.

Groundwater contamination at Waste Management Area B-BX-BY had various sources within and outside the waste management area. Contaminants include nitrate, technetium-99, and uranium.

Groundwater Flow

The hydraulic gradient is nearly flat across Waste Management Area B-BX-BY (see Figure 2.9-2), making it difficult to determine upgradient versus downgradient wells from water elevations. Inaccuracies in water elevations become more important when the difference in elevations between wells is <7 centimeters as at Waste Management Area B-BX-BY. This small variation is less than the errors in the water elevations, which can exceed 13 centimeters at some wells. Errors in water elevations have a variety of sources. For example, measurement errors can be up to 3 centimeters (PNNL-12086), small deviations from vertical of the borehole range from <1 to 13 centimeters (PNNL-13116), small errors in well elevation surveys can be as much as 5 centimeters (PNNL-13022), and pressure effects associated with changing weather conditions can result in a temporal change of 5 centimeters (PNNL-13078). Lateral changes in sediment-grain-size distribution across a site may also cause slight undulations in the water table. Because these errors can exceed the difference in elevations across the waste management area, water elevations alone should not be used to interpret flow directions (PNNL-13022; PNNL-13023; PNNL-13116). Consequently, flow directions were estimated at Waste Management Area B-BX-BY using in situ flow techniques such as the colloidal borescope (PNNL-13404; Narbutovskih et al. 2002). The results of these studies confirm a southerly flow direction across the waste management area. The direction of groundwater flow tends to be southwest from the BY cribs across the north BY Tank Farm and south to southeast through the BX and B Tank Farms.

In situ flow measurements conducted in fiscal year 2000 indicate that the north part of the area under the BY cribs and the BY Tank Farm has a low flow rate that is close to stagnant. The unconfined aquifer in this region was formed artificially by rising water levels related to intentional and unintentional releases of liquid waste to the ground. Presently, the unconfined aquifer in the north is <2 meters thick and dropping ~18 centimeters a year. In addition, this thin aquifer is located on a hummocky basalt surface with structural relief that varies from 1.5 to 3.4 meters. This may cause the local flow paths to vary markedly as the water flows around basalt highs. The combination of low transmissivity and obstacles to flow cause this north section to drain slowly as the area returns to pre-Hanford conditions. Conversely, in situ flow measurements indicate the flow in the south is quite high. Based on water elevations in wells where the borescope data indicate a strong, consistent flow, the flow rate was calculated with the Darcy equation at 0.5 meter per day for fiscal year 2002.

Groundwater Contamination

Groundwater monitoring at Waste Management Area B-BX-BY has identified several distinct groups of contaminants based on chemical associations, spatial relationships, historic plume movement, knowledge of process chemistry, and characteristic chemical ratios of contaminant concentrations (PNNL-13116). A plume consisting of nitrate, nitrite, technetium-99, and uranium is located under and east of the BY Tank Farm. Past releases from the waste management area may be the source of this contamination. Another plume with low levels of nitrate associated with relatively high tritium is found along the south border of the waste management area. Movement through the vadose zone from a tritium-rich perched water table located ~4.6 meters above the water table under the BX Tank Farm may be the cause of this contamination. Further to the north under the BY cribs is a plume containing high levels of nitrate, cyanide, cobalt-60 and technetium-99. These contaminants extend from the BY cribs to the north, westward to the northeast corner of Low-Level Waste Management Area 1 and south to the north part of BY Tank Farm, where only cyanide and cobalt-60 are found. Uranium is also found locally in the south part of the BY cribs. These contaminants are attributed to releases from the BY cribs in the mid-1950s.

Results of recent assessment studies suggest most of the groundwater contamination in the vicinity of Waste Management Area B-BX-BY may be related to vertical infiltration of residual waste from the vadose zone. This waste appears to be driven to the unconfined aquifer primarily by natural precipitation and leakage from water lines.

Recent data evaluation studies center on pattern matching of trend plots and chemical fingerprinting using the ratio of nitrate to technetium-99. Nitrate and technetium-99 levels began rising under the B-61 crib and BY cribs in the north to the southwest side of the waste management area between 1995 and 1996 (Figures 2.9-11 and 2.9-12). The peak contamination was seen in November 2000 with higher values in the north grading to lower values in the south. This peak in late 2000 occurred at about the same time over most of the site. For example in Figure 2.9-11a, technetium-99 is plotted for well 299-E33-7 in the BY cribs and well 299-E33-42 on the west side of the BY Tank Farm (see Appendix A, Figure A.16 for well locations). The two trend plots display nearly the same pattern of peaks and troughs with both trends showing a double peak pattern, though the maximum value is less at well 299-E33-42 than at well 299-E33-7.

This same matching pattern can be seen when comparing technetium-99 trend plots for a series of wells across the site (see Figures 2.9-11 and 2.9-12). Comparisons are made between wells that are close together on the west side of the BX Tank Farm (Figure 2.9-11b) and between more widely separated wells as shown in Figure 2.9-11c (i.e., 299-E33-7 in the BY Tank Farm and well 299-E33-44 on the east side of the BY Tank Farm). Figure 2.9-11d compares the trend plots for the area west of the BY Tank Farm (well 299-E33-31) with well 299-E33-26, located to the northwest at the B-61 crib. As can be seen, once again the trend patterns are similar.

Figure 2.9-12a shows an east-west comparison between well 299-E33-42 in the west to well 299-E33-18 north of the B Tank Farm. On the southwest side of the BX Tank Farm, Figure 2.9-12c shows that although the match is not as good between wells 299-E33-32 and 299-E33-43, the double peaks still correlate. This match in contaminant trends is observed not only for technetium-99 but also for nitrate as shown Figure 2.9-12d that compares nitrate between the BY cribs (well 299-E33-38) and the area west of the BY Tank Farm (well 299-E33-31). This same double peak pattern also was observed in cyanide and cobalt-60 as shown in Figure 2.9-13 for well 299-E33-9. These contaminants are usually found together if the cyanide levels are high. The same patterns are found in uranium; however, the uranium peaks are retarded as might be expected because uranium has an estimated distribution coefficient (K_d) value of 0.2 (PNNL-11800).

Contaminant trends in wells monitoring Waste Management Area B-BX-BY show concurrent peaks, even in widely-spaced wells. This appears to indicate that the changes are not due to horizontal movement in the aquifer.

Notice that in all these comparisons, there is no significant difference in the times that peak values occur. Hence, the contamination has increased and decreased across the area at about the same time. When groundwater plumes move through an aquifer, the peak of the contamination passes by downgradient wells at a later time than observed in upgradient wells. Because there is little or no time difference when the contamination was observed at widely separate locations, the contamination may not be moving through the aquifer. One possibility is that contamination may be moving vertically into the groundwater from the vadose zone near the network monitoring wells. Alternatively, the contamination may be high-density waste that previously sank to the bottom of the aquifer and accumulated in erosional pockets on the basalt surface. In the latter scenario, the concentrations pumped from the wells increase as the water level drops. However, the existence of high-density waste at the bottom of the aquifer is not consistent with the observed rapid decrease in contamination across the area since early 2001.

Evidence for local sources of contamination is found by studying the history of the nitrate to technetium-99 ratios over time in data from individual wells. Ratios plots constructed of two co-varying mobile contaminants have been helpful to chemically fingerprint and identify different sources moving through the groundwater. When a pure waste source enters the groundwater and mixes with uncontaminated groundwater, the ratio of the two waste constituents will remain constant over time, yielding a horizontal straight line when the ratio is plotted against the concentration of one of the contaminants. Thus, even though concentrations may change over time, the ratio will remain constant as long as no other source mixes with the initial source waste. If two different sources with different contaminant ratios mix over time, a plot of contaminant ratios versus concentration will result in a diagonal "mixing" line.

In Figure 2.9-14a, the nitrate to technetium-99 ratio is plotted against the technetium-99 for well 299-E33-7. The early data from 1988 to 1995 display a trend, as shown by the linear fit to the data, from a less contaminated end member (i.e., low technetium-99) to a more contaminated end member (higher levels of technetium-99) (see Figure 2.9-11a). When contamination rose from the late 1990s to November 2000, the ratio values moved subhorizontally clustering about a value of 50 to 60 as the technetium-99 levels rose to the double peaks in May 2000 of 11,200 pCi/L and 11,600 pCi/L in November 2000. No identifiable mixing trend is seen in the data after the contamination level began to rise. This indicates that the contamination seen in the groundwater at well 299-E33-7 from 1998 to present is from a single source and is not a mixture of a cleaner end member with a more contaminated end member. The data gap from 1995 to 1998 is because the technetium-99 and nitrate analyses were not performed on the same groundwater samples during this time.

North of the BY cribs, high levels of cyanide and cobalt-60 were found in the early 1980s along with elevated nitrate and technetium-99 in well 699-50-53A. The nitrate to technetium-99 ratios from this well for the peak values seen at 30,000 pCi/L are plotted for comparison (see Figure 2.9-14a). The original mixing curve for well 299-E33-7 is clearly not heading toward the contamination seen in well 699-50-53A. Also, the recent contamination at well 299-E33-7 does not appear to be related to that seen farther north in the past in well 699-50-53A. The source of the contamination beneath the BY cribs today (well 299-E33-7) may be related to residual vadose zone contamination located close to the well.

Ratio data from well 299-E33-38, located to the south of well 299-E33-7 in the BY cribs, is shown in Figure 2.9-14b. As in Figure 2.9-14a, the early data prior to the increase in contaminant concentrations displays a two-end member mixing line that would be expected for a contaminant plume moving through the groundwater (i.e., two different waste sources that become mixed as groundwater moves through the aquifer). When the contamination began to rise in the mid-1990s (see Figure 2.9-12b), the ratios move off the mixing line and onto a horizontal trend that is followed until the peak values are seen in late 2000. There are two observations to make from this figure. First, the horizontal plot indicates that the recent (1996 to 2001) contamination observed at well 299-E33-38 is from a single source. Second, this single source may not be the same source as that seen in well 299-E33-7 in the north part of the BY cribs because the ratios for the same time period are different; ratios for well 299-E33-38 in the south part of the BY cribs lie slightly below the ratios for well 299-E33-7 (see Figure 2.9-14b).

Evidence for local sources of contamination is found by studying the history of the nitrate to technetium-99 ratios over time in data from individual wells.

Similar plots are presented in Figure 2.9-15 for wells located along the west side of Waste Management Area B-BX-BY. As can be seen, the early data from wells 299-E33-31 and 299-E33-42 lie on linear trends of a two-end member mixing line. When the contamination began to rise, the ratios move sharply off the curve to horizontal trends in each case. The peak values for upgradient well 299-E33-38 are shown in Figure 2.9-15a for comparison. Although the nitrate trends match (see Figure 2.9-12d), the nitrate to technetium-99 ratio plots indicate that there are two distinct sources for the contamination found at these two locations. The two horizontal trends seen in Figure 2.9-15b show that even though wells 299-E33-31 and 299-E33-42 are both on the west side of the BY Tank Farm, the sources of groundwater contamination at the two locations may be different.

Ratio plots for contamination found beneath and to the east of the BY Tank Farm are shown in Figures 2.9-16a and b. The early mixing curve for well 299-E33-44 (see Figure 2.9-16a), located east of the BY Tank Farm, shows the same change to a horizontal path (1999 to 2001) when the contaminant concentrations increase, indicating a single source for this area. The ratios for the peak concentrations for upgradient well 299-E33-38 plot above the ratios for well 299-E33-44. This suggests the contamination in groundwater beneath the BY Tank Farm is from a different source than that beneath the BY cribs. Figure 2.9-16b shows the ratio trend for well 299-E33-9 located inside the BY Tank Farm. The recent ratio data for groundwater at this well appears to converge with the ratio cluster for recent data from well 299-E33-44, suggesting that the contamination in groundwater at these two wells has a common origin.

The data from well 299-E33-18, located north of the B Tank Farm, is one of the few wells in the area to display a well-developed mixing line when the contamination rose to the double peak pattern. As seen in Figure 2.9-16c, the ratios from this well move to lower ratios/higher technetium-99 values along the same trend as the contamination found under the BY Tank Farm. This suggests that the source of the contamination around well 299-E33-18 may be the same as that found beneath and east of the BY Tank Farm. This correlation implies that contamination is moving into the area from the northwest to the southeast. Currently, there is not enough data from the newly installed wells along the south border of the waste management area to include this area in this type of study.

There are at least two possible scenarios that could allow peak concentrations of contaminants to occur in nearly all the wells at the same time. The first scenario suggests there must be a uniform driver operative over the entire area. This driver must then transport residual contaminants from multiple source areas in the vadose zone to the aquifer at about the same time. Natural infiltration is the most likely driver that can satisfy this condition. It has been shown that the fiscal year 1997 nitrate and technetium-99 peaks in well 299-E33-41 were related to vertical migration driven by recent water lines leaks (PNNL-11826). These contaminant events, however, are not related to the later widespread contamination shown in Figures 2.9-11 and 2.9-12. The mechanics of this hypothesized vadose zone migration are not clearly understood at this time. It may be that the water sources and flow paths are so complicated and of such mixed origin that we will never fully understand them. However, we can at least suggest some ways that would effectively move the residual vadose zone contamination to the groundwater universally across the BY cribs and the Waste Management Area B at approximately the same time.

Data from steady-state water balance studies, performed at the Hanford Site on bare unvegetated surfaces over a series of years, show that recharge values vary with annual precipitation from 111 millimeters per year for high precipitation years to 40 millimeters per year for lowest precipitation years (Gee et al. 1992). Using a one-dimensional flow calculation described in Gee et al. 1992, contaminant travel through the vadose zone can be determined. The steady-state discharge rate is directly related to the total travel time for the contamination to drain through the vadose zone. Excluding the short-term appearance of contaminants in the groundwater seen in the 1950s from the initial large-volume discharges to the BY cribs in 1955, and assuming the 1995 increase reflects the steady-state drainage of the residual vadose zone contamination, a 40-year travel time can be calculated. Using the 72-meter-thick vadose zone at Waste Management Area BY-BX-BY, and a water content of 0.063 cm^3/cm^3, found to be typical in well 299-E33-338 in the southeast corner of the B Tank Farm (RPP-10098), and a 40-year travel time (1955 to 1995), it would require a recharge rate of 114 millimeters per year for stable drainage to cause the residual contamination associated with the surface contamination, cribs, tank associated leaks, and retention trenches to begin affecting the groundwater by 1995. This rate of 114 millimeters per year is above the range of recharge rates found from direct measurement of infiltration for this area. This suggests that although the process of steady-state recharge is a viable mechanism to explain a uniform pattern of contamination across Waste Management Area B-BX-BY, the BY cribs, and the B-61 crib, artificial sources of surface water, such as pipeline leaks, might also contribute to the net infiltration at depth where the moisture has spread out and become relatively uniform over time.

An alternative hypothesis involves the possible occurrence of residual, high-density waste at the bottom of the aquifer. In this scenario, high-density tank waste from either planned or unplanned releases to the vadose zone sank to the bottom of the shallow sand/gravel aquifer. Flood-scoured pockets in the basalt underlying the saturated sediments may act as traps for higher density waste mixtures, as postulated by Narbutovskih in PNNL-13022. Because there was no aquifer under much of this area prior to past-practice discharges to the ground, the initial waste may have flowed into these pockets in the hummocky basalt surface. If so, the higher density waste may still be trapped, and as the water level continues to drop to pre-Hanford operations levels, the contribution of these pockets to the pumped water samples increases. Although this mechanism allows contamination to increase uniformly across the area, it is difficult to see how concentrations would subsequently decrease as sharply as observed in Figures 2.9-11 and 2.9-12. In this scenario, contaminant levels continue to rise, eventually stabilizing when the water level stops decreasing. Vertical or depth data from the water table down to the bottom of the aquifer could provide information to investigate the above possibilities.

Preliminary analytical results from discrete-depth testing suggest contaminant concentrations are significantly lower near the top of the water table than at the depth used for routine sampling.

To gain a better understanding of how contamination may be entering the groundwater from the vadose zone or may be layered on the basalt, discrete depth sampling was listed as a task in the assessment monitoring plan for the site (PNNL-13022). This sampling task began in fiscal year 2002 with further development of low flow rate, zero purge, discrete-depth-sampling devices that cause minimal vertical disturbance. Preliminary analytical results from the discrete-depth testing performed in well 299-E33-334 suggest contaminant concentrations are significantly lower near the top of the water table than at the depth used for routine sampling. For example, an abrupt increase with depth was noted in well 299-E33-334 for specific conductivity and associated anions. However, no unusually high concentrations were observed at the middle or bottom of this well. The lower concentration seen is a thin layer near the water table is probably due to recharge of natural precipitation that migrates through a relatively uncontaminated vadose zone. Upon reaching the water table, it dilutes the contaminant plume at the top of the aquifer. The reverse can also occur if the recharge water passes through a contaminated vadose zone. In the latter case, much higher concentrations would be expected at the water table, especially close to the source. To evaluate this possibility, additional sampling in other tank farm groundwater monitoring wells is planned for 2003, subject to funding constraints.

Tritium concentrations near BX Tank Farm have been increasing since 1999. Tritium appears to have a different source than nitrate, technetium-99, and uranium.

Tritium is one contaminant that does not display the double peak pattern observed for technetium-99 and nitrate. For example, elevated tritium along the west side of the BX Tank Farm, and extending southeast to well 299-E28-8, exhibits a sharply increasing trend since 1999. Low levels of nitrate, generally below 35 mg/L, are associated with the tritium plume. Tritium began rising abruptly in wells 299-E33-43 and 299-E33-32 (Figure 2.9-17) on the west side of the BX Tank Farm from local background values around 2,000 pCi/L in early 1999. Current values for the two wells are 17,300 and 16,100 pCi/L, respectively, in August 2001. This trend is matched in wells 299-E33-334 and 299-E33-335 located in the southwest corner of the site. The highest value of 21,400 pCi/L was found at the southeast corner of the BX Tank Farm in August 2001 (well 299-E33-339; see Figure 2.9-17). This is above the drinking water standard of 20,000 pCi/L for tritium. To the north, tritium is still at background levels of <3,000 pCi/L, indicating that tritium is not migrating into the local area from the north. A significant perched water zone with a tritium level over 75,000 pCi/L was discovered on a local silt layer ~4.6 meters above the water table in the characterization borehole 299-E33-45 (drilled by the Tank Farm Vadose Zone Project). Evaporator and tank condensate transfer lines run from south to north through the BX and BY Tank Farms to disposal cribs in the north and may have leaked in the past. Recent breakthrough of this perched contamination to the groundwater may be the source of the tritium.

The historical discharge of effluent to the ground in and around Waste Management Area B-BX-BY has resulted in complex patterns of groundwater contamination. The highest level of technetium-99 is located beneath the BY cribs to the north and is attributed to discharges to the cribs in the mid-1950s. The technetium-99 is associated with high concentrations of nitrate and cyanide with some cobalt-60. This contamination forms a plume that is moving southward, affecting the groundwater under the north part of Waste Management Area B-BX-BY. Elevated uranium is found locally beneath the BY Tank Farm while a small tritium plume has been found along the south margin of the waste management area. Residual waste from the waste management area may be contributing to the nitrate, technetium-99, uranium, tritium, and other contamination in the vicinity of the BY and BX Tank Farms. Quarterly monitoring of the groundwater at Waste Management Area B-BX-BY will continue.

RCRA Assessment Summary

This section discusses contaminant monitoring and investigations that relate directly to RCRA assessment activities at the waste management area. General discussions of the contaminants in this vicinity are discussed in other sections of this chapter. The monitoring frequency at this site was increased in 1996 from semiannual to quarterly when the site was placed in a groundwater quality assessment program. Outlying wells were sampled to provide coverage for surrounding past-practice liquid effluent discharge facilities, which was needed to identify non-tank farm sources that may have caused the increase in groundwater contamination. Nitrate, along with calcium and sodium, is the apparent cause of the elevated specific conductance first observed in downgradient well 299-E33-32.

RCRA assessment monitoring continued in fiscal year 2002 at Waste Management Area B-BX-BY. Preliminary results of vertical profiling indicate that natural recharge may control vertical movement of contaminants through the vadose zone to groundwater.

During 1997, nitrate concentrations rose above the drinking water standards of 45 mg/L in well 299-E33-41 (PNNL-11826). Associated metals and anions also rose sharply. This well is located between the B and the BX Tank Farms. In an assessment report (PNNL-11826), it was concluded that residual waste in the vadose zone, related to a tank farm leak in 1951 had, most likely, been driven to the groundwater close to this well by recent fresh water flooding from leaking water lines.

Although concentrations of nitrate with some nitrite, cyanide, and other tank-associated contaminants were also rising beneath and around the BY Tank Farm, the source could not be identified at the time the assessment report was prepared. A further determination has been conducted to identify the source of this contamination and to determine the rate and extent of groundwater contamination associated with the Waste Management Area B-BX-BY (PNNL-13022). The results of this investigation, discussed above, suggest that the contamination observed in downgradient wells around Waste Management Area B-BX-BY is due to vertical movement of residual waste left in the soil under the tank farms. Alternatively, the bulk of the contamination as a high-density salt, may have sunk as a high-density salt into pockets of the basalt. However, this explanation is not congruent with the observed recent decreases in contamination as explained above. Most of the contamination observed at wells in and downgradient of the waste management area is, most likely, associated with past tank-associated discharges to the vadose zone. If the contamination is migrating from the vadose zone to the groundwater, the source of the water driver is not clearly understood. However, it appears to be related primarily, but not solely, to long-term steady-state recharge from natural precipitation.

Vertical depth profiling was being conducted at one well, 299-E33-44, to better understand movement of contaminants from the vadose zone to the groundwater and to locate high-density pockets of contamination, if such exist. Preliminary testing of the equipment and methods were performed in fiscal year 2002 in well 299-E33-334. Preliminary results from well 299-E33-334 suggest fresh water related to natural precipitation is entering the groundwater and forming a thin, low contamination layer at the surface of the water table. These results would support the role that steady-state natural recharge from the surface might be the primary control on the vertical movement of contamination through the vadose zone at Waste Management Area B-BX-BY. At this time, it has been reasonably established that the contamination found in the groundwater at Waste Management Area B-BX-BY is from local sources that are superimposed on regional plumes.

2.9.1.12 216-B-63 Trench

Groundwater monitoring continues to provide no evidence that dangerous non-radioactive constituents from the 216-B-63 trench have entered groundwater. The RCRA interim status indicator parameters are pH, specific conductance, total organic carbon, and total organic halides (40 CFR 265, Subpart F). Included in the analysis list (see Appendix A, Table A.13) for this trench are alkalinity, gamma scan, gross beta, and turbidity. Statistical analyses revealed no exceedances in pH, specific conductance, total organic carbon, or total organic halides (see Appendix A, Section A.1.7).

Groundwater analysis continues to indicate an increase in concentrations of calcium, magnesium, sodium, and sulfate in several wells. The rate of change in concentration, however, has slowed and may indicate that groundwater chemistry has stabilized beneath the trench. The constituent concentrations do not exceed maximum contaminant levels. The source responsible for the increase in the concentration of these constituents is unknown at this time.

Current groundwater monitoring data indicates that dangerous non-radioactive constituents have not entered the groundwater at the 216-B-63 trench, but an increase in calcium, magnesium, sodium, and sulfate has been detected.

The current network is composed of six wells drilled specifically to monitor this trench. The network also includes five upgradient wells drilled to monitor the low-level burial grounds located just north of the trench and one upgradient well drilled to monitor Waste Management Area B-BX-BY. The network currently is considered adequate. The estimated flow rate at the 216-B-63 trench is 0.1 meter per day (see Appendix A, Table A.2).

2.9.1.13 Low-Level Waste Management Areas 1 and 2

The low-level burial grounds in the 200 East Area, Low-Level Waste Management Areas 1 and 2, are monitored under RCRA interim status detection monitoring and for performance assessment for the low-level burial ground under *Atomic Energy Act of 1954* (DOE/RL-2000-72).

Low-Level Waste Management Area 1

Groundwater monitoring under interim status requirements continued at this RCRA site in fiscal year 2002. The well network was sampled twice for indicator and site-specific parameters (see Appendix A, Table A.20). No additional wells are planned for this site.

An application was submitted to the Washington State Department of Ecology in June 2002 to incorporate the low-level burial grounds into the Hanford Part B RCRA permit (DOE/RL-88-20). This would have the effect of changing the groundwater monitoring requirements for the burial grounds from interim status monitoring to final status monitoring. As part of the application, new groundwater monitoring constituents, and statistical evaluations are proposed.

An application was submitted to the Washington State Department of Ecology in June 2002 to incorporate the low-level burial grounds into the Hanford Part B RCRA permit. As part of the application, new groundwater monitoring constituents, and statistical evaluations are proposed.

The groundwater gradient in this portion of the 200 East Area is almost flat making the determination of groundwater flow direction difficult (see Figure 2.9-2). Based on contaminant plumes, the flow direction appears to be to the northwest. A series of calculations were made to fit planes to different sets of three wells in the Low-Level Waste Management Area 1 network. The magnitude and direction of the gradient was determined from each plane. March 2002 water-level measurements were used in the calculations. The results are variable, as expected for a low gradient area, but the majority of the calculated flow directions were to the northwest, north, or southwest with the mean direction to the northwest (Figure 2.9-18). This supports the flow direction to the northwest used for upgradient:downgradient statistical comparisons at Low-Level Waste Management Area 1. The mean of the calculated gradients was 0.00006. The estimated flow rate at Low-Level Waste Management Area 1 is ~0.01 to 0.5 meter per day (see Appendix A, Table A.2).

Specific conductance continued to increase through December 2001 in monitoring wells in the northeast corner of Low-Level Waste Management Area 1 but declined in the June 2002 samples (Figure 2.9-19). Downgradient monitoring wells 299-E33-34 and 299-E32-10 continued to exceed the critical mean for specific conductance in samples taken in fiscal year 2002. This exceedance is related to the nitrate plume and not Low-Level Waste Management Area 1. DOE notified the Washington State Department of Ecology in 1999. Because no waste has been placed in the north portion of this site and there is a known nitrate plume from an upgradient source, no further action is necessary. Critical mean values and the results exceeding drinking water standards are listed in Appendix A, Table A.21.

Statistical comparisons of RCRA contamination indicator parameters at Low-Level Waste Management Areas 1 and 2 did not sow evidence of groundwater contamination from the burial grounds in fiscal year 2002.

Low-Level Waste Management Area 2

This RCRA site continued in RCRA interim status (indicator-evaluation requirements) in fiscal year 2002. Wells were sampled twice for indicator and site-specific parameters (see Appendix A, Table A.22). Monitoring well 299-E34-11 went dry after the first sampling event. The monitoring network for Low-Level Waste Management Area 2 appears to monitor the facility effectively. Continued water-level decline may cause additional wells to go dry.

An application was submitted to the Washington State Department of Ecology in June 2002 to incorporate the low-level burial grounds into the Hanford Part B RCRA permit (DOE/RL-88-20). When the permit becomes effective, the groundwater monitoring requirements for the burial grounds will change from interim status monitoring to final status. As part of the application, new groundwater monitoring constituents, and statistical evaluations are proposed. No new wells were proposed, in spite of wells going dry, because the water-table elevation is receding below the top of the basalt. Where basalt is present above the water table, it is impossible to monitor the unconfined aquifer. Deeper aquifers are isolated from the burial grounds by the low-permeability basalts.

Groundwater flow appears to be to the west based on small differences in head at wells along the south boundary of Low-Level Waste Management Area 2. The flow regime in this area is influenced by the basalt subcrop to the north and east. The remaining monitoring well, 299-E34-5, along the north side of the burial ground is interpreted as being separated from the rest of the wells by a basalt high (see Figure 2.9-1). However, this interpretation is uncertain. The major ion chemistry of this well is similar to most wells on the south side of the basalt high (Figure 2.9-20), so hydraulic connection cannot be ruled out on that basis. The monitoring configuration and the extremely flat gradient make it difficult to use the 3-point method of fitting a plane to water level data in order to determine flow direction. If well 200-E34-5 is considered to be isolated, then the calculations indicate flow has a component toward the north (Figure 2.9-21). This is not likely to be correct due to the presence of the basalt and may be due to the low gradient (mean of 0.0002 for the 3-point calculations) combined with poor spatial distribution of the wells for performing these calculations. If well 299-E34-5 is connected to the rest of the wells through an erosional low in the basalt, then a component toward the south to the flow would be indicated (Figure 2.9-22) and the mean gradient is higher, 0.001. The previous interpretation of flow direction to the west is in keeping with the regional data and the flow to the northwest seen at Low-Level Waste Management Area 1. The gradient calculated from wells along the south boundary of the burial ground is 0.00003. The estimated flow rate at Low-Level Waste Management Area 2 using a gradient of 0.00003 is ~0.04 to 0.5 meter per day (see Appendix A, Table A.2).

Statistical evaluations for this area determined that upgradient well 299-E34-7 continued to exceed the critical mean for specific conductance, total organic carbon, and total organic halides. This well was only sampled one time in fiscal year 2002 due to safety issues with the well location, which have since been resolved. The major contributors to the increase in specific conductance are sulfate, chloride, and calcium. Figure 2.9-23 shows the concentration of sulfate initially increased more rapidly than chloride, but that the proportion of chloride is now increasing. The source of these constituents is not clear. In the fiscal year 2001 groundwater report (PNNL-13788), it was suggested that the increase may be related to the basalt chemistry. However, the major ion chemistry is distinctly different from the chemistry of water in the uppermost basalt confined aquifer (PNL-10817; PNNL-14107). Alternatively, the source of the ions may be leaching or infiltration processes within the vadose zone.

The cause of the increase in total organic carbon and total organic halides, shown in Figure 2.9-24, is also not known. The average total organic carbon concentration for fiscal year 2002 samples was 6,500 µg/L and the average total organic halide concentration was 19.2 µg/L. No organic hazardous constituents were identified in the fiscal year 2002 sampling. Samples collected in April 2001 were analyzed for oil and grease and total petroleum hydrocarbons (diesel). These results were consistent with the total organic carbon values. However, total petroleum hydrocarbons were not detected during sampling for an extensive list of 40 CFR 264, Appendix IX constituents early in fiscal year 2003 (October). The only organic constituent detected during that fiscal year 2003 sample was 0.076 µg/L of Endrin aldyhyde. This is an impurity or breakdown product of the pesticide Endrin that has not been sold in the United States since the 1980s. There is no drinking water maximum contaminant level for Endrin aldyhide, but the drinking water standard for Endrin is 2 µg/L. The level of Endrin aldyhide is far lower than the total organic halides, indicating the main sources of the elevated total organic halide readings are substances that are not on the 40 CFR 264, Appendix IX hazardous substances list. Because of the anomalous chemistry in this upgradient well, it is not used in the statistical upgradient:downgradient comparisons. Appendix A, Table A.23 lists the critical mean values based on data from the other designated upgradient wells. Appendix A, Table A.3 summarizes constituents exceeding drinking water standards.

2.9.1.14 Liquid Effluent Retention Facility

Groundwater monitoring at the Liquid Effluent Retention Facility has been guided by the conditions set forth by the operating permit. A RCRA final status detection-monitoring program was in place at the Liquid Effluent Retention Facility until June 1999 when downgradient well 299-E26-9 no longer provided representative groundwater information (i.e., it went dry). The Washington State Department of Ecology granted a variance in September 1999 to allow DOE to operate the remaining network wells as the compliance system. This variance gave DOE 18 months, or until the next downgradient well became non-functional, to develop and deploy an alternative monitoring system. The Washington State Department of Ecology rescinded the variance in January 2001 when downgradient well 299-E35-2 no longer produced representative samples. The Washington State Department of Ecology has suspended groundwater monitoring statistical analyses at the Liquid Effluent Retention Facility effective January 14, 2001. The direction of groundwater flow beneath the facility is generally to the southwest, based on regional water-table contours (see Figure 2.9-2).

The Washington State Department of Ecology has suspended groundwater monitoring statistical analyses at the Liquid Effluent Retention Facility because all but one downgradient well are dry.

Groundwater monitoring (until January 2001) continued to show no evidence that regulated groundwater constituents from the Liquid Effluent Retention Facility entered the groundwater.

2.9.1.15 Single-Shell Tank Waste Management Area C

Located in the northeast part of the 200 East Area, Waste Management Area C consists of the C Tank Farm (see Appendix A). The following discussion describes the local hydrogeology of the waste management area and the current state of groundwater contamination associated with this tank farm. A summary of monitoring specific to RCRA-regulated constituents is presented at the end of the section.

Groundwater Flow

A general flow direction to the southwest has been established for this site using in situ flow measurements, plume tracking and water elevations corrected for borehole deviations from vertical (PNNL-13788). Hydrographs are compared in Figure 2.9-25 and show that the flow direction is still to the southwest, which is consistent with the regional water-table map (see Figure 2.9-2). When the monitoring network was designed, flow was believed to be due west. Proposed changes to the monitoring network can be found in the groundwater monitoring plan for this site (PNNL-13024) and in a recently released interim change notice (PNNL-13024-ICN-1).

The estimated groundwater flow rates calculated using the Darcy equation range from 1.0 to 1.9 meters per day (see Appendix A, Table A.2). Based on these estimates of flow rate, the groundwater could flow as much as 529 meters per year. The rate of water table decline beneath Waste Management Area C was about 0.2 meter this last year. If this rate continues, wells at this site should be usable for at least 7 to 8 years.

Groundwater Contamination

Specific conductance is still increasing sharply in upgradient well 299-E27-7 (523 µS/cm) and cross-gradient well 299-E27-14 (643 µS/cm). Figure 2.9-26 shows the current trends across the site. The increase in specific conductance is due primarily to rising sulfate and calcium along with some nitrate and chloride. Sulfate dominates with the highest value found in well 299-E27-14 at 142 mg/L in September 2002 (maximum contaminant level = 250 mg/L). There has been a tendency since the mid-to-late 1990s for sulfate and calcium to increase along the basalt subcrop in the north part of the 200 East Area (PNNL-13404). This rising sulfate/calcium trend seen at C Tank Farm may be related to these increases seen further north.

Although nitrate has not risen above the drinking water standard of 45 mg/L, it is increasing in all wells except upgradient well 299-E27-7. Levels in this well decreased from a maximum of 27.4 mg/L in January 2002 to 19.5 mg/L in September 2002 (Figure 2.9-27). Technetium-99 follows a trend similar to nitrate in this well and reached a maximum of 2,760 pCi/L also in January 2002. Technetium-99 concentrations continue to increase with the nitrate downgradient at Waste Management Area C currently ranging from 1,890 pCi/L on the south side of C Tank Farm to 65.4 pCi/L in the north. Figures 2.9-28 and 2.9-29 show nitrate to technetium-99 comparisons for wells on the south and southwest of the waste management area.

The use of chemical ratios can be useful to correlate groundwater contamination to possible sources and from one well to another. The nitrate to technetium-99 ratio in upgradient well 299-E27-7 was 48 in November 2000. At the peak, it dropped to 9.9 in January 2002 as the technetium-99 rose more rapidly than the nitrate (see Figure 2.9-27). The contaminant levels are nearly back to those seen in November 2000, and the ratio has increased to 36 for September 2002. Low nitrate to technetium-99 ratios generally suggest the source may be related to residual tank waste in the vadose zone. The low levels of cyanide (<18 μg/L) that have been found in the groundwater at well 299-E27-7 also suggest the source may be related to residual tank-related vadose zone waste because C Tank Farm is the only known local source for cyanide (HNF-SD-WM-TI-740). However, there are no known artificial water drivers in or around C Tank Farm that could drive the waste to the groundwater.

Another possibility is that the contamination may be related to the upgradient 216-B-3-1 ditch. As part of a continuous ditch system connected to the 216-B-63 trench, this ditch was decommissioned in 1964 after an accidental release of mixed fission products from the PUREX Plant was discharged directly to the 216-B-3-1 ditch (DOE/RL-89-28). However, the sharp rise and fall of the contaminant peak at well 299-E27-7 indicates a short travel distance from the point of entry into the groundwater.

At well 299-E27-14, the nitrate does not correlate as well with the technetium-99 as it does in the north (see Figure 2.9-28). The peak in the nitrate does not occur at the same time as the peak in technetium-99. This may be due to chemical heterogeneities in the plume, but presently we cannot use ratio data in this well to correlate contamination with that observed in upgradient well 299-E27-7. However, we can track the nitrate and technetium-99 seen upgradient at the waste management area to the southwest in well 299-E27-13 (see Figure 2.9-29). The February 2000 nitrate to technetium-99 ratio was 47, similar to that upgradient from the site. The current ratio in September 2002 is 8.3 with the technetium-99 value at 1,060 pCi/L and the nitrate at 8.5 mg/L. This ratio is very similar to that seen at the peak contamination level in upgradient well 299-E27-7 indicating that the plume is moving in a southwestward direction across the site. There does not appear to be other tank-related waste in the groundwater at Waste Management Area C.

RCRA Parameters

This RCRA site continued to be monitored under an interim status indicator evaluation program in fiscal year 2002. Wells were sampled quarterly at the request of the Washington State Department of Ecology due to rising trends in sulfate and nitrate currently detected in both upgradient and downgradient wells. In addition, the required detection sampling was conducted twice for indicator and site-specific parameters (see Appendix A).

During fiscal year 2002, the site was monitored with the original configuration of wells (see Appendix A). Because the upgradient well is currently experiencing rapidly increasing specific conductance, no upgradient/downgradient comparisons can be made for this indicator parameter until a new upgradient well has been drilled and a reliable critical mean value calculated or contaminant levels stabilize in upgradient well 299-E27-7. The indicator parameters (pH, total organic carbon and total organic halide) did not exceed the upgradient/downgradient comparison values in downgradient wells during fiscal year 2002. Table A.3 in Appendix A summarizes results exceeding drinking water standards.

Waste Management Area C continued to be monitored under requirements for a RCRA indicator evaluation program in fiscal year 2002. Because the upgradient well is currently experiencing rapidly increasing specific conductance, no upgradient/downgradient comparisons can be made for this indicator parameter until contaminant levels stabilize.

2.9.1.16 Gable Mountain Pond (216-A-25 Pond)

Gable Mountain Pond is located in the area between the 200 East Area and Gable Mountain. Beneath the south portion of the pond, basalt bedrock is above the water table. Beneath the north portion of the pond, the groundwater flow direction is probably to the west based on the water-table map.

Between July 1999 and January 2000, contamination was characterized at Gable Mountain Pond as part of the 200-CW-1 Operable Unit remedial investigation (BHI-01367). Although significant amounts of cesium-137 and strontium-90 were detected in vadose zone sediment, the cesium-137 remains higher in the profile and strontium-90 is the most significant groundwater contaminant. The drinking water standard for strontium-90 is 8.0 pCi/L and the DOE derived concentration guide is 1,000 pCi/L. Strontium-90 in the Gable Mountain Pond area apparently resulted from the discharge of waste to that pond during its early use. Wells completed above the basalt in the vicinity of this pond are becoming difficult to sample because of declining water levels.

Strontium-90 concentrations reversed a rising trend during fiscal years 1999 and 2000 in several wells near Gable Mountain Pond. Strontium-90 was detected in groundwater at levels above the DOE derived concentration guide in the only well that was sampled at Gable Mountain Pond in fiscal year 2000. The concentration in the sample from that well, 699-53-47A, was 1,210 pCi/L, considerably higher than the 1999 sample, although concentrations were also above the DOE derived concentration guide in 1997 and 1998. The wells near Gable Mountain Pond were not sampled in fiscal year 2002 owing to the need to develop waste management documentation in support of CERCLA sampling activities.

Nitrate continued to be detected in wells monitoring Gable Mountain Pond at levels above the maximum contaminant level in fiscal years 1999 and 2000 (see Figure 2.9-8). Well 699-53-47A contained 106 mg/L of nitrate in the fiscal year 2000 sample. In fiscal year 1999, 402 mg/L of nitrate was detected in well 699-53-48B, which was not sampled in fiscal year 2002.

2.9.2 PUREX Plant

Monitoring Objectives at PUREX Plant

Groundwater monitoring is conducted near PUREX Plant:

- triennially to annually to describe the nature and extent of contamination
- semiannually to monitor trends in variable constituents/wells
- semiannually to detect possible impact of five RCRA waste management areas
- quarterly to assess contamination from one RCRA waste management area
- quarterly or semiannually to detect possible impact of the Treated Effluent Disposal Facility

Numerous disposal facilities received waste from PUREX Plant operations. In particular, numerous cribs to the south and east of the PUREX building (see Figure 2.9-1) affected groundwater quality over a large area of the site. The most extensive and significant contaminants are iodine-129, nitrate, and tritium (see Figures 2.1-3, 2.1-4, and 2.1-5). Three cribs (216-A-10, 216-A-36B, and 216-A-37-1) are at least partially responsible for the significant contamination and are monitored in accordance with RCRA. Monitoring results indicate that the impact to groundwater originates from other facilities as well. These other facilities are located generally northeast and east of the plant, and are being addressed under the CERCLA/RCRA past-practice process (200-PO-1 Operable Unit). The 216-A-29 ditch, 216-B-3 pond (B Pond), Liquid Effluent Retention Facility, 200 Areas Treated Effluent Disposal Facility, and high-level waste tanks in Waste Management Area A-AX are also monitored in accordance with RCRA. However, to date there is little evidence to suggest that groundwater at these sites has been contaminated with RCRA-regulated waste. Groundwater constituents exceeding drinking water standards in the PUREX Plant area are tritium, iodine-129, nitrate, strontium-90, manganese, and chromium. However, chromium and possibly manganese may be contaminants caused by corrosion of well casings or screens.

2.9.2.1 Groundwater Flow

Groundwater beneath the PUREX Plant occurs in an unconfined aquifer, one or more confined aquifers overlying basalt bedrock, and confined aquifers within the basalt sequence (see Section 2.14 for more information on the upper basalt-confined aquifer). However, none of the confined aquifers above the basalt is continuous across the entire PUREX area. Unconfined groundwater in the west part of the PUREX Plant area is influenced by a highly-permeable buried Pleistocene flood channel located in the northwest-southeast direction across the 200 East Area. Further influences include the Ringold Formation mud units, the May Junction fault, and past disposal of liquid effluents at B Pond. These features interact to produce a complex flow system. A detailed discussion of the 200 East Area hydrogeology can be found in PNNL-12261. Consequently, only a brief overview along with recent findings are presented below.

Groundwater beneath the PUREX Plant vicinity flows generally to the southeast in the unconfined aquifer.

Groundwater in the unconfined aquifer entering the 200 East Area from the west divides and flows to the Columbia River along two separate paths: one to the southeast and one to the northwest through the gap between Gable Butte and Gable Mountain. Because of the very low hydraulic gradient in the buried flood channel (and the entire PUREX Plant area; see Figure 2.1-1), the flow direction is difficult to determine with certainty. The flow is currently thought to divide in the northwest corner of the 200 East Area, but this conclusion is still tentative (see Section 2.9.1.1). Flow within the south part of the PUREX Plant area is currently thought to be toward the southeast within the unconfined aquifer. This is confirmed by the migration of contaminant plumes from the PUREX cribs. In the north part of the PUREX Plant area, flow is believed to have a significant south flow direction (southwest to southeast), as groundwater must flow south and around the mud units that are located in the vicinity of B Pond.

Typically, groundwater flow direction and flow rates in the unconfined aquifer can be estimated from water-table maps. However, estimates of flow direction and rate from water-table maps are difficult in the PUREX Plant area because of the very low water-table gradient. Alternate techniques for characterizing groundwater flow direction and flow rate have been incorporated to supplement the water-table map method. They include groundwater contamination plume maps, contaminant concentration trend plots, and data from the use of the colloidal borescope (a down-well flowmeter for measuring horizontal flow; Kearl 1997). Results of a colloidal borescope investigation of 20 wells in 2001 were generally inconclusive except for groundwater flow in the vicinity of Waste Management Area A-AX where the flow direction appears to be toward the southeast. Further details about groundwater flow direction and flow rate are provided in the discussion of groundwater flow at each of the sites (see Sections 2.9.2.7 through 2.9.2.13).

2.9.2.2 Tritium

The highest tritium concentrations in the 200 East Area groundwater continued to be found in wells near cribs that received effluent from the PUREX Plant (see Figure 2.1-3). In fiscal year 2002, concentrations >2 million pCi/L (the DOE derived concentration guide) were detected only in well 299-E17-9 next to the 216-A-36B crib (Figure 2.9-30). The maximum concentration detected in this well in fiscal year 2002 was 4.2 million pCi/L, which is down slightly from the highest fiscal year 2001 reported value of 4.3 million pCi/L. Tritium concentrations that exceed the 20,000-pCi/L drinking water standard continued to be found in many wells affected by cribs near the PUREX Plant. In the area immediately downgradient of the cribs where concentrations are >200,000 pCi/L, tritium is attenuating naturally as a result of radioactive decay and dispersion combined with the decreasing source that resulted from the termination of operations.

The highest tritium concentrations in the 200 East Area groundwater continued to be found in wells near cribs that received effluent from the PUREX Plant. The maximum concentration detected in fiscal year 2002 was 4.2 million pCi/L.

Prior to fiscal year 1998, tritium levels measured in well 699-37-47A, near the southeast corner of the 200 East Area and completed in 1996, remained below 20,000 pCi/L (the drinking water standard). In 1998, tritium concentration rose to 36,000 pCi/L (Figure 2.9-31). The rise in tritium concentration was probably due to the reduction in wastewater discharged in the vicinity of B Pond. Well 699-37-47A is very near the mixing area of groundwater from the northwest that has higher tritium concentration and groundwater from the B Pond area that has lower tritium levels. As the influence of wastewater in the B Pond continued to shrink, the mixing area for groundwater from the two sources (near well 699-37-47A) became more dominated by groundwater from the northwest that has higher tritium concentration. The concentrations remained steady during fiscal year 2002 at 29,300 pCi/L for the October 2001 sample and 28,600 pCi/L for the April 2002 sample.

The widespread tritium plume extends from the southeast portion of the 200 East Area to the Columbia River. The overall decline in tritium concentrations throughout this plume indicates that the greatest impact expected at the Columbia River has already occurred.

The widespread tritium plume (see Figure 2.1-3) extends from the southeast portion of the 200 East Area to the Columbia River. Separate tritium pulses associated with the two periods of PUREX Plant operations contributed to the plume. The first pulse, which resulted from discharges during 1956 to 1972, can be detected near the Columbia River (e.g., well 699-40-1; Figure 2.9-32). Elevated tritium concentrations measured immediately downgradient from the 200 East Area (within the 80,000-pCi/L isopleth line) represent the second pulse associated with the re-start of operations between 1983 and 1988. Figure 2.9-33 shows the arrival of the plume in early 1987 at well 699-24-33, near the Central Landfill, long after the passage of the plume from the earlier operation. The tritium concentrations in this well during the passage of the first pulse were at least three times the maximum concentration in the second pulse. Thus, the second pulse is expected to have a significantly lower impact that the first pulse downgradient toward the Columbia River. The overall decline in tritium concentrations throughout this plume indicates that the greatest impact expected at the Columbia River has already occurred. Comparison of tritium concentration maps (see Figure 2.1-3 of this document and Figure 2.1-3 of PNNL-13788) between 2001 and 2002 indicates that there was a very slight recession of the contour lines in the south and east portions of the major tritium plume.

The zone of lower tritium concentration near Energy Northwest (see Figure 2.1-3) may be due to a zone of lower hydraulic conductivity in the unconfined aquifer. At that site, the water table is within the upper portion of the Ringold Formation that locally may have a greater degree of cementation. Tritium at the 618-11 burial ground is discussed in Chapter 2.12.

2.9.2.3 Iodine-129

Concentrations of iodine-129 in groundwater near the PUREX cribs are generally declining slowly or are stable. The iodine-129 plume extends southeast into the 600 Area and appears to coincide with the tritium and nitrate plumes.

The highest iodine-129 concentrations (drinking water standard of 1.0 pCi/L) detected in the 200 East Area in fiscal year 2002 were near the PUREX Plant cribs (Figures 2.9-34 and 2.1-5). The maximum concentration of iodine-129 detected in fiscal year 2002 was 11.2 pCi/L at well 299-E17-14 near the 216-A-36B crib. Concentrations of iodine-129 in groundwater near the PUREX cribs are generally declining slowly or are stable, as shown for well 299-E17-9 (Figure 2.9-35). The iodine-129 plume extends southeast into the 600 Area and appears to coincide with the tritium and nitrate plumes (see Figures 2.1-3 and 2.1-4). At the scale that the iodine-129 concentration map is plotted, there appears to be very little difference between this year's map (see Figure 2.1-5) and the corresponding map in last year's groundwater annual report (see Figure 2.1-5 in PNNL-13788). Although the iodine-129 plume is disseminating, it is doing so at a very slow rate.

2.9.2.4 Nitrate

High nitrate concentrations continue to be found near liquid waste disposal facilities that received effluent from PUREX Plant operations, and the concentrations are generally decreasing with time. The maximum nitrate concentration detected near the PUREX Plant in fiscal year 2002 was 52.6 mg/L in well 299-E17-9, with is adjacent to the 216-A-36B crib. The extent of the nitrate plume that originates from the 200 East Area (see Figure 2.1-4) is nearly identical to that of the tritium plume. However, the area with nitrate concentration >45 mg/L (the maximum contaminant level) is considerably more restricted than the area with tritium above its drinking water standard (20,000 pCi/L). Nitrate at levels above the maximum contaminant level north of the 400 Area and at Energy Northwest, within the area impacted by PUREX operations, can be attributed to wastewater disposal or activities in those areas (see Section 2.10.2). The nitrate plume (see Figure 2.1-4) appears to have receded slightly over previous years, except for in the south portion of the Hanford Site near the 300 Area where the nitrate plume is expanding (see Section 2.12.5).

2.9.2.5 Strontium-90

A single well (299-E17-14), near the 216-A-36B crib, had a concentration above the drinking water standard (8.0 pCi/L) for strontium-90, a beta emitter, in fiscal year 2002. The maximum strontium-90 concentration detected in fiscal year 2002 was 21 pCi/L, which is slightly higher than the maximum concentration during fiscal year 2001 (17.7 pCi/L). In general, the concentration of strontium-90 has been rising in this well since 1997. The impact is localized because of the lower mobility of strontium-90 compared to iodine-129, nitrate, and tritium. This result is consistent, in part, with a gross beta (drinking water standard 50 pCi/L) concentration of 58 pCi/L in the same well. Strontium-90 was detected at five other wells near the 216-A-10 and 216-A-36B cribs during fiscal year 2002. The concentrations in these five wells have been stable or decreasing since 1994 except for well 299-E24-16 (near the 216-A-10 crib), where it has been increasing or steady since 1997.

The 58 pCi/L result for gross beta at well 299-E17-14 during fiscal year 2002 is more than can be accounted for from the 21 pCi/L result for strontium-90 in the same well. If the only beta emitter present were strontium-90, gross beta would be 33.2 pCi/L. Therefore, the 58 pCi/L must include another beta emitter. The higher result for gross beta is due to technetium-99 (also a beta emitter). The last technetium-99 result from well 299-E17-14 was 209 pCi/L in fiscal year 1994. Technetium-99 is no longer routinely analyzed in PUREX Plant area well samples because previous results were significantly less than the drinking water standard (900 pCi/L), and gross beta analysis could be used as a screening tool for technetium-99 and other beta emitters.

2.9.2.6 Manganese

Filtered manganese concentrations remained elevated at wells near all three of the PUREX cribs, but only one well had reported values that exceeded the drinking water standard (50 µg/L) during fiscal year 2002. The exceedance was at well 299-E17-9 near the 216-A-36B crib where the reported value for manganese was 50.5 µg/L in October 2001. The trend is part of a rapid increase and decrease that occurred from 1999 to October 2001 (Figure 2.9-36). At the peak of the rise in October 2000, the reported value was 191 µg/L. The only well showing an increase in manganese concentration during fiscal year 2002 was well 299-E17-19 at the 216-A-10 crib (Figure 2.9-37). The reported values for fiscal year 2002 were 41.7 and 31.1 µg/L. The source of the increased levels of manganese is unknown but is presumed to be from the associated PUREX cribs. However, spurious occurrences of manganese (as well as iron) groundwater contamination such as these reported at the PUREX cribs wells have occurred at other Hanford Site wells also and may be due to corrosion of the well screens or casings.

2.9.2.7 RCRA Assessment Summary for the PUREX Cribs

Groundwater is monitored for RCRA assessment at three cribs associated with the PUREX Plant. The cribs contributed to the extensive contaminant plume extending from 200 East Area to the Columbia River.

The PUREX cribs (216-A-10, 216-A-36B, and 216-A-37-1) are monitored in interim status to assess groundwater quality (see Appendix A, Section A.1.17). Groundwater flow for the two west cribs (216-A-10 and 216-A-36B) is most likely toward the southeast (see Section 2.9.2.1).

The PUREX cribs are located in a region where several groundwater contaminant plumes contain constituents that exceed drinking water standards. The similarities in effluent constituents disposed to these cribs, as well as to the 216-A-45 crib, make determining the contribution of the PUREX cribs difficult. During fiscal year 2002, nitrate and filtered manganese exceeded drinking water standards in at least one well (see Appendix A, Table A.3). See Sections 2.9.2.1 through 2.9.2.6 for more information on groundwater flow and groundwater contamination in the PUREX cribs area.

The far-field monitoring well network of the PUREX cribs is integrated with the well network for the 200-PO-1 Operable Unit. These well networks monitor the approximate area of the Hanford Site covered by the extensive nitrate plume emanating from the PUREX cribs area. The data from RCRA monitoring of the PUREX cribs are integrated into the assessment of the overall extent of contamination for the major plumes from the PUREX cribs including tritium, iodine-129, as well as nitrate (see Sections 2.9.2.2 through 2.9.2.6). The nitrate plume is generally decreasing in concentration except for localized places were slight increases are observed.

During fiscal year 2002, the water level in well 299-E17-9 near the 216-A-36B crib dropped to a level too low for sampling. Another well near this crib will be used as a substitute (well 299-E17-16). However, this substitute well (299-E17-16) is located southeast of well 299-E17-9 and does not intercept the groundwater contamination plumes in a location where concentrations are as high as the well 299-E17-9 location.

2.9.2.8 Single-Shell Tank Waste Management Area A-AX

This section provides information on the current nature of the unconfined groundwater in the immediate vicinity of the single-shell tanks at Waste Management Area A-AX. The most recent description of stratigraphy for this site can be found in PNNL-13023.

Groundwater Flow

Based on local hydrographs and colloidal borescope measurements, it has been determined that the groundwater flow direction is generally to the southeast (Figure 2.9-38). The existing well network at Waste Management Area A-AX was designed for groundwater flow to the southwest. An interim change notice to the groundwater monitoring plan for this site (PNNL-13023) discusses the proposed changes in the network. The estimated flow rate at Waste Management Area A-AX is 1.6 to 3 meters per day (see Appendix A, Table A.2) depending on the hydraulic conductivity value used in the Darcy equation. Using these estimates of flow rate, the average distance of groundwater flow at the site may be as high as 840 meters per year, reflecting the high permeability of the sediment in the aquifer.

Groundwater monitoring at Waste Management Area A-AX to date provides no evidence that the site has contaminated groundwater.

Groundwater Contamination

Groundwater monitoring to date provides no evidence that the site has contaminated groundwater.

With the exception of well 299-E25-41, reported sulfate values are within the Hanford Site background values reported in WHC-EP-0595 (~14 to 60 mg/L). Although in the past, sulfate concentrations above background values were identified in two wells, 299-E25-40 and 299-E25-41, the recent trend in well 299-E25-40 is to decrease to 54 mg/L and increase in well 299-E25-41 to 89.4 mg/L. Calcium (~47 mg/L) and technetium-99 (220 pCi/L) levels have also increased in well 299-E25-41. Although there are still low levels of technetium-99 at well 299-E24-19 (~38 pCi/L) on the southwest side of the waste management area, other wells including upgradient 299-E24-20 show no detectable levels of technetium-99. Well 299-E25-41 is downgradient from the AX Tank Farm, which currently has no upgradient coverage. This slight rise in sulfate and technetium-99 is probably moving into the area from further north, possible the same pocket of contamination currently seen at Waste Management Area C.

Nitrate values currently range from ~4 to 17 mg/L, which falls within the ranges of background values of 3 to 17 mg/L for the Hanford Site (WHC-EP-0595) except for one well. Nitrate concentrations in well 299-E24-20 are ~31 mg/L, which has decreased from last year when the value was ~36 mg/L. This well is located south of the 244-AR vault and is the upgradient well for the A Tank Farm. Values are still well below the maximum contaminant level of 45 mg/L, and there does not appear to be a connection to the waste management area. Technetium-99 is currently undetected in the well.

Tritium values in wells at the waste management area range from 4,150 to 8,750 pCi/L. The drinking water standard for tritium is 20,000 pCi/L. This local region had extremely high values of tritium (over 200,000 pCi/L) in the late 1960s when the PUREX Plant was operating. Although the tritium concentration appears to be slowly rising across the area, it does not appear to be related to the waste management area and is, most likely, part of a slight regional trend.

In filtered samples from well 299-E24-19, chromium continues to be detected at values above the maximum contaminant level of 100 µg/L at ~1,000 µg/L. Historically, this well also has concentrations of manganese that exceed the maximum contaminant level (50 µg/L). The elevated metal concentrations are most likely associated with corrosion of the well screen (see PNNL-13788).

Elevated chromium (281 µg/L) was observed for the June 2002 sampling event at well 299-E25-46, which is downgradient from 299-E24-19. The pH is historically above 7 at this well and above 8 at other wells in the area. Comprehensive purge sampling is scheduled for the fiscal year 2003 to determine if the elevated chromium in this well is local to the well or is moving through the groundwater. Chromium concentrations, specific conductance, and pH will be monitored during an extensive purge as water is removed from the well.

RCRA Parameters

This site continued to be monitored under an interim status indicator evaluation program in fiscal year 2002. Wells were sampled twice for indicator and site-specific parameters (see Appendix A, Table A.31 and Figure A.15). Values from downgradient wells were compared to those established from the upgradient wells. The indicator parameters (specific conductance, total organic carbon, and total organic halides) did not exceed critical mean values during fiscal year 2002. The pH valued reported in downgradient well 299-E25-46 for the June 2002 sampling event was 6.62, which is below the critical mean range set at 6.81 to 9.67. Verification sampling, performed in July 2002, showed this value was in error and that the correct pH was 7.

Waste Management Area A-AX continued to be monitored under a RCRA indicator evaluation program in fiscal year 2002. The indicator parameters did not exceed critical mean values during fiscal year 2002.

Specific conductance values ranged from 267 to 436 µS/cm during fiscal year 2002 (Figure 2.9-39), reflecting little or no change from last year except in well

299-E25-41. Specific conductance increased in this well from 346 to 436 μS/cm over the year. In general at this waste management area, the specific conductance values, which are well below the critical mean of 516.7 μS/cm, correspond to changes in sulfate and calcium.

2.9.2.9 RCRA Parameters for the 216-A-29 Ditch

The 216-A-29 ditch is a RCRA disposal facility. To date, there is no evidence that the site has contaminated groundwater with regulated constituents.

The 216-A-29 ditch is a RCRA disposal facility in the 200 East Area and is monitored under an interim status detection program. To date, there is no evidence that the site has contaminated groundwater with regulated constituents. At one time, the site was in assessment monitoring status because of high specific conductance, which was caused by sulfate from the site. However, sulfate is not a regulated groundwater constituent. Specific conductance in well 299-E25-48 continues to exceed the critical mean, but no concomitant rise in hazardous constituents has been observed.

The direction of groundwater flow beneath the ditch is west-southwest (~240 degrees azimuth) based on tritium and nitrate plume maps (see Figures 2.1-3 and 2.1-4) and on water-level elevations in the monitoring wells. The tritium plume map (see Figure 2.1-3) shows that the flow direction swings to the southeast as groundwater flows to the southeast corner of the 200 East Area. The calculated gradient is ~0.0002 for the entire length of the ditch and the flow rate is ~0.01 to ~0.04 meter per day (see Appendix A, Table A.2). This estimate of flow rate is lower than the nearby Waste Management Areas A-AX and C because of the much lower estimate of hydraulic conductivity. The water table beneath the ditch has steadily declined since discharges to the B Pond system were terminated.

Other than specific conductance at well 299-E25-48, there were no exceedances of contaminant indicator parameters during fiscal year 2002. Water-level measurements were taken during routine sampling throughout the year. The continued regional groundwater decline has rendered well 699-43-43 incapable of producing representative samples. The other wells, however, continue to have sufficient water for groundwater monitoring purposes.

2.9.2.10 BC Cribs and Trenches

The BC cribs and trenches were used from 1956 to 1958. They received the majority of the discharged tank waste inventory. Recent studies have focused on these facilities, which have not been extensively monitored. A new sampling plan for the 200-PO-1 Operable Unit proposes installing two new wells near the BC cribs.

These facilities (Figure 2.9-40) were used from 1956 to 1958 to dispose uranium recovery supernatant. A composite analysis for low-level waste disposal in the 200 Area (PNNL-11800) and the initial assessment completed with the System Assessment Capability (PNNL-14027) both make the point that the majority of the tank waste inventory sent to the discharge sites was disposed at the BC cribs and trenches. The constituents of interest include ferrocyanide, various radionuclides (specifically technetium-99 and cobalt-60), cyanide, and chromium. Highly mobile constituents, such as technetium-99, have most likely traveled in the groundwater to the Columbia River in the years since 1958.

Currently, there are two wells at the BC cribs, wells 299-E13-5 and 29-E13-14 (see Figure 2.9-40), that are sampled annually for gross alpha, gross beta, anions, gross gamma, filtered metals, iodine-129, strontium-90, tritium, and uranium. Technetium-99 (technetium-99 is a beta emitter) was not included because the gross beta results do not indicate the presence of beta-emitting constituents at any significant activity level. Although the constituents analyzed and the sampling frequency is adequate to detect waste constituents disposed at the BC cribs and trenches, the well network is lacking in properly located wells. Because of the concern recognized in reports for the composite analysis for low-level waste disposal in the 200 East Area (PNNL-11800) and the initial assessment by the System Assessment Capability (PNNL-14027), the well network needs to be upgraded to provide confidence that waste constituents are not moving away from the BC cribs undetected. Therefore, the 200-PO-1 sampling and analysis plan (DOE/RL-2003-04) proposes two additional wells to remedy the network shortcomings. The locations selected are east and northeast of the BC cribs and trenches site (see Figure 2.9-40), which is the interpreted downgradient flow direction based on the current water-table map and major plume maps (tritium, nitrate, iodine-129).

2.9.2.11 Monitoring at the River Shoreline (Hanford Town Site)

Groundwater contaminant plumes containing iodine-129, nitrate, technetium-99, and tritium enter the Columbia River at the Hanford town site and along the river downstream of the town site. There are no known local sources for these contaminants, which are believed to have migrated to the river from 200 East Area sources (PNL-8167). Water samples are collected annually by the Surface Environmental Surveillance Project from riverbank seepage sites during the seasonal low river stage, which occurs during the fall months. Two seepage sites were sampled during fiscal year 2002; no aquifer tubes were sampled. A river water sampling transect is located along the town site and the results for nearshore river water samples are included in the following discussion.

Iodine-129, nitrate, technetium-99, and tritium have been detected in riverbank seepage at the Hanford town site. The contaminants originated in the 200 East Area.

Table 2.9-1 lists the analytical results for key constituents for samples collected from riverbank seepage sites and from nearshore river water, along the Hanford town site shoreline. The specific conductance of riverbank seepage samples ranged between 314 and 401 μS/cm, indicating that the samples were primarily groundwater, with little dilution by river water that periodically infiltrates the riverbank. Gross beta was measured at 22.8 and 23.5 pCi/L at the two sites, which is below the 50-pCi/L drinking water standard. The cause for the slightly elevated gross beta activity is likely to be technetium-99 and tritium. Iodine-129 and technetium-99 have been detected previously in seepage samples at low concentrations (e.g., technetium-99 in the range 45 to 112 pCi/L and iodine-129 in the range 0.1 to 0.27 pCi/L during fiscal year 2001). No new results for iodine-129 and technetium-99 were obtained for these seepage sites during fiscal year 2002. Tritium was measured at 53,900 and 58,400 pCi/L at the two sites, thus still exceeding the 20,000-pCi/L drinking water standard. These concentrations are consistent with data from wells that monitor the groundwater plume that approaches the river in this area. Nitrate in seepage is in the range 20.8 to 22.6 mg/L, which is below the 45-mg/L drinking water standard.

The two seepage sites are located near Hanford River Marker #28, with the closest groundwater monitoring wells being 699-45-2, 699-44-4, and 699-46-4. A summary of concentrations in these wells for the key constituents is presented in Table 2.9-2. The seepage sites have been monitored for numerous years and have revealed increasing concentration trends for gross beta, tritium, technetium-99, and iodine-129 since 1994 (PNNL-13230). The increasing trends are not reflected in nearby groundwater monitoring wells, where concentrations for these constituents have remained relatively constant or declined somewhat in recent years (see Figure 2.9-32). This suggests that the portions of the plume with highest concentrations have passed the shoreline along the Hanford town site.

2.9.3 Confined Aquifer in the Lower Ringold Formation

PNNL-10886 subdivided the Ringold Formation into six hydrogeologic units (units 4 through 9). The Ringold Formation confined aquifer consists of the lowermost hydrogeologic unit (unit 9), which consists of fluvial sand and gravel overlying the uppermost basalt flow. It is confined by hydrogeologic unit 8, also referred to as the lower mud unit, which is the thickest and most laterally continuous mud unit beneath the Hanford Site. The base of the aquifer is the dense interior of the uppermost basalt flow. Previous studies have often included portions of the Ringold confined aquifer when describing and mapping the unconfined aquifer. Interpretations prior to 1999 generally did not differentiate these aquifers and did not attempt to distinguish the groundwater results (i.e., contaminant-plume and potentiometric-surface mapping) for the separate aquifers. Recent re-evaluation of hydrostratigraphy in the 200 East Area and vicinity attempt to refine the interrelationships between confined and unconfined aquifers, and explain differences in groundwater chemistry between these two systems (PNNL-12261).

The Ringold confined aquifer is known to be in communication with the unconfined aquifer in the 200 East Area, where they are adjacent to the unconformity created by erosion and subsequent deposition of the Hanford formation (PNNL-12261). Currently, there is no monitoring network designed specifically to monitor conditions within the Ringold confined aquifer. Most of the wells that monitor the Ringold confined aquifer are located east and south of 200 East Area. Therefore, this section focuses on that region. Confinement in the Ringold aquifer is identified chemically and physically by observation of groundwater levels during drilling or pumping tests, by stratigraphic relationships, and by comparison of groundwater chemical characteristics, such as ionic proportions, with those of adjacent portions of the aquifer.

The Ringold confined aquifer is the uppermost aquifer beneath two regulated disposal facilities, B Pond and the 200 Areas Treated Effluent Disposal Facility. Groundwater monitoring at those facilities is discussed in this section.

2.9.3.1 Groundwater Flow

Figure 2.9-41 presents the potentiometric surface for a portion of the confined aquifer in the Ringold Formation. This aquifer occurs within fluvial sand and gravel comprising the lowest sedimentary unit of the Ringold formation (unit 9). It is confined below by basalt and above by the lower mud unit (unit 8). This map is incomplete and subject to uncertainty because only a few wells monitor this aquifer.

Groundwater in the Ringold Formation confined aquifer flows generally west to east in the vicinity of the 200 West Area and west to east along the south boundary of the aquifer. These flow patterns indicate that recharge occurs west of the 200 West Area (Cold Creek Valley) as well as from the Dry Creek Valley and possibly the Rattlesnake Hills. In the central portion of the aquifer, west and south of the 200 East Area, groundwater flow is to the northeast. In addition, a groundwater mound is present northeast of B Pond as a remnant of past wastewater discharges to this facility. This mound causes groundwater to flow southwest beneath B Pond. A stagnation point is believed to exist to the south of B Pond, where the flow of water divides with some moving northwest toward the 200 East Area and some moving toward the east or southeast. Therefore, groundwater flow converges on the 200 East Area where the confining mud unit (unit 8) is absent, so the 200 East Area represents a discharge area for this aquifer. The water flowing toward the east is expected to eventually discharge to the Columbia River.

Groundwater in the Ringold confined aquifer west and south of the 200 East Area is to the northeast. In addition, a groundwater mound is present northeast of B Pond. This mound causes groundwater to flow southwest beneath B Pond. The 200 East Area represents a discharge area for this aquifer.

With the exception of the area immediately around B Pond, there appears to be an upward gradient between unit 9 and the Hanford formation near the 200 East Area in a region where the confining unit (unit 8) is absent (Figure 2.9-42). Well 299-E25-28 is completed within hydrogeologic unit 9 of the Ringold Formation (below the water table), and well 299-E25-34 is completed across the water table within the overlying Hanford formation (unit 1). These wells are located only 14 meters apart, and their hydrographs are shown in Figure 2.9-43. The hydraulic heads are apparently slightly higher in well 299-E25-28 indicating a small upward gradient, which supports the inference that groundwater discharging from the confined aquifer in the vicinity of the 200 East Area may recharge the overlying unconfined aquifer. After discharging to the unconfined aquifer, the groundwater is interpreted to flow generally southeastward over the top of the confining unit. This is possible because of the southerly dip of the suprabasalt strata.

The contours on Figure 2.9-44 are similar to the potentiometric surface for the upper basalt-confined aquifer (see Section 2.14). Hydraulic head and flow patterns in the central portion of the Hanford Site are very similar in both aquifers. Hydraulic heads differ in the west portion of the aquifers (~3 to 5 meters of head difference in the north part of the 200 West Area) where a downward hydraulic gradient exists. Hydraulic heads are also interpreted to diverge to the east, and an upward hydraulic gradient is expected in the vicinity of the Columbia River.

Water levels throughout this aquifer declined between -0.07 to -0.51 meter during the period from March 2001 to March 2002. The declining water levels are due to the near cessation of wastewater disposal to the soil column at Hanford. The declines were largest in the 200 West Area and the B Pond vicinity.

2.9.3.2 Contaminant Distribution

Most of the available chemical data from the Ringold confined aquifer are from wells on the Central Plateau. This plateau area is one of two known areas where contamination can migrate from the unconfined aquifer into the confined Ringold aquifer. The other area of potential downward migration is near the B Pond facility, east of the 200 East Area. However, groundwater chemistry data for the Ringold confined aquifer, in general, are limited because of the lack of well completions in the aquifer.

Figure 2.9-42 illustrates proportions of major dissolved ions and shows the extent of tritium penetration into the confined aquifer east of the 200 East Area. The figure illustrates that groundwater chemistry correlates with groundwater in the unconfined aquifer and in the Ringold confined aquifer (unit 9). The major ion chemistry of groundwater in the Ringold confined aquifer, adjacent to the juncture between confined and unconfined, is of the calcium-bicarbonate type and has elevated tritium concentrations similar to groundwater in the unconfined aquifer. South and east of B Pond near the 200 Areas Treated Effluent Disposal Facility, and toward the May Junction Fault, groundwater in the Ringold confined aquifer has lower tritium concentrations and is of the sodium-bicarbonate type. Tritium concentrations and other chemical data (see PNNL-13032) indicate that groundwater in the Ringold confined aquifer east and southeast of the tritium-migration line in Figure 2.9-42 has not been displaced or diluted by wastewater associated with 200 East Area operations.

Tritium was present in discharges to B Pond, which is located directly above the erosional feature that allows communication between the unconfined (Hanford formation and Ringold Formation) and the confined Ringold aquifer. During active disposal, groundwater mounding increased the driving head and forced groundwater and any associated contamination into the confined aquifer. The groundwater moved laterally within the confined aquifer as long as the head remained high from the overlying groundwater mound, although low hydraulic conductivity in the region of the Treated Effluent Disposal Facility limited actual flow in a south-easterly direction. When disposal to B Pond decreased in the late 1980s and then ceased in 1997, water levels and tritium concentrations in the unconfined aquifer decreased significantly. In the case of tritium, decay has contributed significantly to the decline in concentrations. Horizontal flow is now toward the southwest, so the high concentrations of tritium in the confined aquifer are expected to move toward the unconfined aquifer.

Similar groundwater mounding has historically occurred within the 200 West Area, and may be responsible for driving contaminants deeper into locally confined portions of the Ringold aquifer in isolated areas. Wells 299-W7-3 and 299-W6-6, which are deep wells located along the north boundary of the 200 West Area, have indicated incursions of nitrate during the past few years (from <1 mg/L in 1996 to ~60 mg/L in fiscal year 2002 in well 299-W6-6). However, the tritium plume that has been identified in this area in shallow wells (see tritium map of 200 West Area) does not appear in these deeper wells. Well 299-W6-7, which is a shallow companion to well 299-W6-6, produced tritium results of >46,000 pCi/L in fiscal year 2002, and has historically produced elevated nitrate (~139 mg/L in fiscal year 2002). The reason for the appearance of anomalous levels of nitrate in deep well 299-W6-6 without the elevated tritium observed in the shallow companion, may be the result of different sources for the contaminants and, hence, different entry pathways to the lower portion of the aquifer.

The Ringold confined aquifer is contaminated with nitrate and tritium in the 200 Areas.

A similar relationship for nitrate and tritium is seen between shallow well 299-E25-34 and deeper companion 299-E25-28, except here the contamination in the deeper portion of the aquifer appears to be the result of shallow contamination (historically observed in shallow well 299-E25-34) penetrating deeper into the aquifer at this location. Although hydraulic head in the deeper well has marginally exceeded that of the shallow well for the past few years (see Figure 2.9-43), head was historically higher in the shallow well (during 200 East Area operations), and delayed penetration of contamination is now seen at depth.

The State-Approved Land Disposal Site (see Section 2.8.2.14), which is barely within the areal boundaries of the confined portion of the Ringold aquifer, has intermittently discharged tritium to the ground since late 1995. During the past few years, tritium concentrations of up to 980,000 pCi/L have reached the deepest well (699-48-77C) located near this facility. Although aquifer tests have indicated confined conditions at depth near this facility, apparently, discharged effluent can be driven into these portions of the aquifer if sufficient head is available. An increase in hydraulic head of up to 1 meter above preoperational conditions has resulted from discharges to the State-Approved Land Disposal Site in the immediate vicinity of the facility.

2.9.3.3 RCRA Parameters for B Pond

An interim status RCRA facility, the B Pond system originally consisted of a main pond, three expansion ponds, and portions of several ditches leading to the main pond (see Figure 2.9-1 and Appendix A, Figure A.5). Currently, only the main pond and an adjacent portion of the 216-B-3-3 ditch are regulated as a RCRA treatment, storage, and disposal facility.

B Pond was placed into assessment in 1990 because of elevated total organic carbon and total organic halides in groundwater from two wells. Following the initial excursion, occurrences of elevated results for total organic carbon and total organic halides were isolated and generally declining with time. Groundwater quality assessment that concluded in 1996 (PNNL-11604) determined that no specific compounds could be identified in sufficient concentration or with consistency that would allow correlation to elevated total organic carbon and total organic halides.

In fiscal year 2002, DOE began a 2-year trial period for a new approach to RCRA groundwater monitoring at B Pond.

The groundwater monitoring well network in this area was more extensive in the past when groundwater was interpreted to flow radially away from the facility, and the now clean-closed expansion ponds were still part of the regulated facility. In late 2001, a new approach to groundwater monitoring (PNNL-13367-ICN-1) was presented by DOE, and a variance for this purpose was granted by the regulators for a 2-year trial period. This approach, placed into effect in December 2001, allows intra-well comparisons of successive analytical results on a semiannual basis for site-specific indicator constituents. The comparisons are based on methods prepared by the American Society for Testing and Materials, and apply a combined Shewhart-Cumulative Sum control chart method of statistical analysis. This approach allows the site-wide false-positive rate (the erroneous declaration of contamination) to be kept acceptably low in all wells for all constituents, while providing adequate statistical power to detect real contamination, should it occur. The constituents selected for site-specific monitoring are gross alpha, gross beta, and specific conductance. DOE has allowed the radionuclide indicators to remain in the RCRA monitoring at B Pond by a specific exception to the *Atomic Energy Act of 1954*/RCRA separation of constituents, and by agreement with the Washington State Department of Ecology. This new approach allows a more refined and appropriate evaluation of groundwater quality at the B Pond facility, instead of defaulting to prescribed indicator parameters (total organic carbon, total organic halides). The agreement also requires monitoring of cadmium, lead, mercury, and silver annually for four years, then allows discontinuation of these if concentrations remain below maximum contaminant levels. The entire list of constituents in provided in Appendix A., Table A.11.

The groundwater monitoring well network, which consists of a total of four wells, was also revised to more closely target the regulated facility (see Appendix A, Figure A.5). One well, 699-44-39B, is located in an area currently upgradient of the B Pond, with three wells (699-42-42B, 699-43-44, and 699-43-45) located at the downgradient edges of the main pond and B-3-3 ditch.

Groundwater Flow

Groundwater flow at B Pond during fiscal year 2002 appeared to be from northeast to southwest across the main pond, and is changing rapidly because of declines in the water table and the patterns of drainage in the aquifer.

The groundwater flow rate was estimated at 0.008 (see Appendix A, Table A.2). This velocity reflects the relatively low hydraulic conductivity of the Ringold Formation.

Groundwater flow in the Ringold confined aquifer near B Pond is very slow. Chemical evidence indicates that the confined groundwater in this region is relatively old compared with elsewhere in the Ringold aquifer, and was virtually unaffected by B Pond discharges.

Actual flow may be extremely limited in a southeast direction (toward the Treated Effluent Disposal Facility) as indicated by tritium concentrations and ionic proportions in groundwater in this area (see Figure 2.9-42). Tritium concentrations in this area are well below background levels for surface water (e.g., Columbia River) and the unconfined aquifer elsewhere (~12 pCi/L in fiscal year 2002). Major ion proportions, which are sodium bicarbonate dominated, also indicate a more highly evolved groundwater chemistry than typical for the unconfined Ringold aquifer. These two circumstances suggest groundwater in this area is relatively old compared with elsewhere in the Ringold aquifer, and was virtually unaffected by B Pond discharges. Hence, net groundwater movement from the B Pond area toward the Treated Effluent Disposal Facility is interpreted to be very limited.

Groundwater is considered to flow more readily southwestward out of the confined portions of the aquifer into the unconfined Hanford formation aquifer beneath the southwest extremity of the main pond and the 216-B-3-3 ditch (see Figure 2.9-30 and Section 2.9.3). This groundwater then encounters a highly conductive northwest-southeast channel in the Hanford formation gravel and flows southeastward, eventually flowing over the top of the same layer (Ringold lower mud unit) that confines groundwater in the east and southeast portions of the B Pond facility. This is possible because the strata dip southward in this area.

A downward hydraulic gradient is indicated between shallow and deep well pairs in the network. Head measurements during fiscal year 2002 indicated downward-directed gradients of 0.5 between wells 699-43-41E and 699-43-41G (measured in September 2001), 0.3 between wells 699-43-42J and 699-42-42B (measured in March 2001), and 0.12 between wells 699-42-39A and 699-42-39B (measured in January 2001). The downward potential is most likely a result of the remnant groundwater mound beneath the facility, and has been slowly diminishing over the past several years.

Groundwater Quality

Chemical parameters sought in B Pond groundwater analyses, which represent both site-specific concerns and regulatory requirements, are listed in Appendix A, Table A.11.

Application of the Shewhart-Cumulative Sum method of statistical evaluation to gross alpha, gross beta, and specific conductance reveals interesting trends during the first two semiannual sampling events using this method (Figures 2.9-45 and 2.9-46). Gross beta in well 699-43-45 briefly exceeded the two-sigma threshold in both concentration and for the Shewhart-Cumulative Sum trend. However, the most recent results indicate that gross beta had retreated from its historical high, and, providing that the concentration does not rebound, suggests that the Shewhart-Cumulative Sum trend will also be below that limit in the next analysis period (January 2003). Likewise, specific conductance in this well has been rising gradually since ~1995. Hence, the Shewhart-Cumulative Sum measurement of this parameter, which is sensitive to longer-term trends, marginally exceeds the mean-plus-two-sigma threshold in the most recent statistical analysis. At the present time, no specific action limit is set for declaring contamination at this site, based solely on these sigma thresholds. The trends for both conductivity, gross beta, and to a lesser degree, gross alpha, likely represent a recovery of groundwater to natural concentrations of these parameters, following the historical diluting effects of the B Pond discharges. Therefore, evaluation of trends will be based on a comparison of actual concentrations with Hanford Site-wide background values and the Shewhart-Cumulative Sum methodology. Historical concentrations in all four B Pond wells are below one estimate of site-wide background (WHC-EP-0595) for all three site-specific parameters: specific conductance (background = 539 µS/cm), gross alpha (background = 5.79 pCi/L) and gross beta (background = 12.62 pCi/L).

Beneath B Pond, increasing trends in specific conductance, gross beta, and gross alpha likely represent a recovery of groundwater to natural concentrations following the historical diluting effects of the B Pond discharges.

Nitrate concentrations display upward trends in some wells (Figure 2.9-47), but concentrations are all well below the maximum contaminant level, and most are near or below Hanford Site background as calculated by DOE/RL-96-61 and WHC-EP-0595. The wells shown in Figure 2.9-47 are still monitored periodically by site-wide groundwater surveillance and/or the B Pond network.

Specific conductance in some wells (Figure 2.9-48) also displayed a recent increase. This increase is interpreted as groundwater returning to equilibrium with the aquifer solids. Past discharges at B Pond mostly diluted the groundwater, artificially depressing specific conductance. This parameter remains below Hanford Site-wide background levels for groundwater in several B Pond wells.

Arsenic, iodine-129, nitrate, and tritium are considered of slight potential concern in the B Pond area, but are part of broader Hanford Site-wide groundwater contamination in the same area. Hence, analyses for these parameters are deferred to site-wide monitoring. No apparent trends are seen for arsenic or iodine-129, and tritium concentrations are generally declining.

2.9.3.4 200 Areas Treated Effluent Disposal Facility

Located southeast of the B Pond RCRA site, the 200 Areas Treated Effluent Disposal Facility has been in operation since June 1995. Groundwater monitoring beneath the facility began in late 1992, initially as an unofficial part of the B Pond

RCRA monitoring. Three wells were installed in 1992 for the express purpose of monitoring groundwater at the Treated Effluent Disposal Facility (see Appendix A, Figure A.5).

The state waste discharge permit (ST-4502), which sets discharge and groundwater monitoring parameters, was revised in May 2000, and extends the operating period through May 18, 2005. A revised groundwater-monitoring plan (PNNL-13032) accompanies this renewed permit.

Discharges to the Treated Effluent Disposal Facility originate from the 200 Areas facilities and consist of Columbia River water and other clean water sources. Since operation of the Treated Effluent Disposal Facility began in April 1995, ~4.7 billion liters of effluent have been discharged to the facility. The highest monthly discharge occurred in September 1997 (375 million liters). The year 1997 was also the year of greatest discharge volume (889 million liters). As Figure 2.9-49 illustrates, the pattern of discharges to the Treated Effluent Disposal Facility is characterized by one dominant discharge month per year that accounts for most of the annual discharge volume, followed by discharges of significantly smaller monthly volumes. The dominant discharge event is the result of periodic campaigns of the 242-A evaporator, and consists of uncontaminated cooling water (raw water) from that facility.

The three monitoring wells at the Treated Effluent Disposal Facility (see Appendix A, Figure A.5) are sampled quarterly for a list of constituents specified by the state waste discharge permit (see Appendix A, Table A.42).

Effluent from the Treated Effluent Disposal Facility flows readily downward through the Hanford formation gravel and is then diverted from the uppermost aquifer by the relatively-impermeable lower mud unit. The effluent is thought to flow generally south along the top of this unit.

The Ringold Formation confined aquifer (uppermost aquifer), which consists of Ringold Formation gravel and sand units 9A-9C (PNNL-12261), is ~35 meters thick beneath the Treated Effluent Disposal Facility (see Section 2.9.4). The confining unit consists of the Ringold Formation unit 8 (lower mud unit), which is ~26 meters thick near well 699-40-36. Effluent from the Treated Effluent Disposal Facility flows readily downward through the Hanford formation gravel and is then diverted from the uppermost aquifer by the relatively-impermeable lower mud unit (unit 8) silt and clay stratum. The effluent is thought to flow generally south along the top of this unit before entering the unconfined Hanford formation aquifer some distance south of the Treated Effluent Disposal Facility.

Since late 1995, hydrographs of the Treated Effluent Disposal Facility wells (Figure 2.9-50) reveal only the continuing decline in hydrostatic pressure from the discontinuation of B Pond discharges. Well 699-43-37 has experienced the most pronounced decline (~0.16 meter during fiscal year 2002), probably because of its proximity to the source of the B Pond hydraulic mound. No obvious features in the hydrographs can be related to operation of the Treated Effluent Disposal Facility, which began in June 1995.

The direction of groundwater flow, or the potential for flow beneath the Treated Effluent Disposal Facility in the confined Ringold Formation aquifer, is southwest (see Figure 2.9-44). Calculations of groundwater flow rate (see Appendix A, Table A.2), from March 2002 measurements, indicate an average linear flow velocity of ~0.004 meter per day. However, groundwater chemistry and recent hydrostratigraphic research suggest that actual flow may be at a very low rate (see Section 2.9.3). Major ion proportions and tritium activity levels 11.7 pCi/L or less in this aquifer near the Treated Effluent Disposal Facility and east portions of B Pond (see Figure 2.9-42) support this inference. Additionally, routine analyses of the Treated Effluent Disposal Facility effluent indicates consistently higher amounts of tritium in the effluent (e.g., 26.4 pCi/L in July 2002), which is more typical of raw Columbia River water, than in groundwater beneath the facility. The results of monitoring suggest that groundwater has been isolated from Hanford Site influences and may be relatively old compared with groundwater elsewhere in the uppermost aquifer.

A list of six constituents is evaluated quarterly and compared with permit enforcement limits. No enforcement limits were exceeded during fiscal year 2002. In fact, none of these parameters have exceeded enforcement limits or practical quantitation limits since monitoring of wells at the Treated Effluent Disposal Facility began in 1992 (2+ years prior to operation). Most results for anions, metals, and radionuclide indicators have been near or below Hanford Site-wide background levels specified in WHC-EP-0595 and DOE/RL-96-61. Groundwater from well 699-42-37 is typically higher than other wells in concentrations of most metals, anions, and produces samples with higher levels of conductivity and total dissolved solids. Anions also are consistently higher in this well than the other two Treated Effluent Disposal Facility wells, with nitrate displaying an apparent upward trend in concentration (Figure 2.9-51). The reason for this increase is unknown, but may be a result of the proximity of this well to the 216-B-3 Pond facility, and hence, peripherally affected by historical discharges to that facility. Sulfate (Figure 2.9-52) also illustrates the difference in concentrations of some constituents between well 699-42-37 and the other wells, but shows no increasing or decreasing trend.

The Treated Effluent Disposal Facility is not affecting groundwater quality in the uppermost aquifer.

Because there was no unconfined aquifer beneath the facility before operation began, wells were installed in the confined Ringold Formation aquifer, even though they are isolated from the effects of operation. Hence, analytical results from the three wells are used to demonstrate that this isolation is still in effect, and that the Treated Effluent Disposal Facility is not affecting the uppermost aquifer in this area. The lack of hydraulic response to Treated Effluent Disposal Facility discharges, groundwater chemical characteristics that differ significantly from Treated Effluent Disposal Facility effluent, and unique tritium activities are cited as evidence of the isolation (see PNNL-11986; PNNL-13032).

Table 2.9-1. Shoreline Monitoring Data for the Hanford Town Site Area, Fiscal Year 2002

Location Name	Sample From[a]	Sample Date[b]	Specific Conductance (µS/cm)[c]	Gross Beta (pCi/L)	Nitrate (mg/L)	Tritium (pCi/L)
SHTS-28-2	Seep	10/07/02	321	22.8	23	58,400
SHTS-DR28-2	Seep	10/07/02	314	23.5	21	53,900
RHTS-287-T1	River	09/10/01			0.53	821
RHTS-287-T1	River	09/09/02			1.50	3,120
RHTS-260-SHR	River	09/10/01			0.28	40
RHTS-260-SHR	River	09/09/02			0.35	23
RHTS-270-SHR	River	09/10/01			0.31	41
RHTS-270-SHR	River	09/09/02			0.34	25
RHTS-280-SHR	River	09/10/01			1.99	5,140
RHTS-280-SHR	River	09/09/02			5.75	15,500
RHTS-300-SHR	River	09/10/01			0.62	1,380
RHTS-300-SHR	River	09/09/02			1.02	1,760

(a) Tube = aquifer sampling tube near shoreline; Seep = riverbank seepage; River = nearshore river water.
(b) Data for October 2002 (fiscal year 2003) provided because seeps were not sampled in fiscal year 2002.
(c) Specific conductance provides an indication of the amount of river water in the sample; uncontaminated groundwater is typically in the range of 350 to 450 µS/cm and river water in the range of 120 to 150 µS/cm.

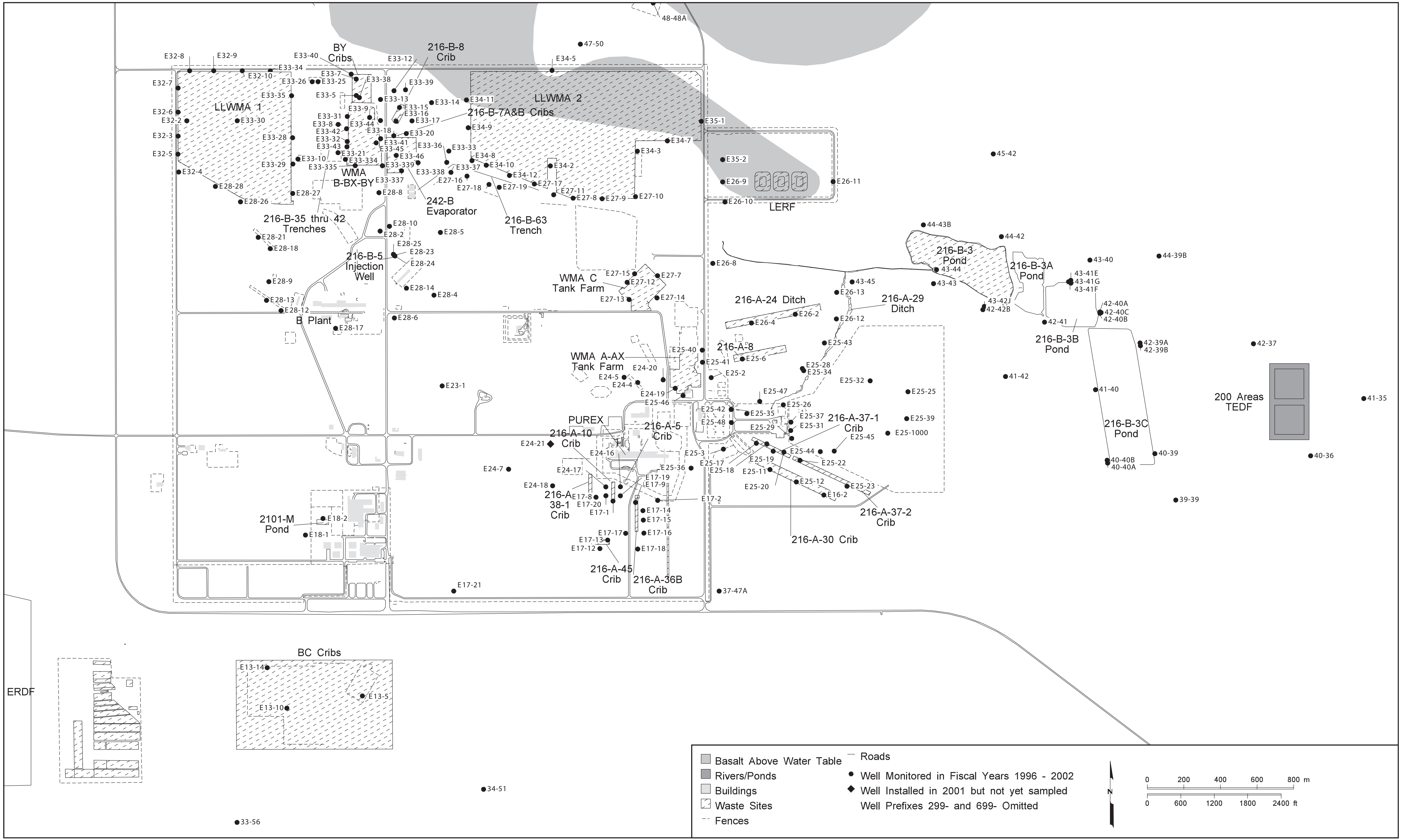
Data sources: Hanford Environmental Information System and various project records.

Table 2.9-2. Key Contamination Indicators in Hanford Town Site Near-River Wells

Well Name	Constituent	No. of Results	No. of Detects	No. of Rejects	Minimum Value	Maximum Value	Average	Units	Standard (MCL)
699-44-4	Specific conductance	2	2	0	224	256	240	µS/cm	
699-45-2	Specific conductance	2	2	0	423	456	440	µS/cm	
699-46-4	Specific conductance	11	11	0	367	435	397	µS/cm	
699-46-4	Gross alpha	4	4	0	2.1	4.4	3.0	pCi/L	15
699-46-4	Gross beta	4	4	0	19.1	31.9	28.0	pCi/L	50
699-45-2	Iodine-129	1	1	0	0.08	0.08	0.08	pCi/L	1
699-46-4	Iodine-129	10	4	0	0.16	0.83	0.47	pCi/L	1
699-44-4	Nitrate	1	1	0	1	1	1	mg/L	45
699-45-2	Nitrate	2	2	0	38	39	39	mg/L	45
699-46-4	Nitrate	2	2	0	31	31	31	mg/L	45
699-46-4	Nitrate	4	4	0	5	7	6	mg/L	45
699-46-4	Strontium-90	4	0	0				pCi/L	8
699-45-2	Technetium-99	2	2	0	107	132	120	pCi/L	900
699-46-4	Technetium-99	6	6	0	56	113	90	pCi/L	900
699-44-4	Tritium	2	2	0	147,000	153,000	150,000	pCi/L	20,000
699-45-2	Tritium	2	2	0	176,000	202,000	189,000	pCi/L	20,000
699-46-4	Tritium	11	11	0	80,500	167,000	119,239	pCi/L	20,000

MCL = Maximum contaminant level.

Data summary for January 1, 1993 to January 7, 2003. Data Source: Hanford Environmental Information System.



wdw03011/can_gw02_3 February 18, 2003 11:10 AM

Figure 2.9-1. Groundwater Monitoring Wells in the 200 East Area

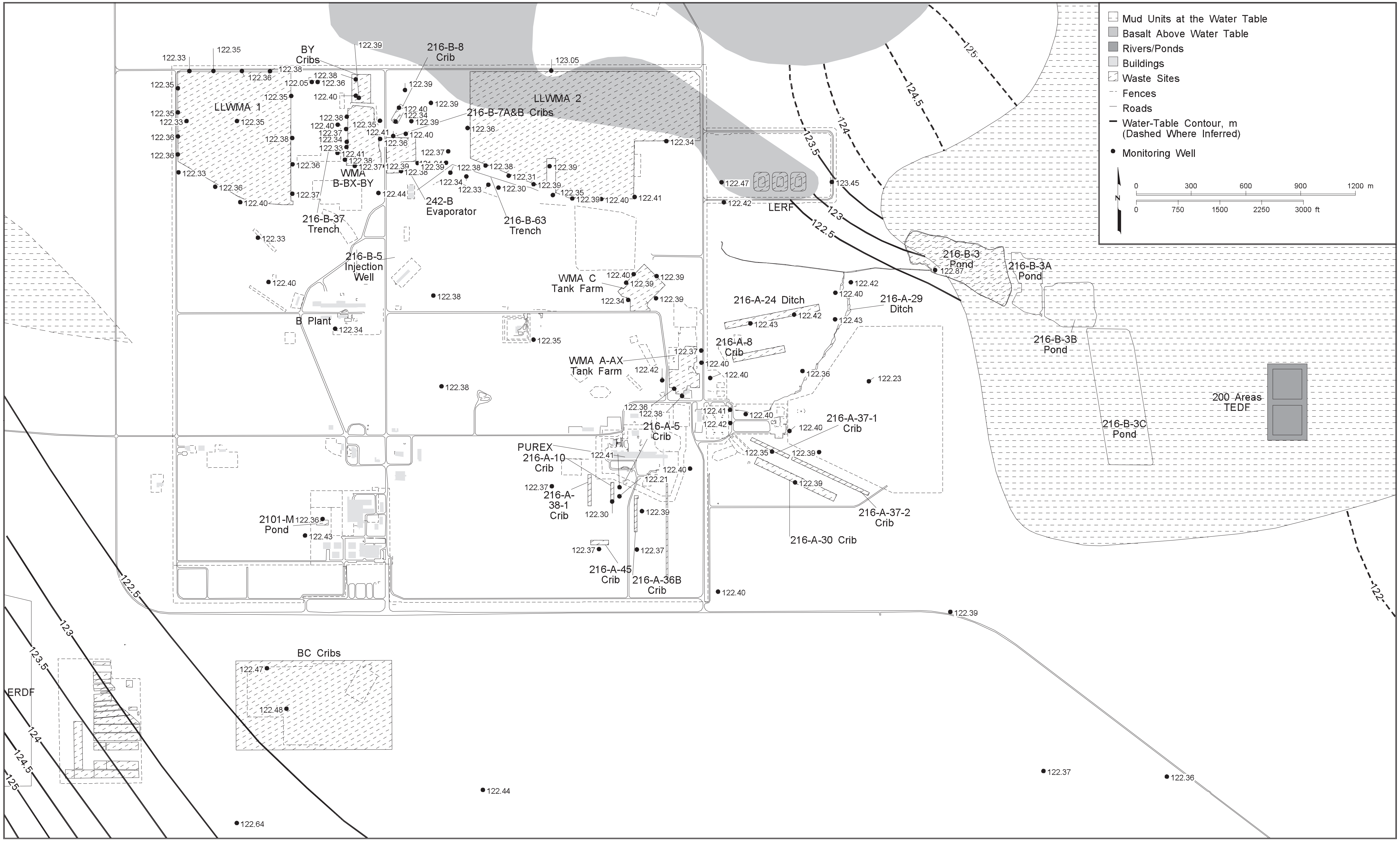


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Figure 2.9-2. Water-Table Map of 200 East Area, March 2002

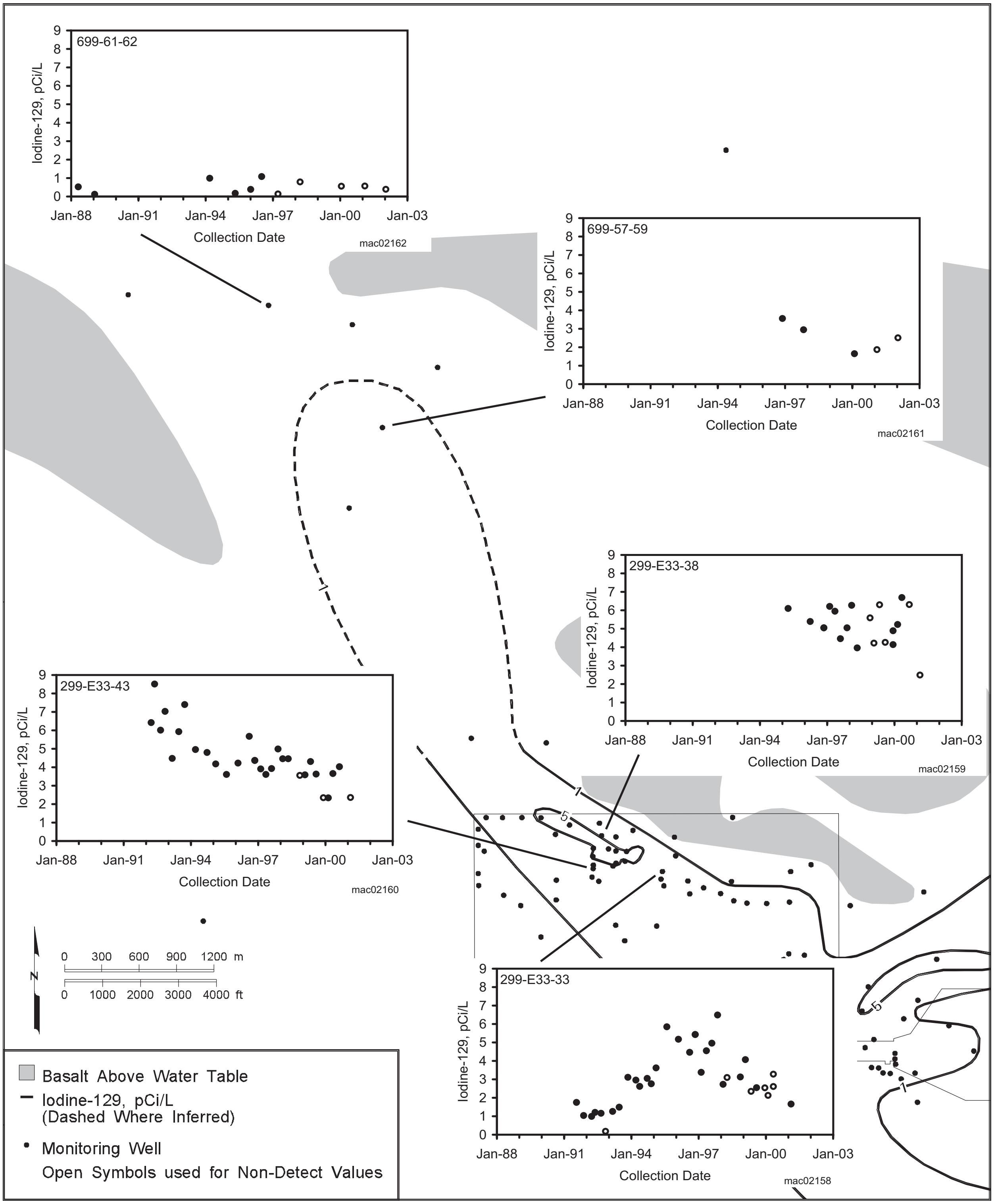

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Figure 2.9-3. Average Iodine-129 Concentrations in the North 200 East Area, Top of Unconfined Aquifer

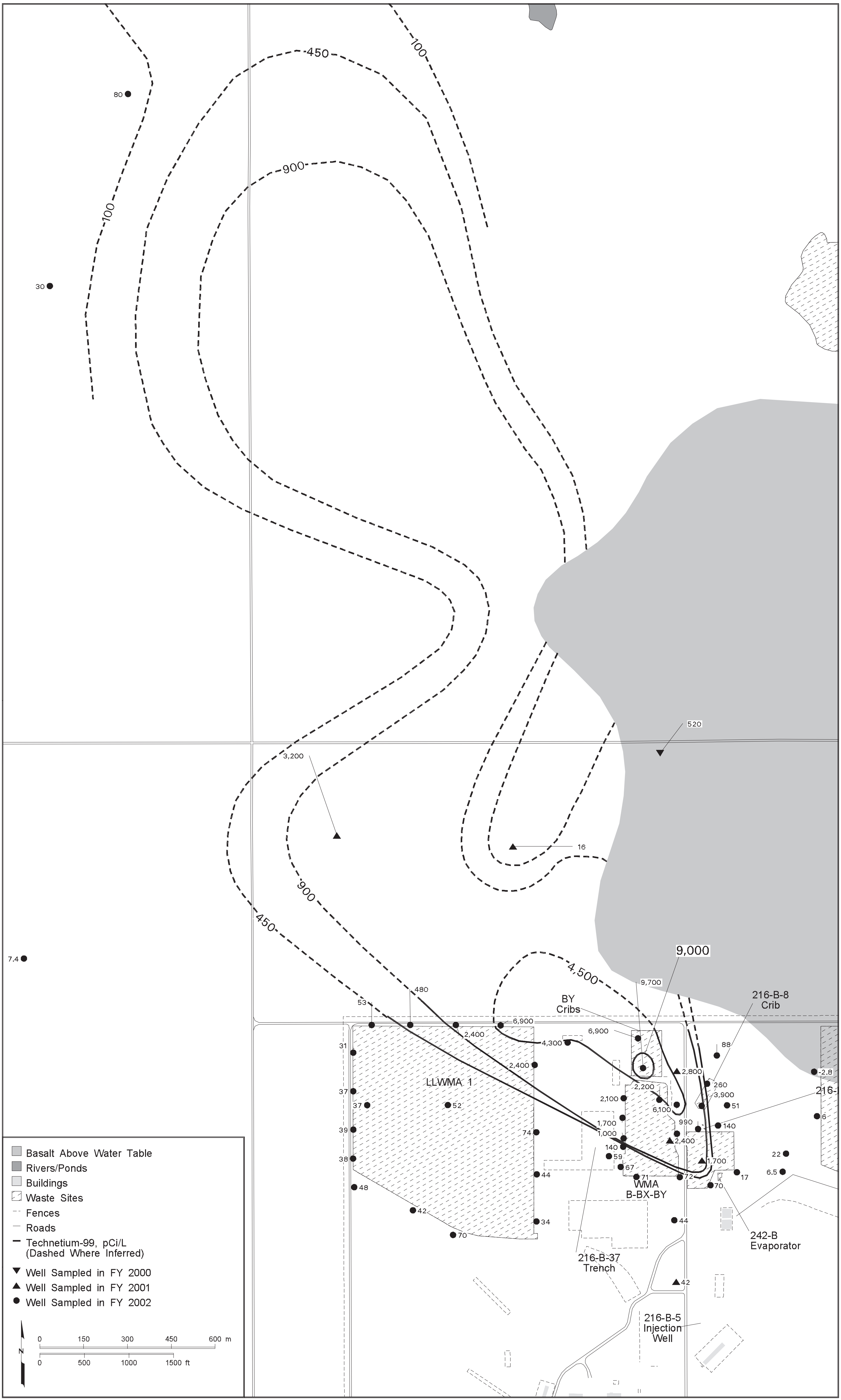

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Figure 2.9-4. Average Technetium-99 Concentrations in the North 200 East Area, Top of Unconfined Aquifer

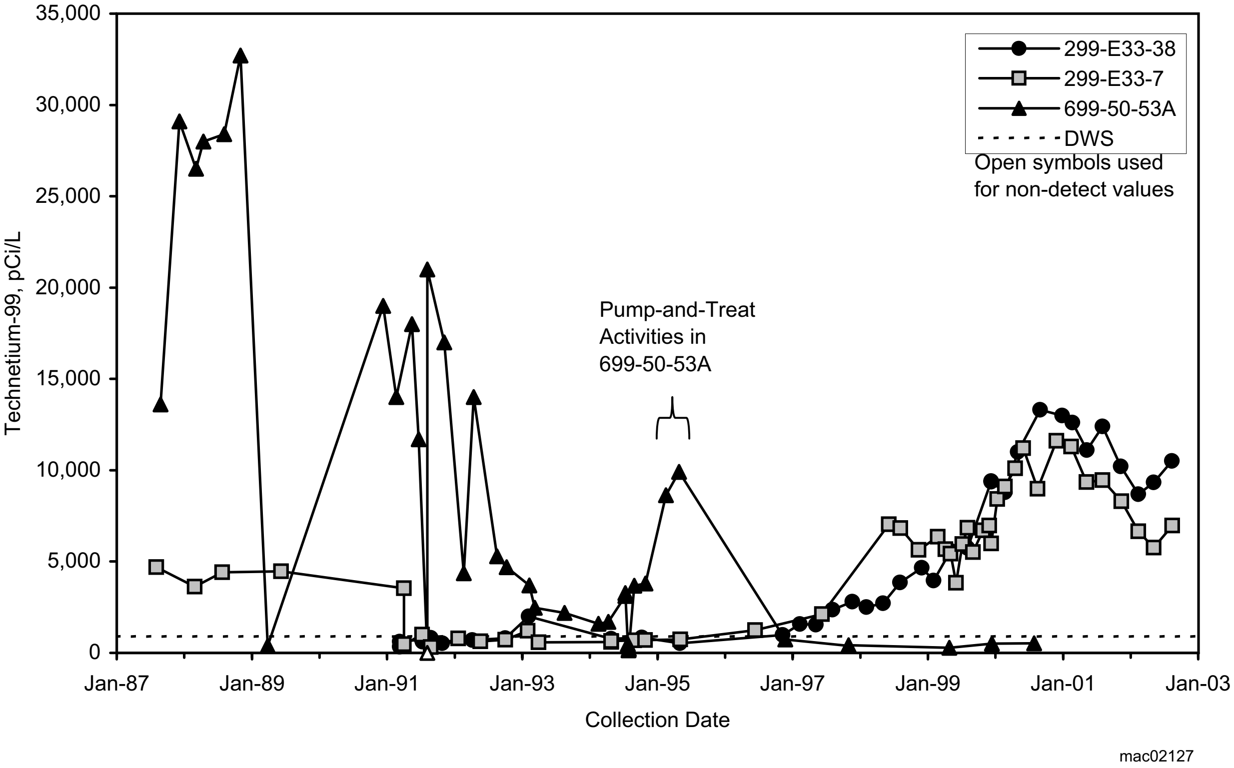


Figure 2.9-5. Technetium-99 Concentrations in Wells 299-E33-7 and 299-E33-38 at the BY Cribs and Well 699-50-53A North of 200 East Area

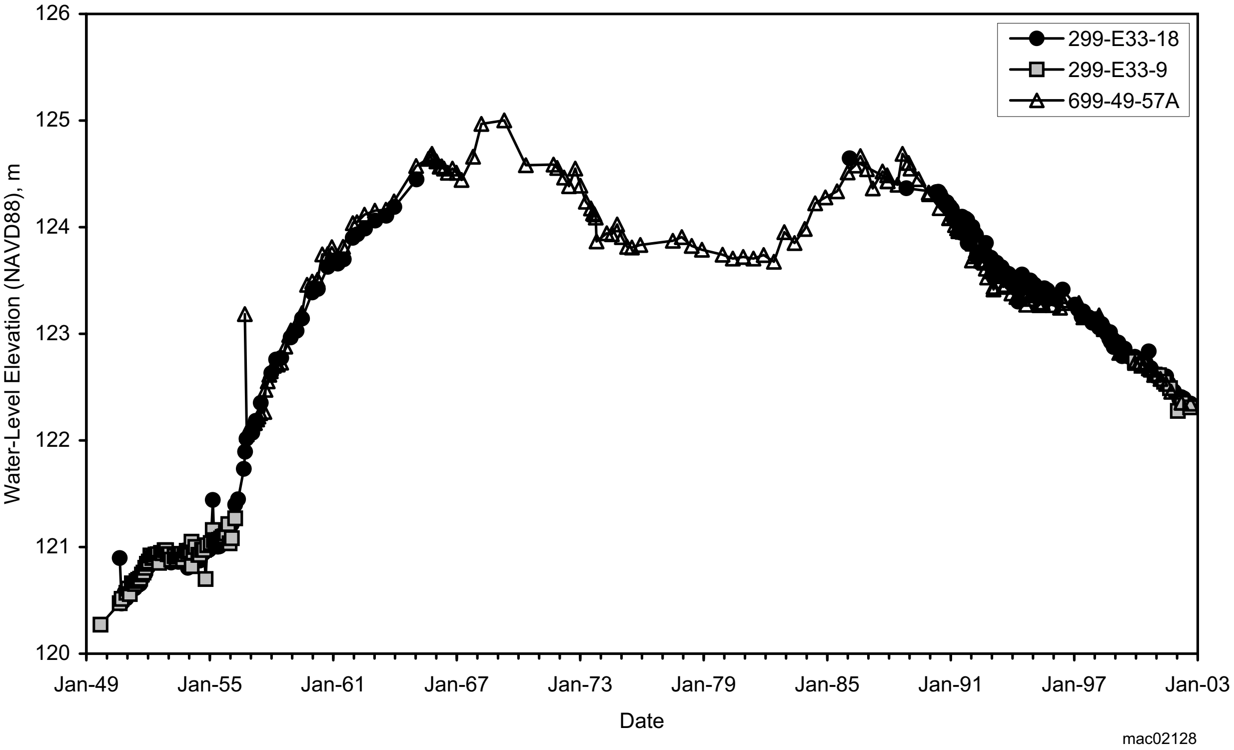
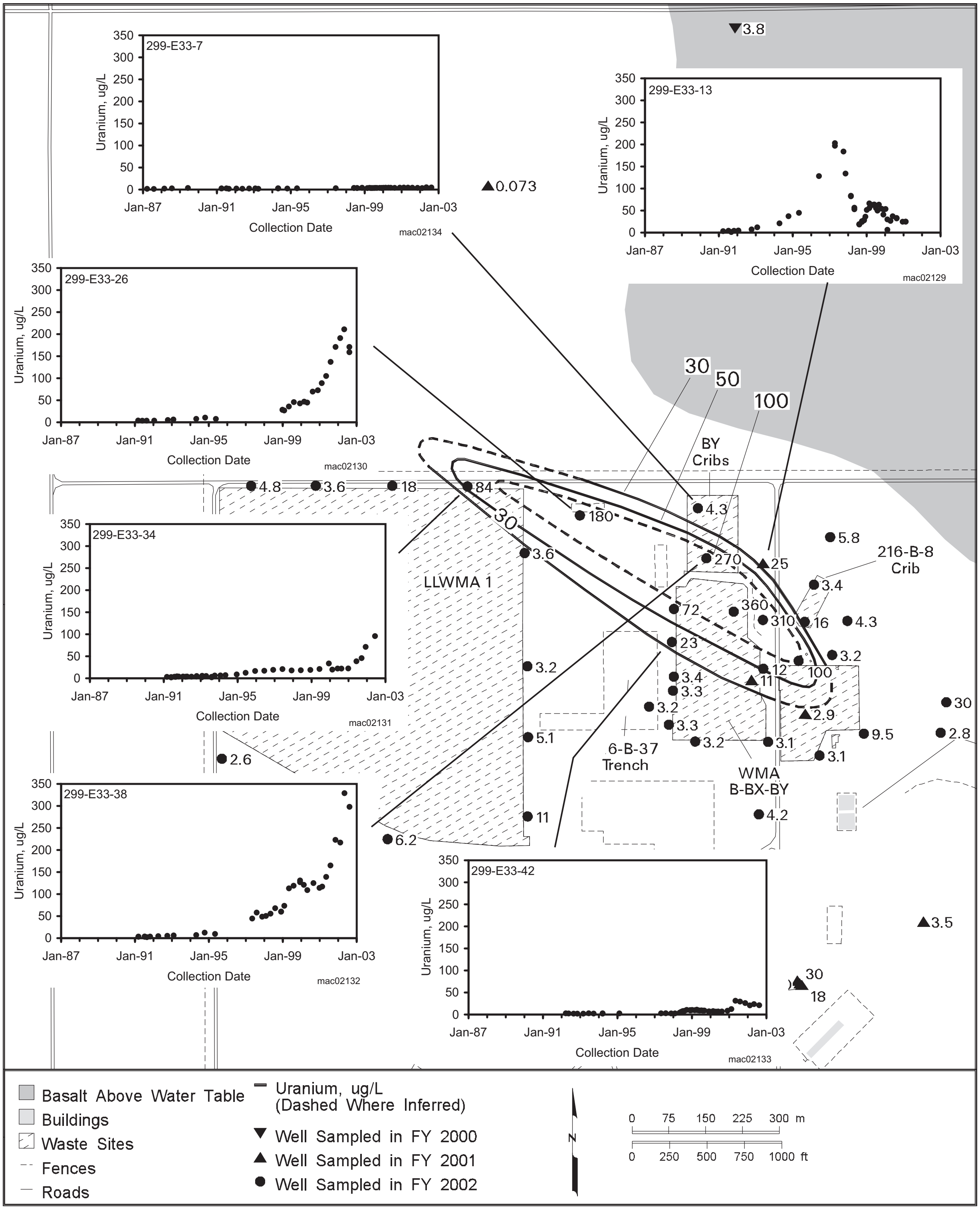


Figure 2.9-6. Water Levels in the Northwest 200 East Area



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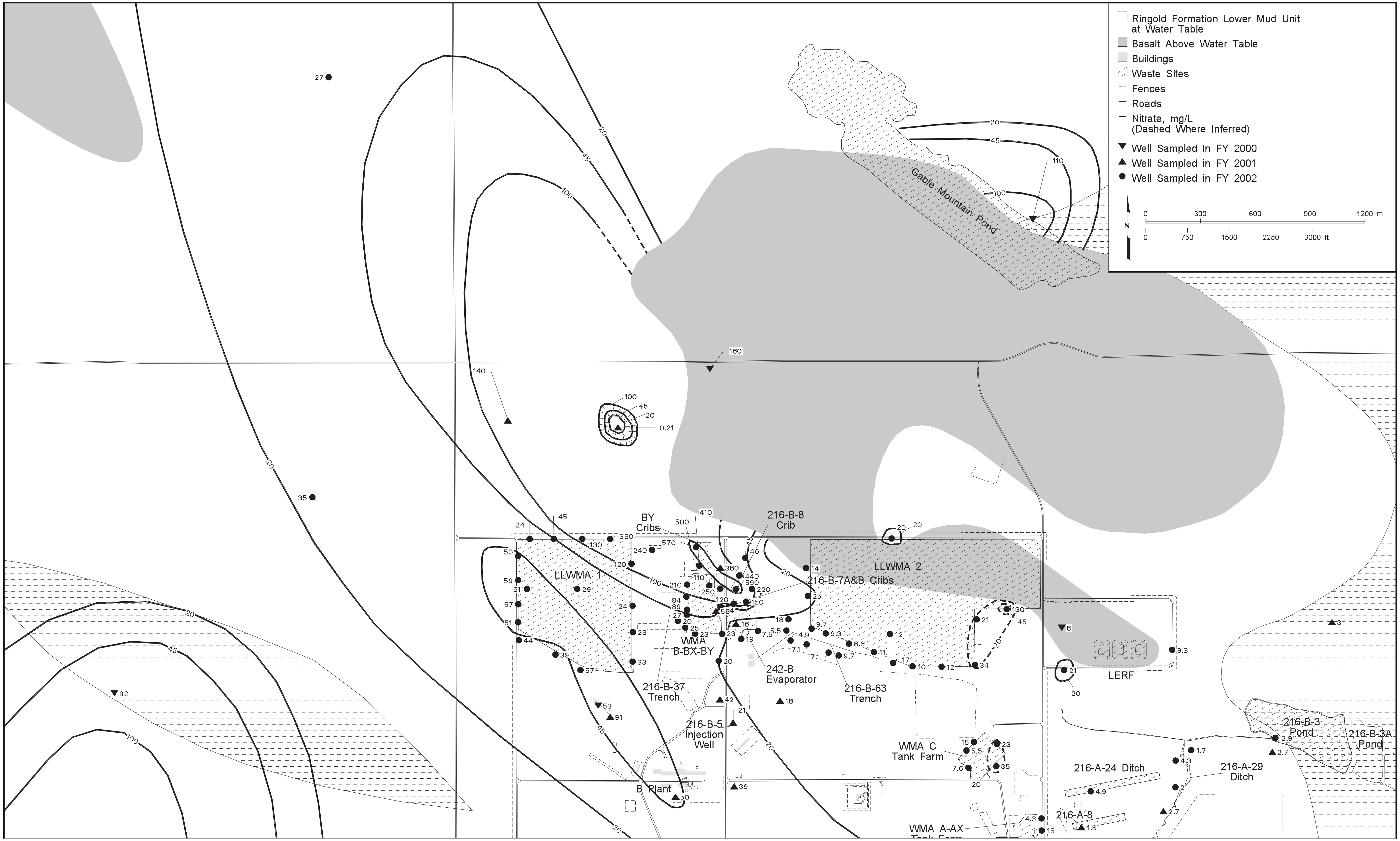
gwf02150

Figure 2.9-7. Average Uranium Concentrations in the Vicinity of BY Cribs, Top of Unconfined Aquifer



can_gwf02_151 February 13, 2003 4:42 PM

Figure 2.9-8. Average Nitrate Concentrations in the North Part of 200 East Area, Top of Unconfined Aquifer

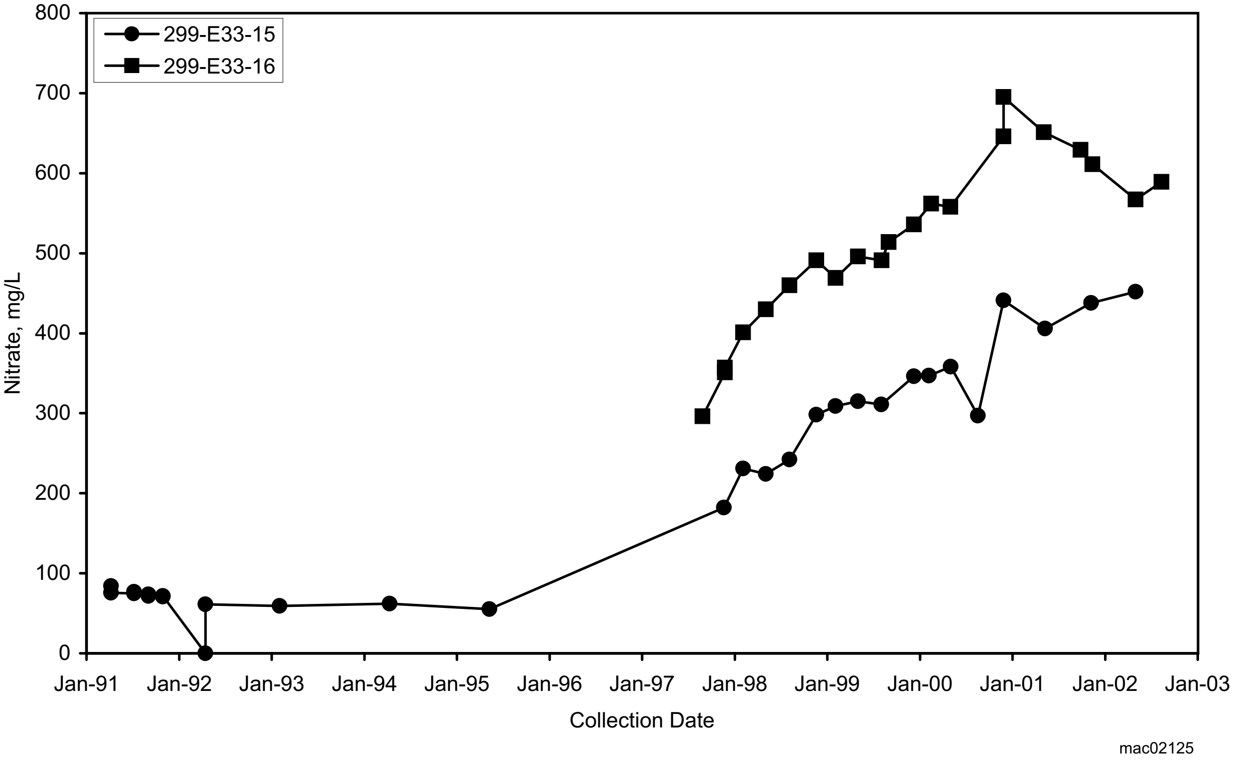


Figure 2.9-9. Nitrate Concentrations in Wells Monitoring 216-B-8 Crib

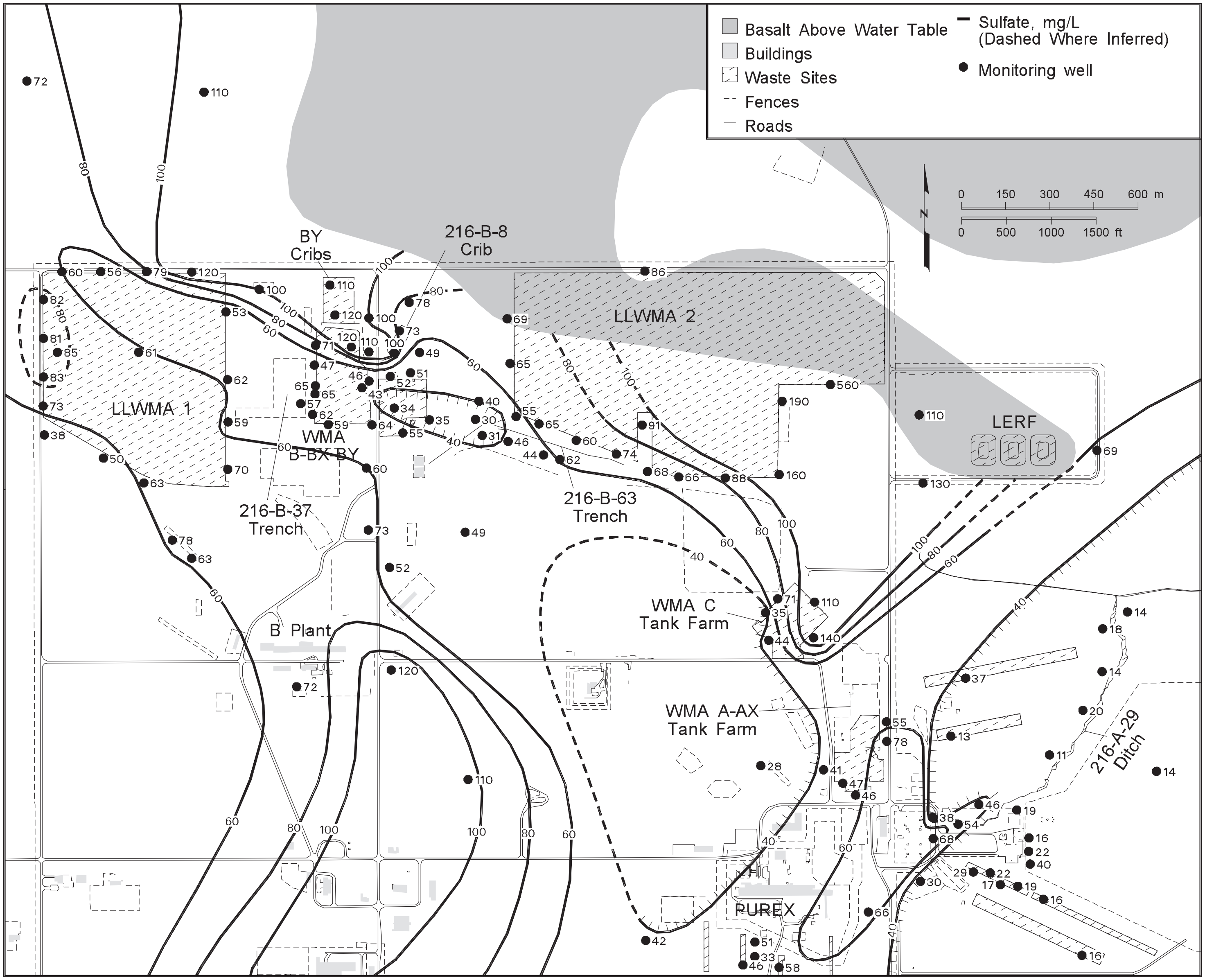


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Figure 2.9-10. Average Fiscal Year 2002 Sulfate Concentrations in the North Part of 200 East Area, Top of Unconfined Aquifer

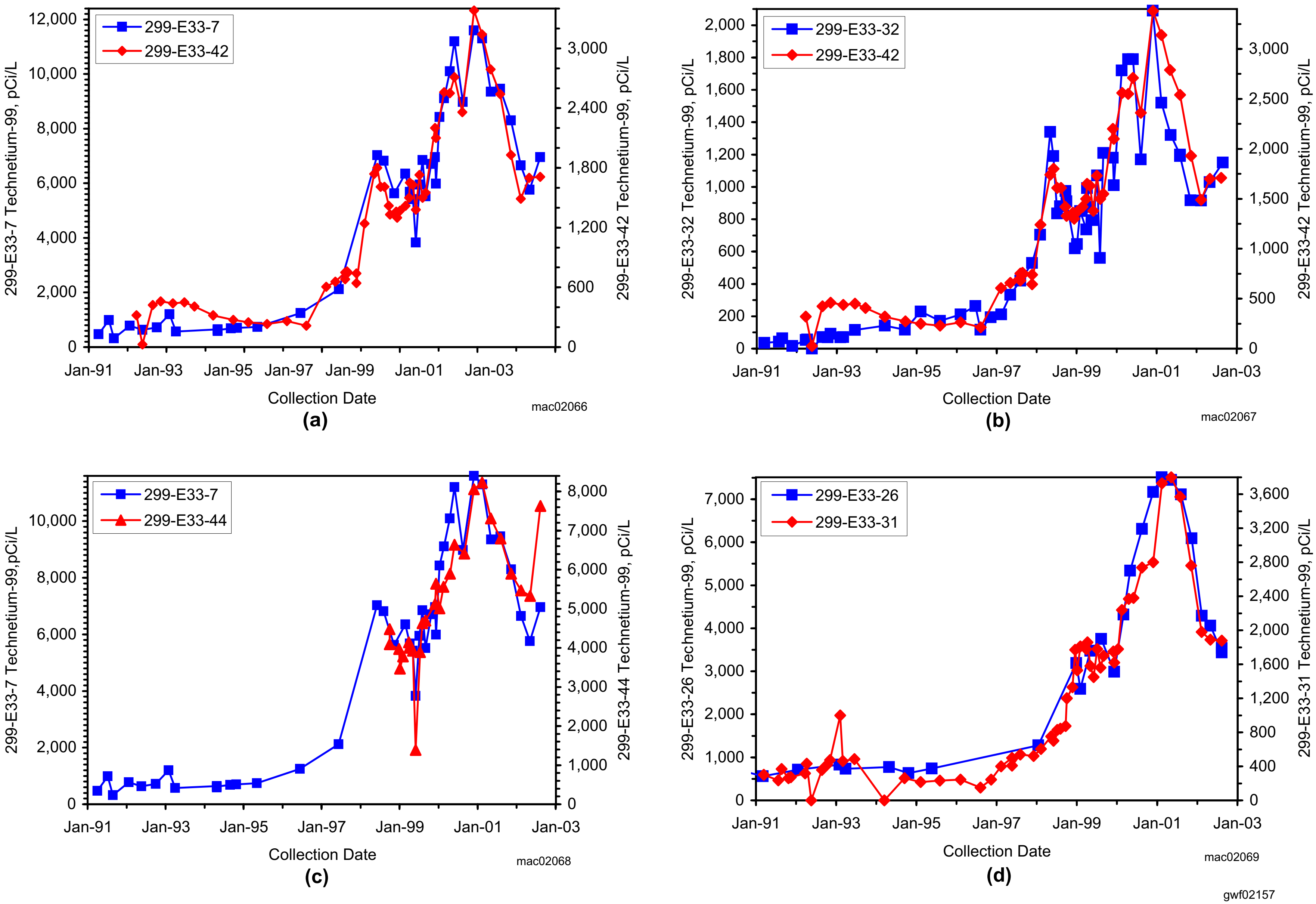


Figure 2.9-11. Pattern Matching of Technetium-99 Trends Between Various Wells Around Waste Management Area B-BX-BY

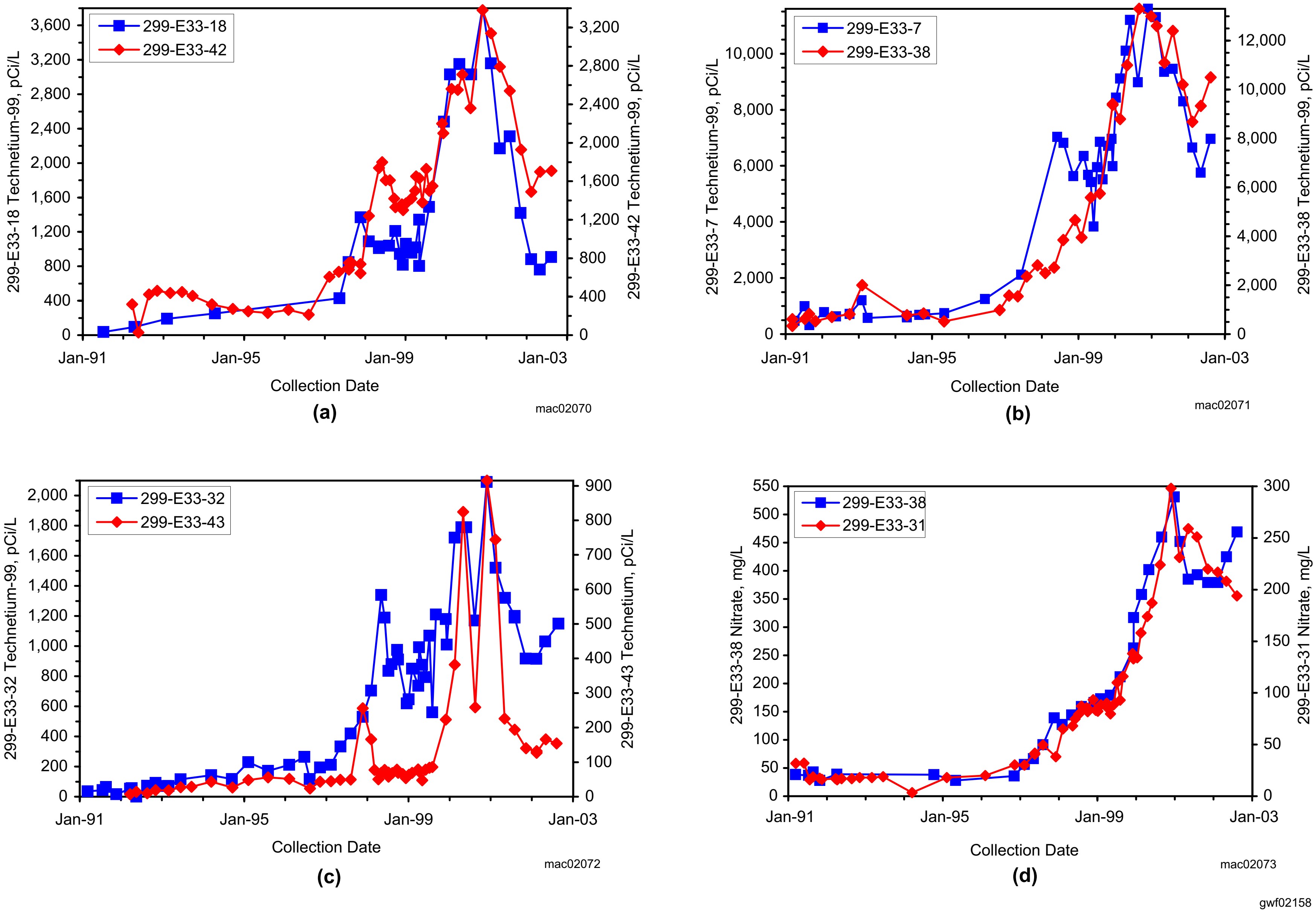


Figure 2.9-12. Pattern Matching of Technetium-99 and Nitrate Trends Between Various Wells Around Waste Management Area B-BX-BY

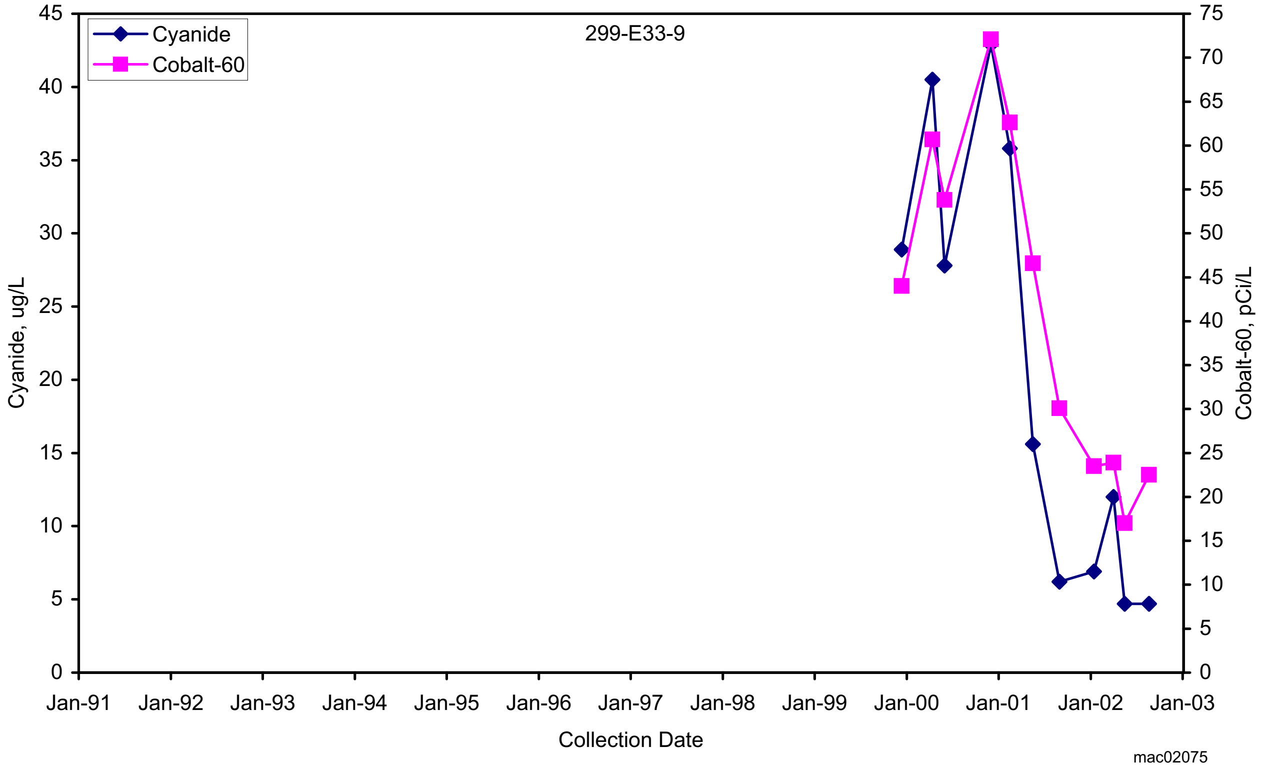


Figure 2.9-13. Cobalt-60 and Cyanide Concentrations in Well 299-E33-9

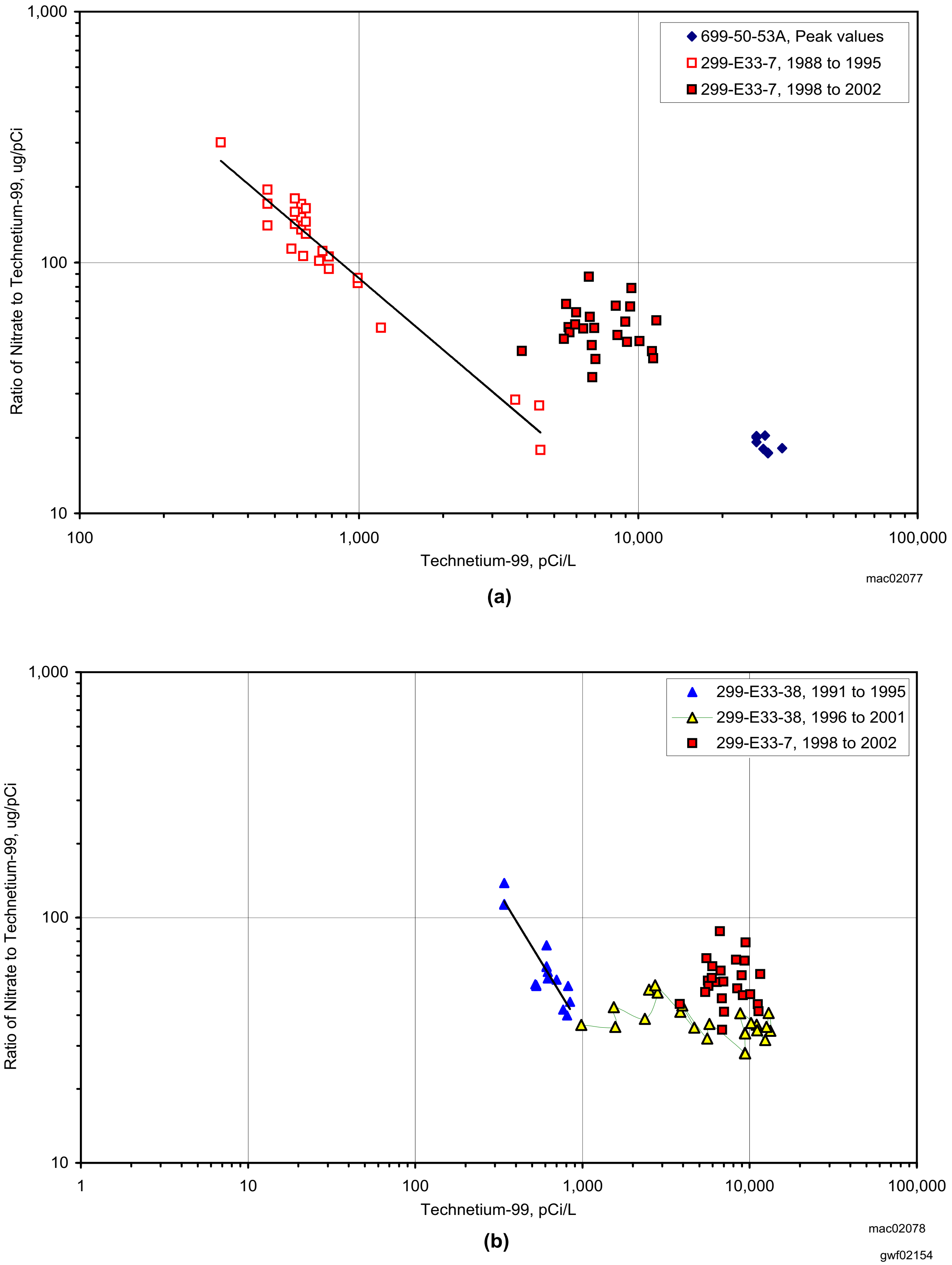


Figure 2.9-14. Nitrate/Technetium-99 Ratio Versus Technetium-99 in Wells Associated with the BY Cribs

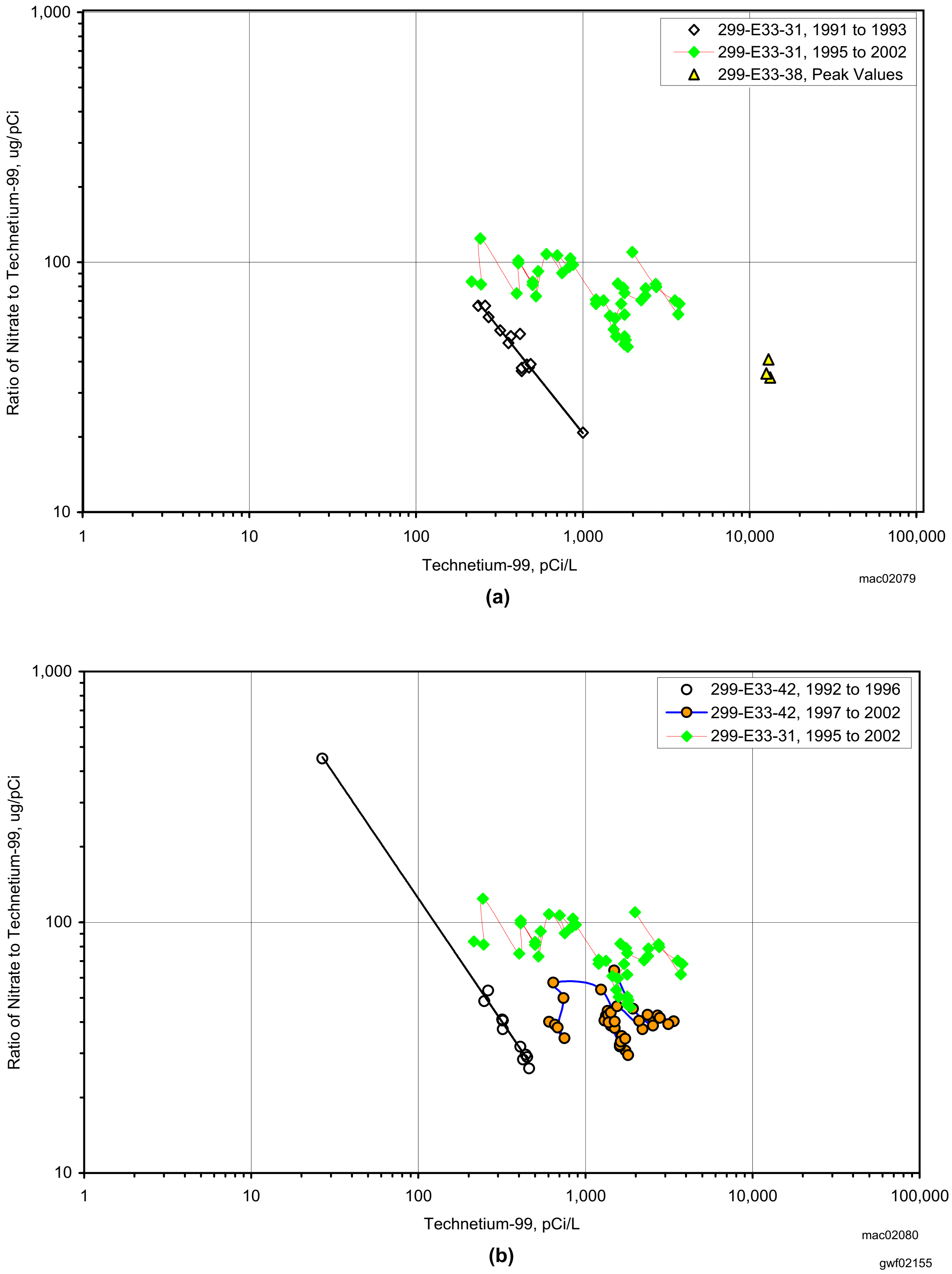


Figure 2.9-15. Nitrate/Technetium-99 Ratio Versus Technetium-99 for Wells on the West Side of Waste Management Area B-BX-BY

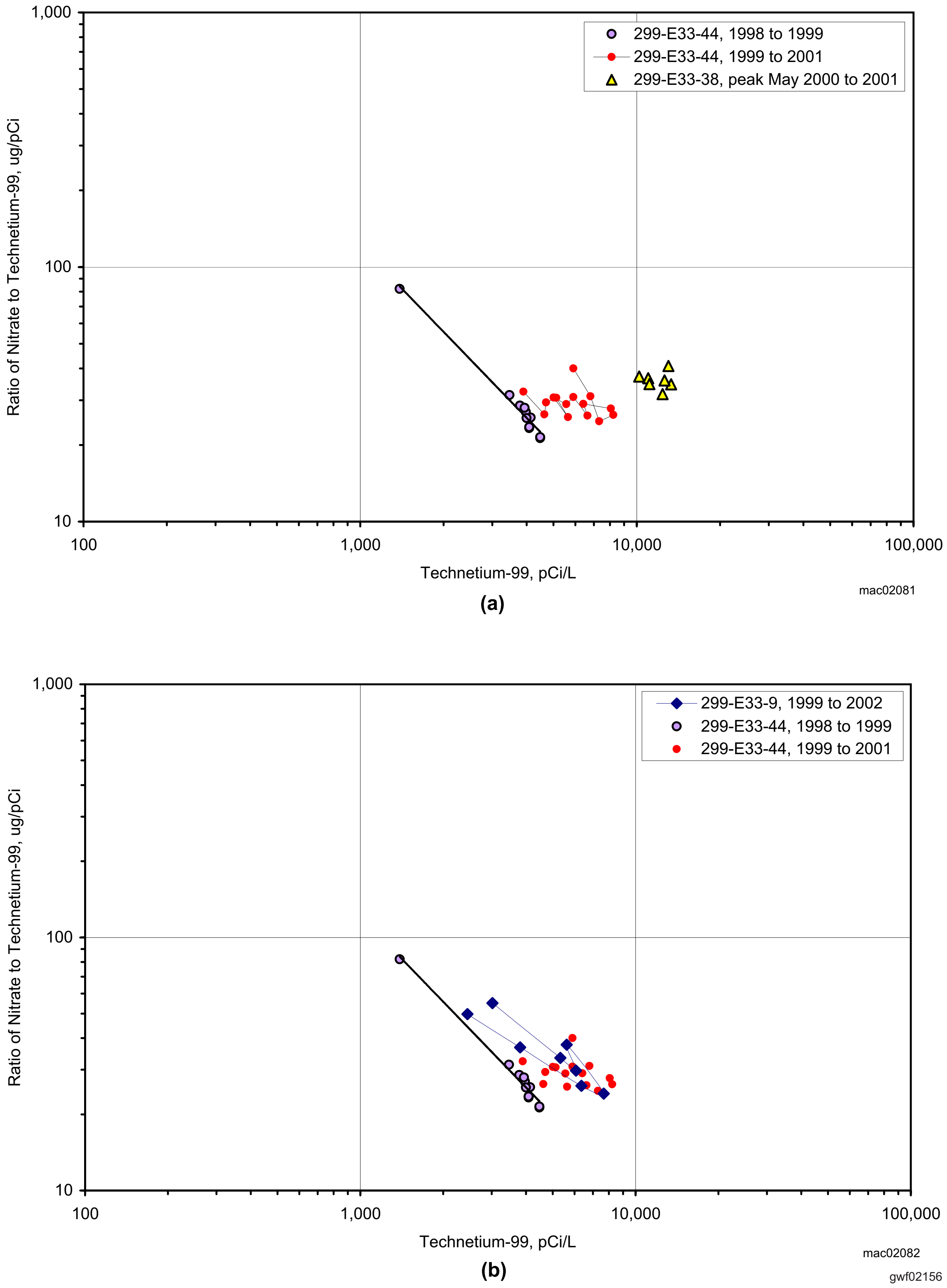
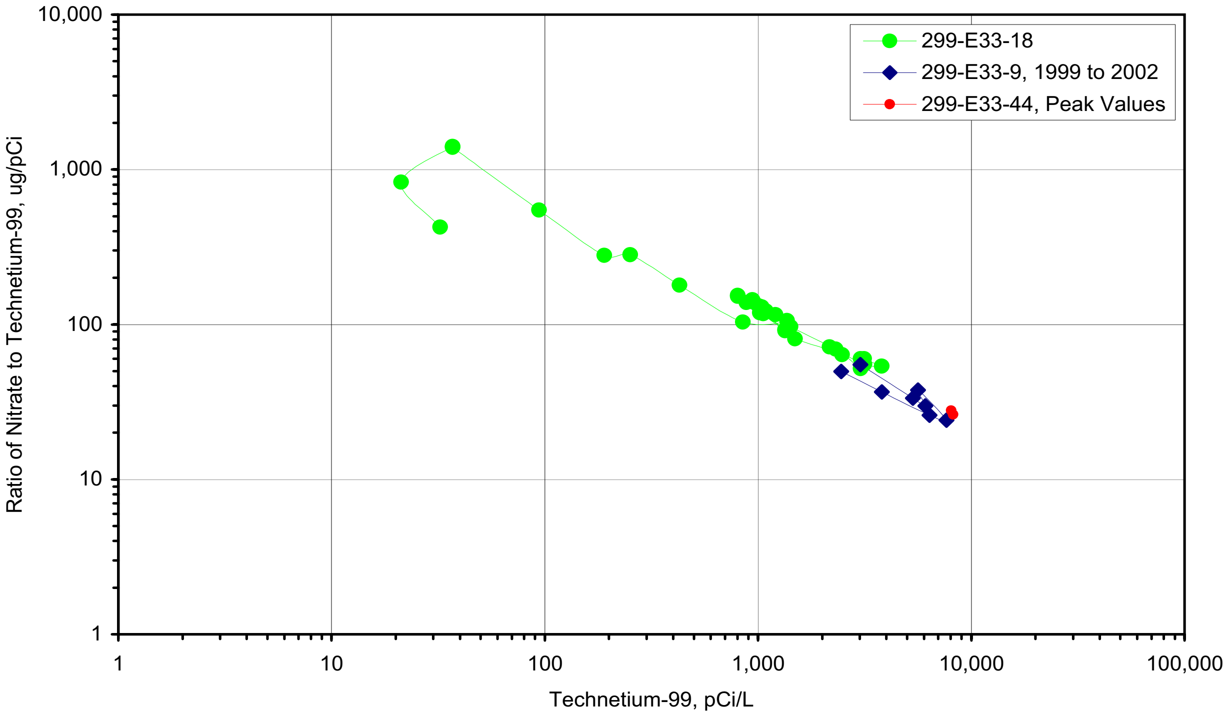


Figure 2.9-16. Nitrate/Technetium-99 Ratio Versus Technetium-99 for Wells Located Beneath and East of the BY Tank Farm



(c)

Figure 2.9-16. (continued)

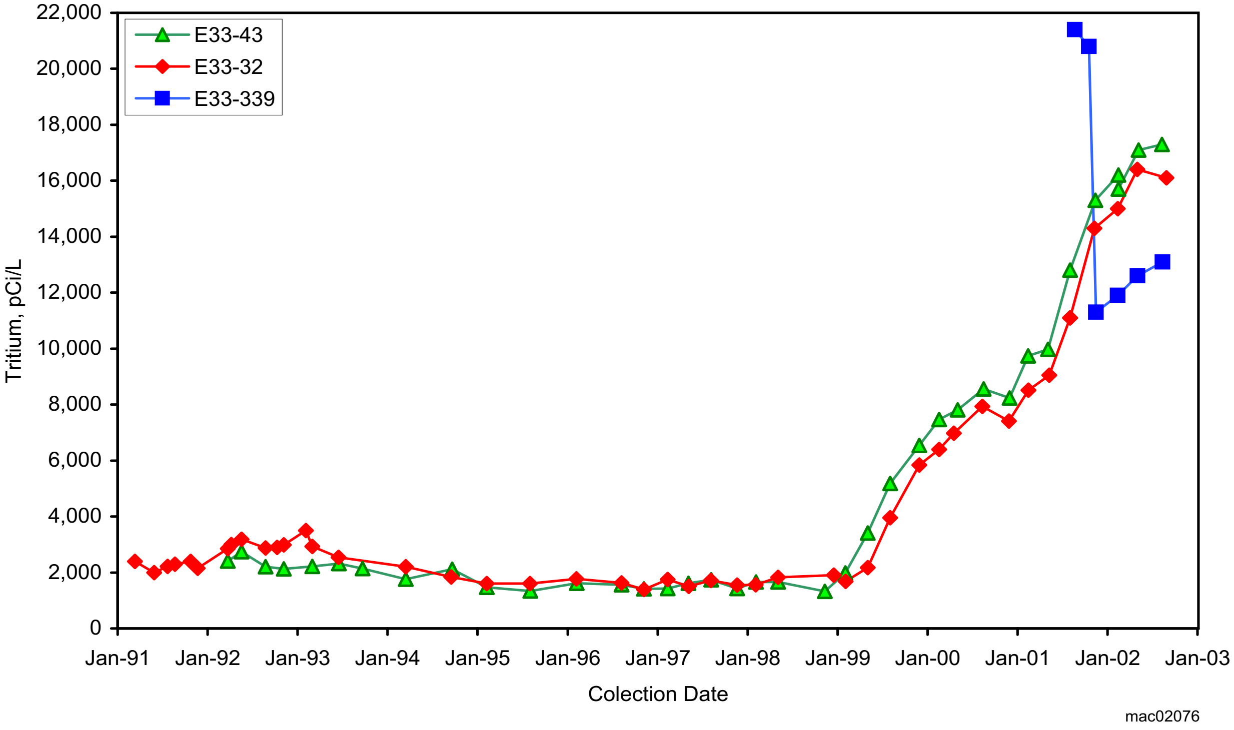


Figure 2.9-17. Tritium Concentrations in Wells South and Southwest of Waste Management Area B-BX-BY

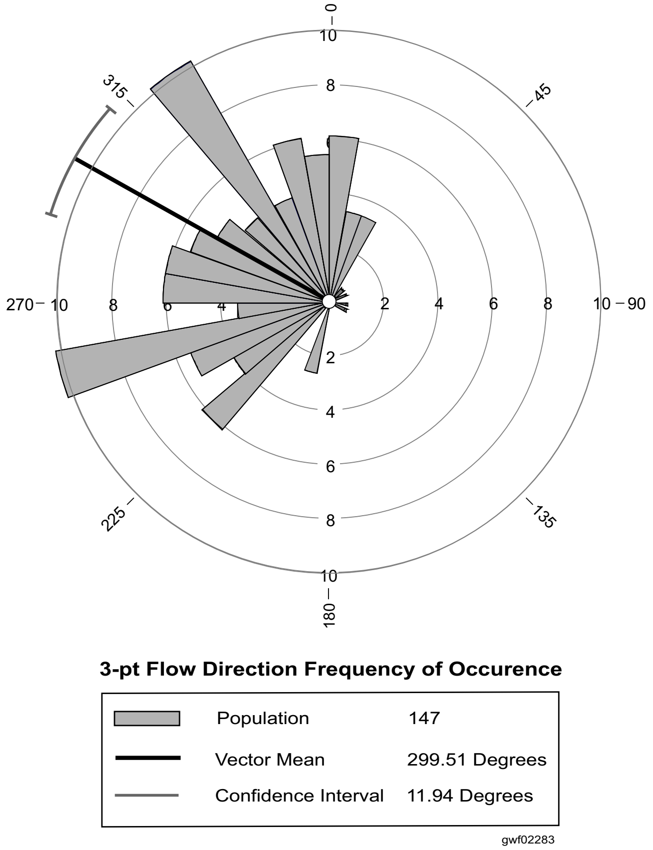


Figure 2.9-18. Gradient Direction for Low-Level Waste Management Area 1 Calculated from Water-Level Measurements in Sets of Three Wells

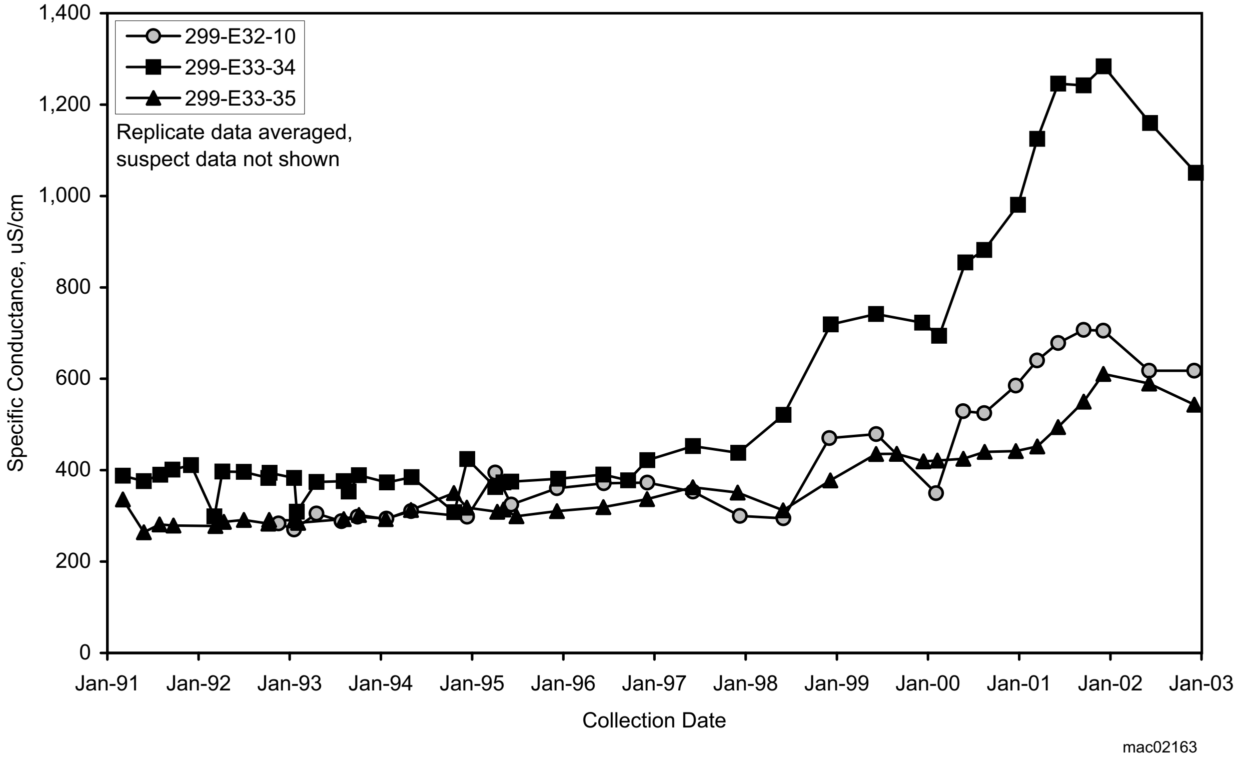


Figure 2.9-19. Specific Conductance in Wells at the Northeast Corner of Low-Level Waste Management Area 1

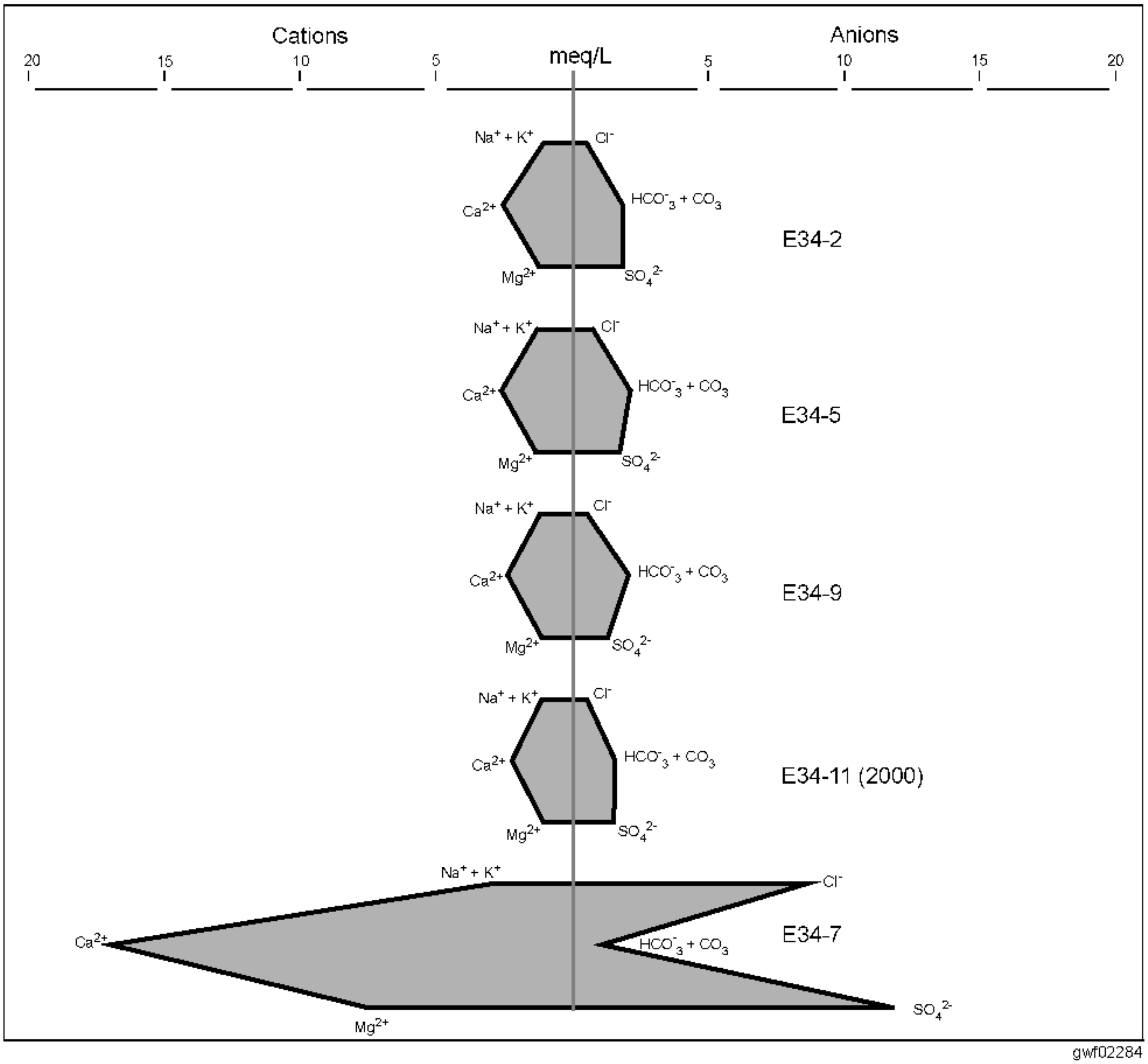


Figure 2.9-20. Stiff Diagrams Showing the Major Ion Chemical Makeup of Samples from Low-Level Waste Management Area 2 Wells

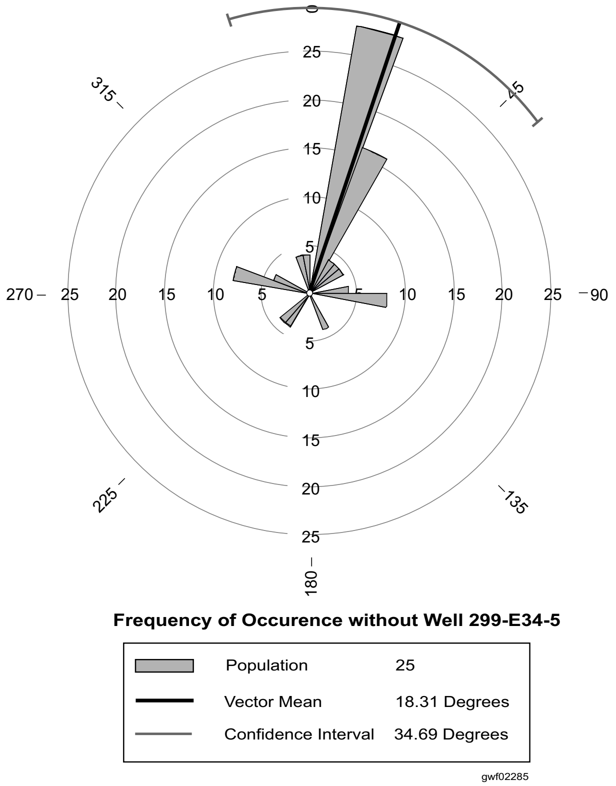


Figure 2.9-21. Gradient Direction for Low-Level Waste Management Area 2 Calculated from Water-Level Measurements in Sets of Three Wells (well 299-E34-5 excluded from analysis)

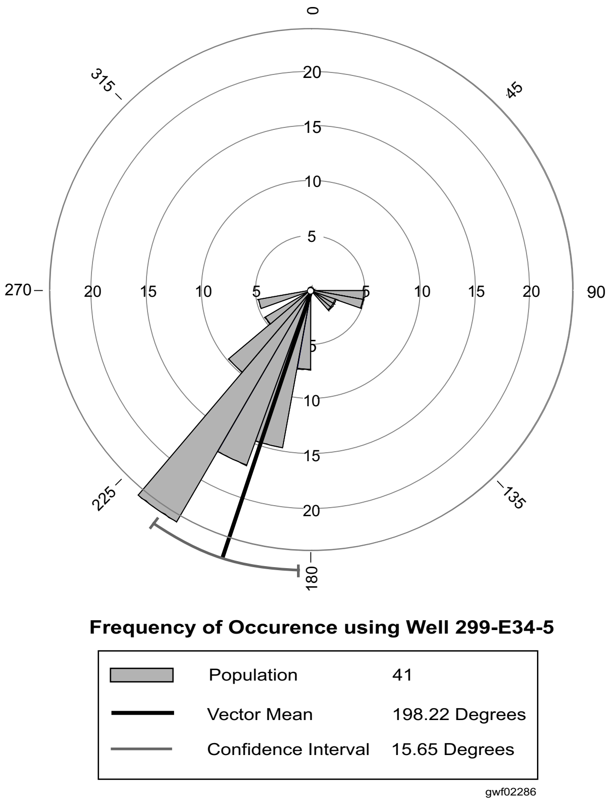


Figure 2.9-22. Gradient Direction for Low-Level Waste Management Area 2 Calculated from Water-Level Measurements in Sets of Three Wells (well 299-E34-5 included in all sets)

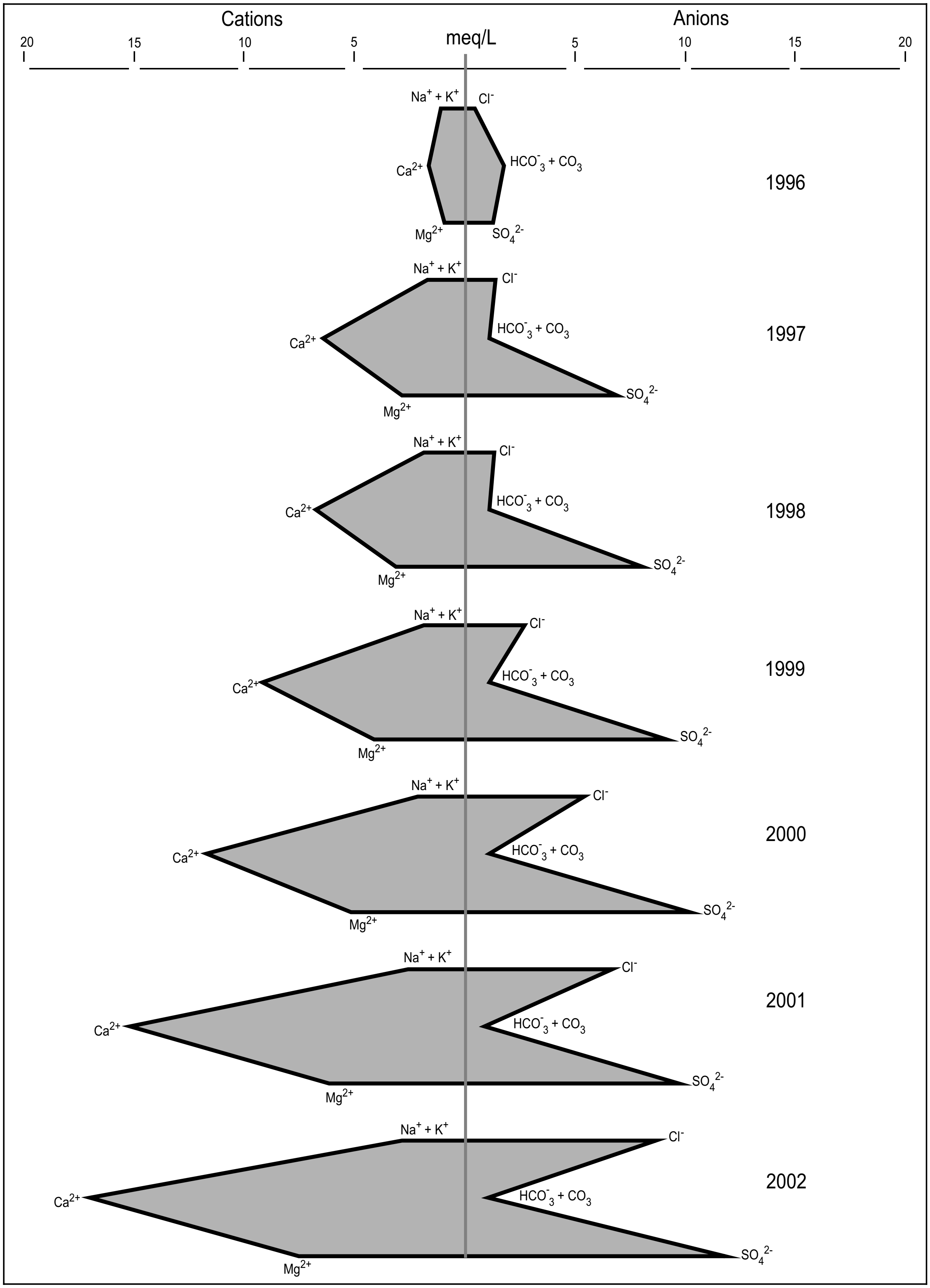


Figure 2.9-23. Stiff Diagrams Showing the Evolution of Major Ion Chemical Makeup of Samples from Well 299-E34-7

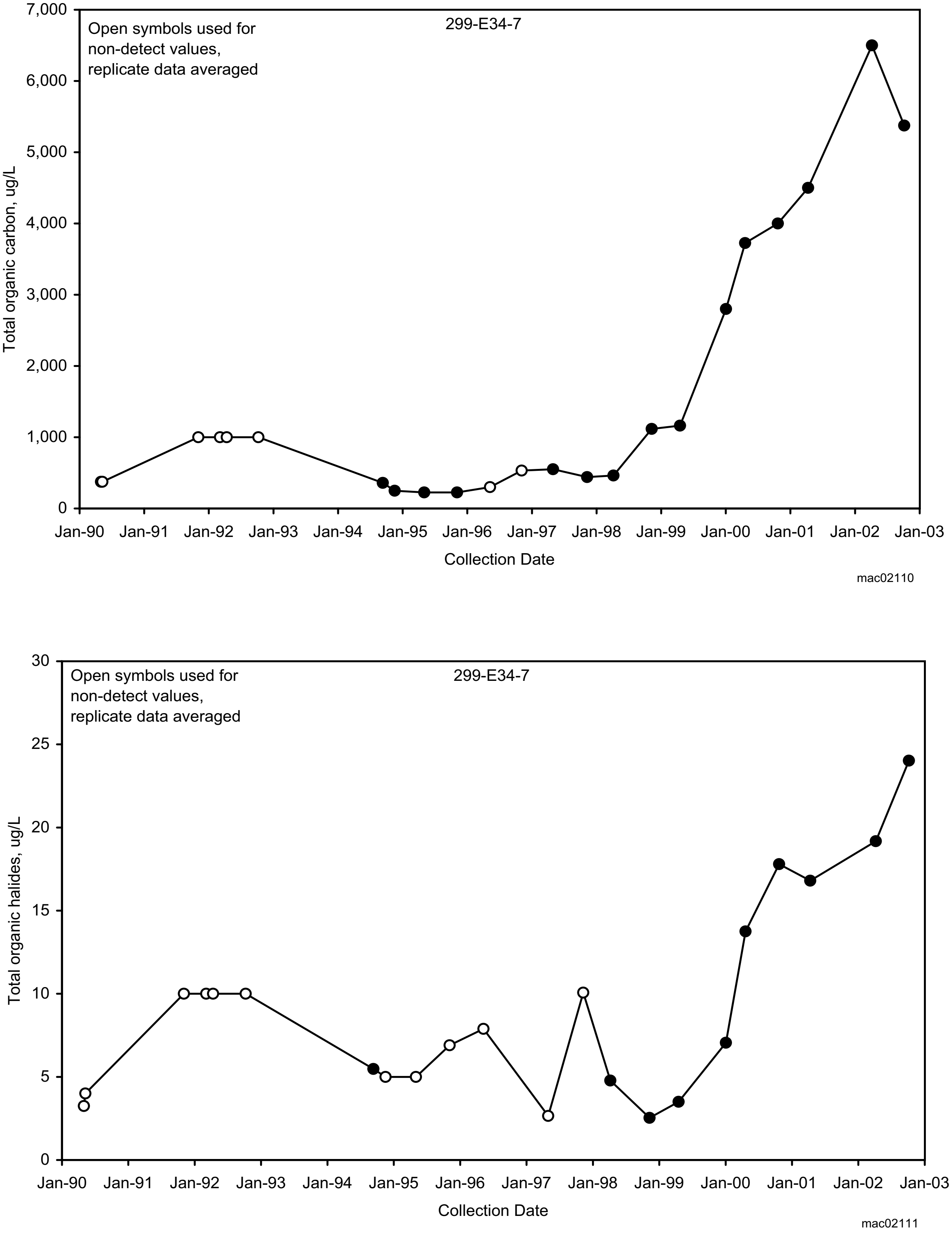


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Figure 2.9-24. Total Organic Carbon and Total Organic Halides in an Upgradient Well at Low-Level Waste Management Area 2

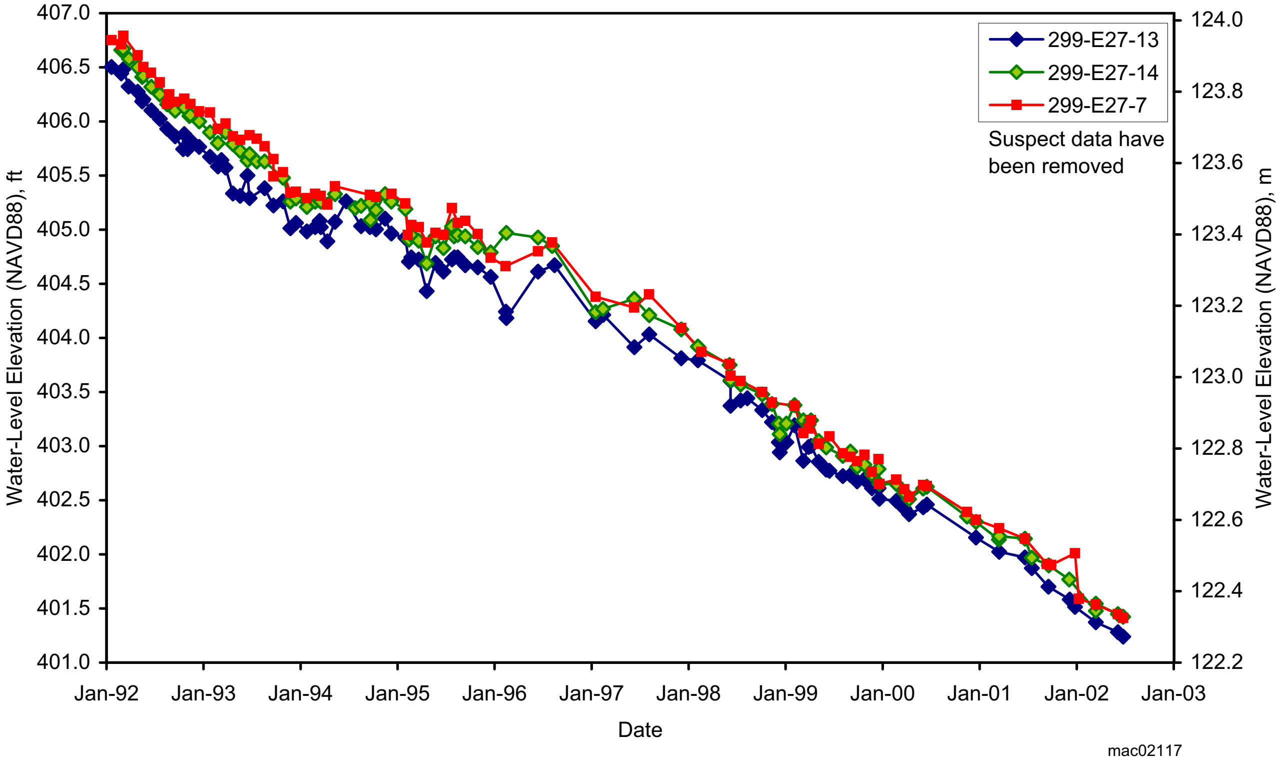

Figure 2.9-25. Water Levels in Wells Monitoring Waste Management Area C

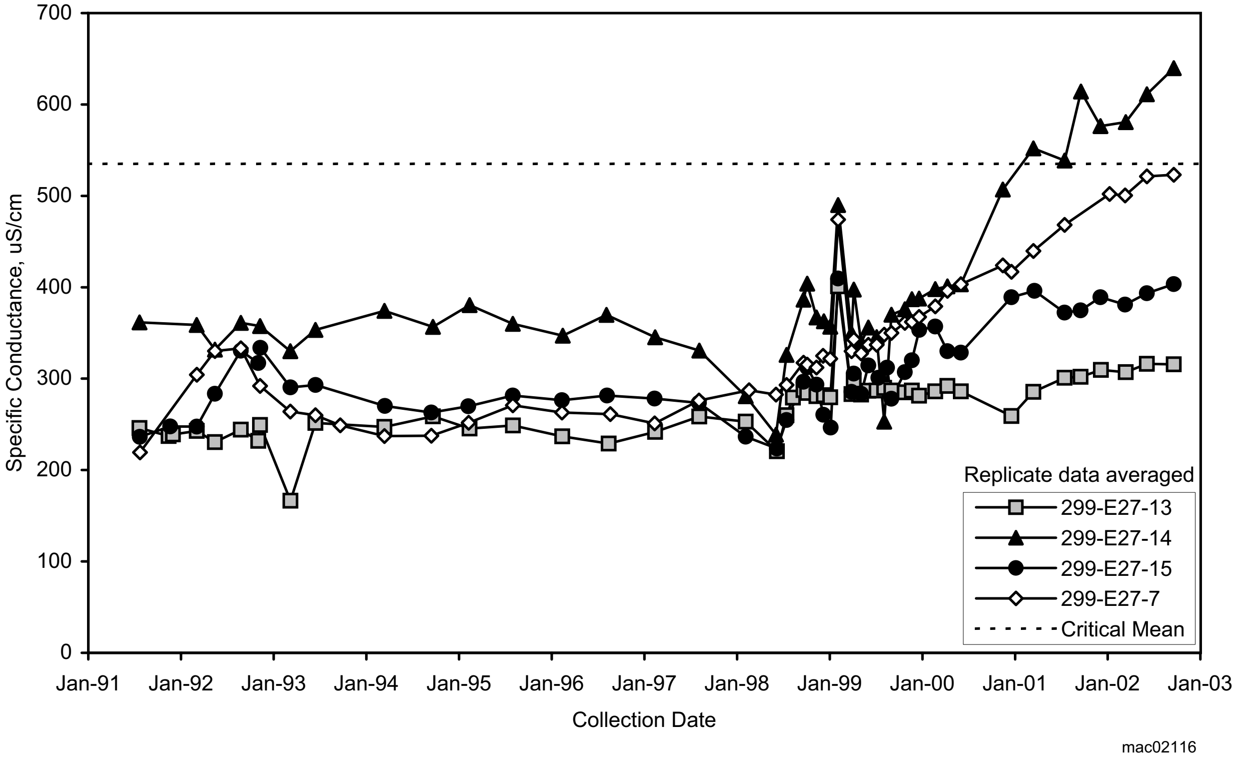

Figure 2.9-26. Current Trend for Specific Conductance at Waste Management Area C

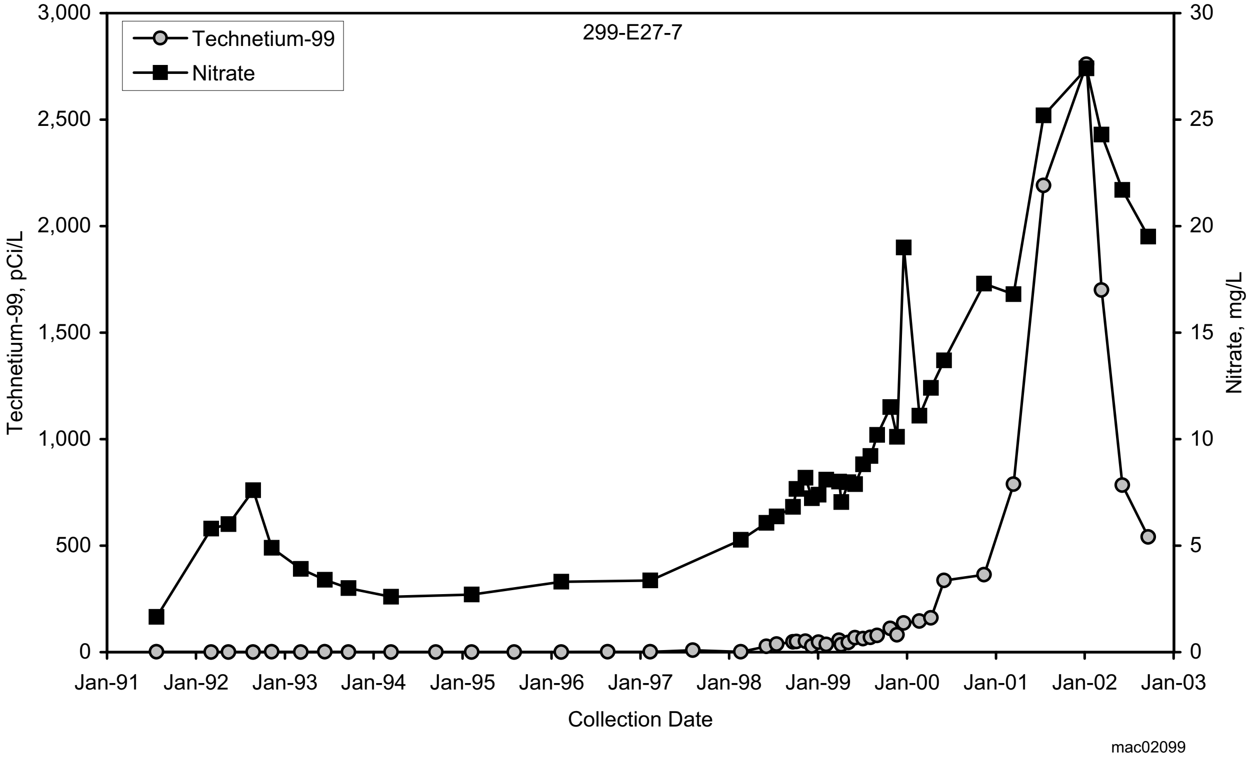

Figure 2.9-27. Nitrate and Technetium-99 Trends in Upgradient Well 299-E27-7

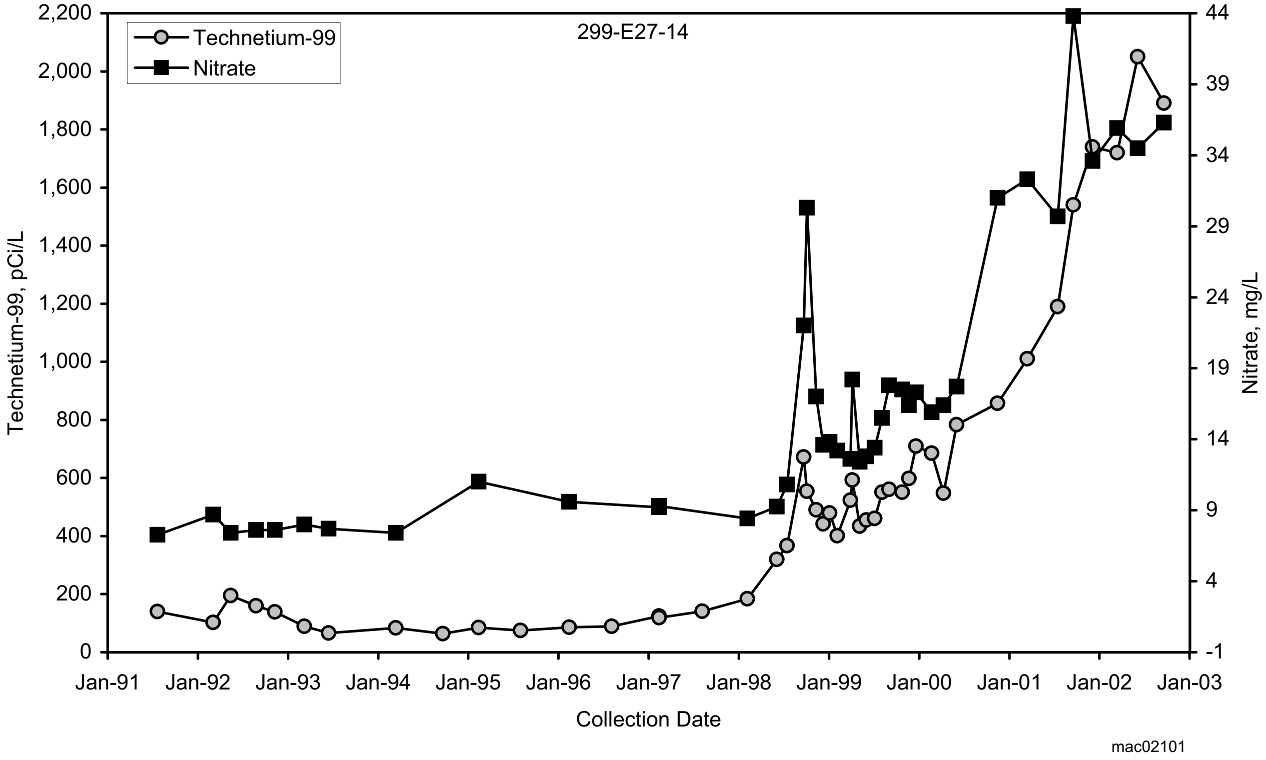

Figure 2.9-28. Nitrate and Technetium-99 Trends South of Waste Management Area C

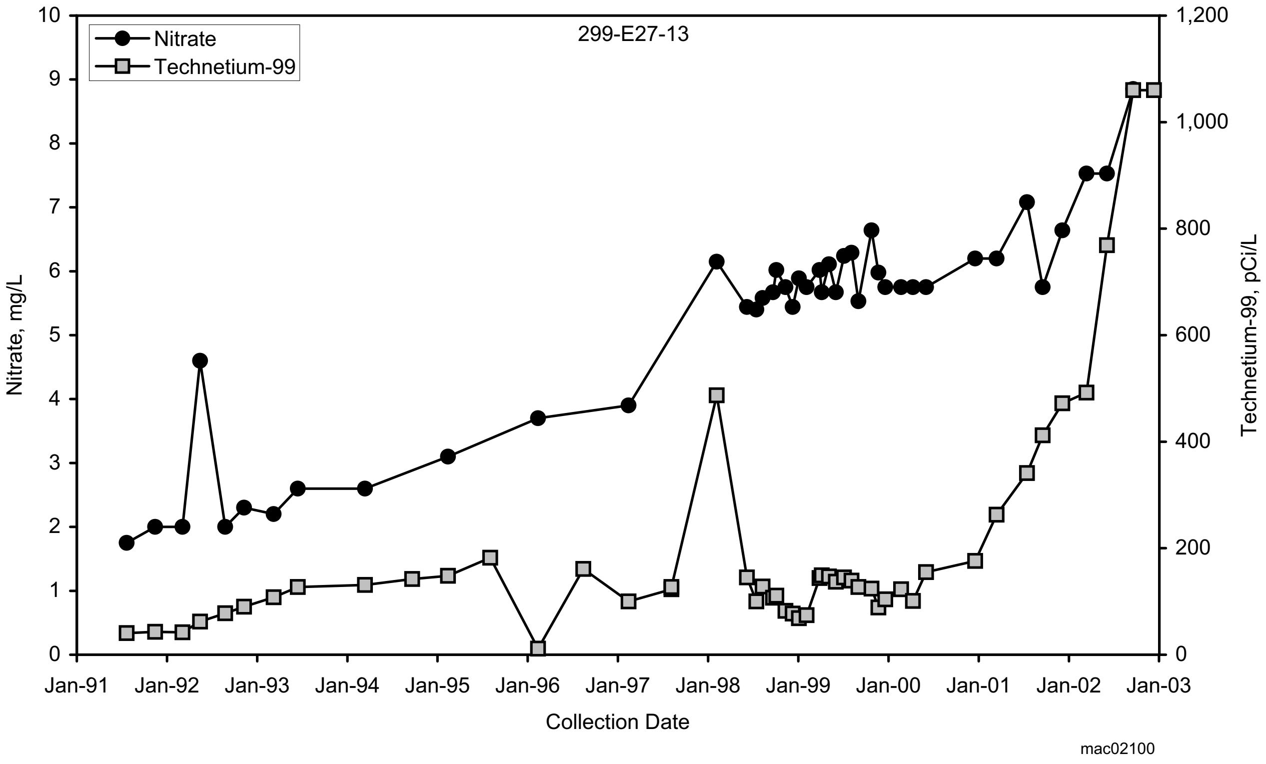

Figure 2.9-29. Nitrate and Technetium-99 Trends Southwest of Waste Management C

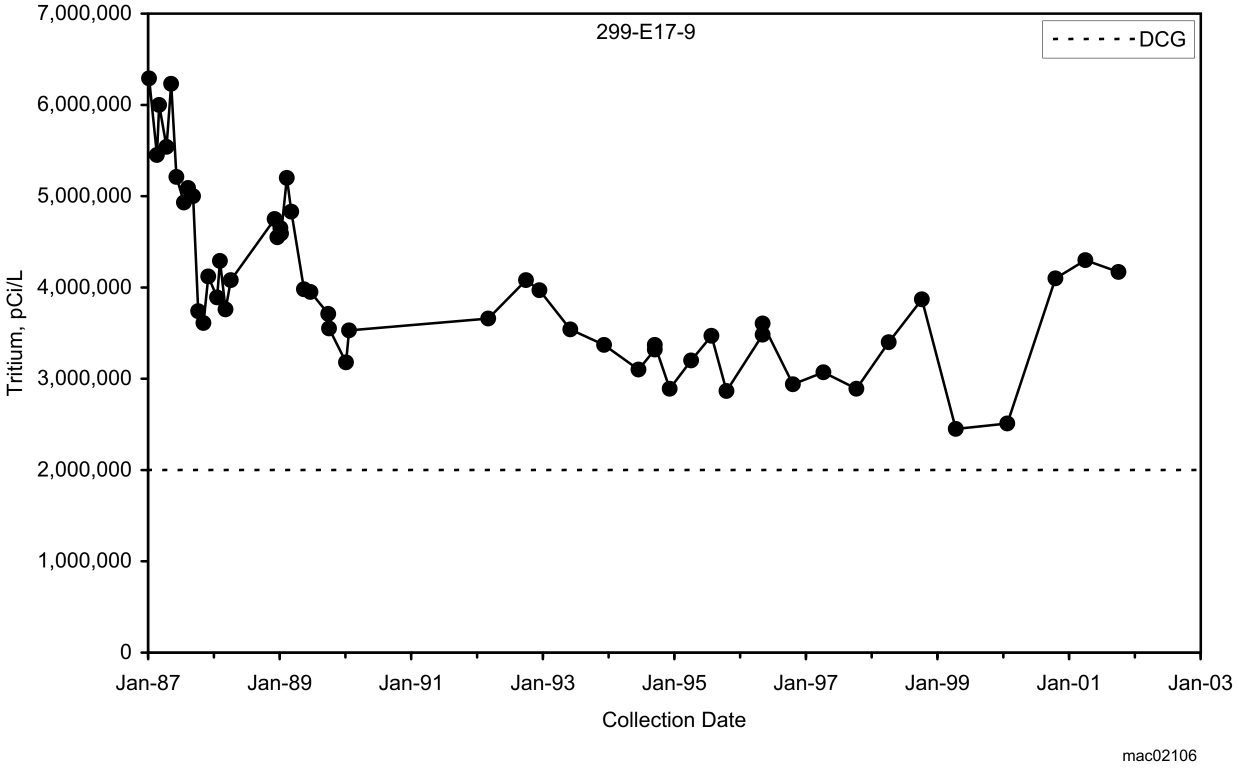

Figure 2.9-30. Tritium Concentrations at the 216-A-36B Crib

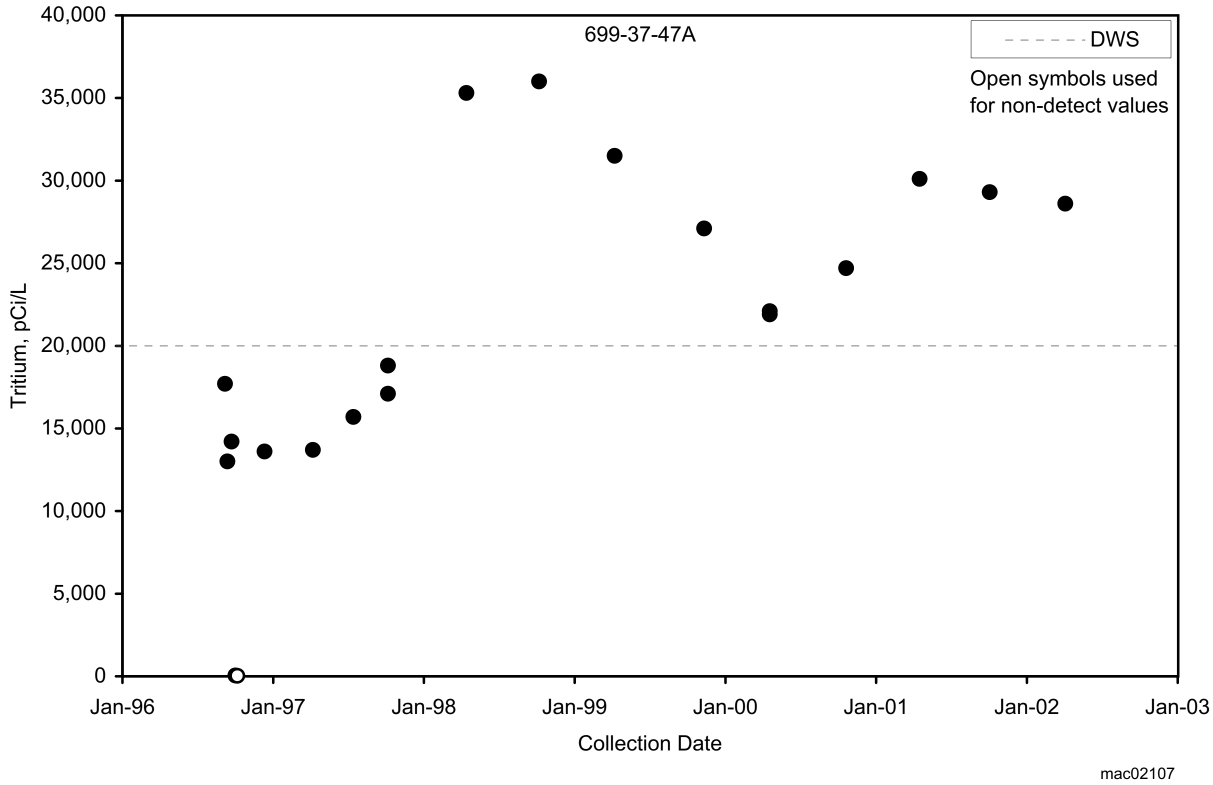

Figure 2.9-31. Tritium Concentrations Southeast of the PUREX Cribs

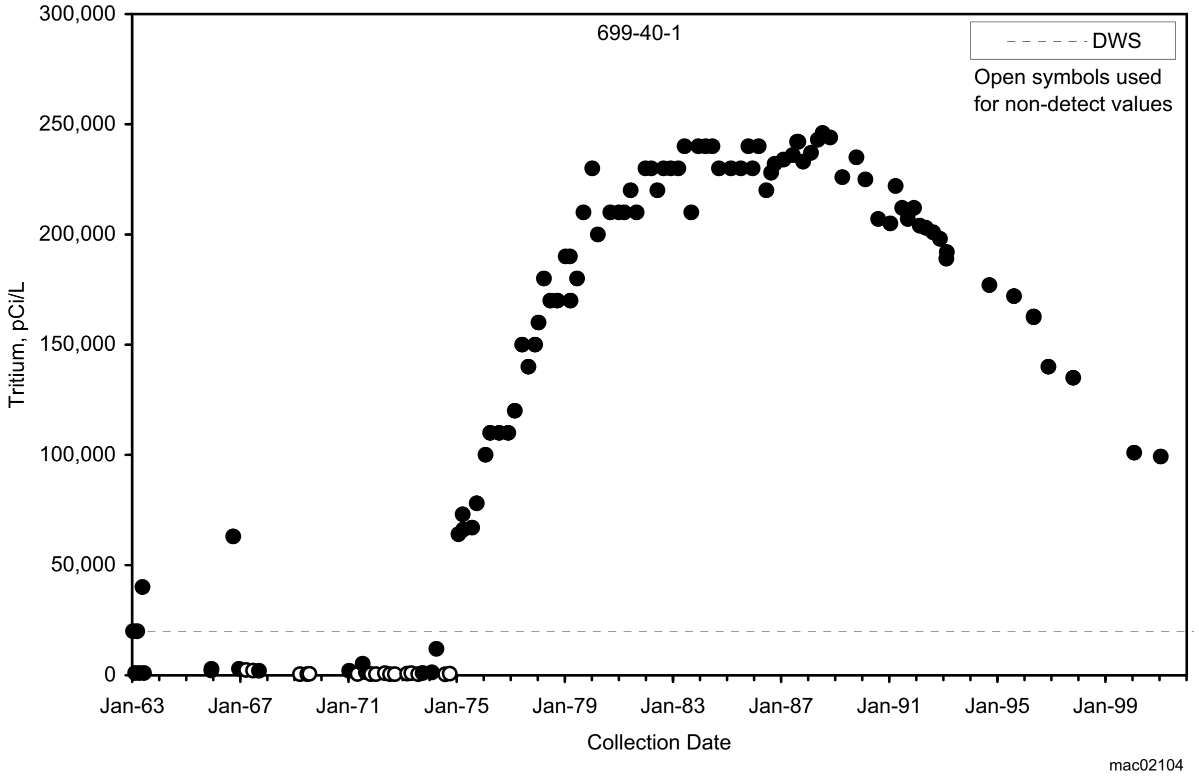

Figure 2.9-32. Tritium Concentrations Within the 200 East Area Plume Near the Columbia River

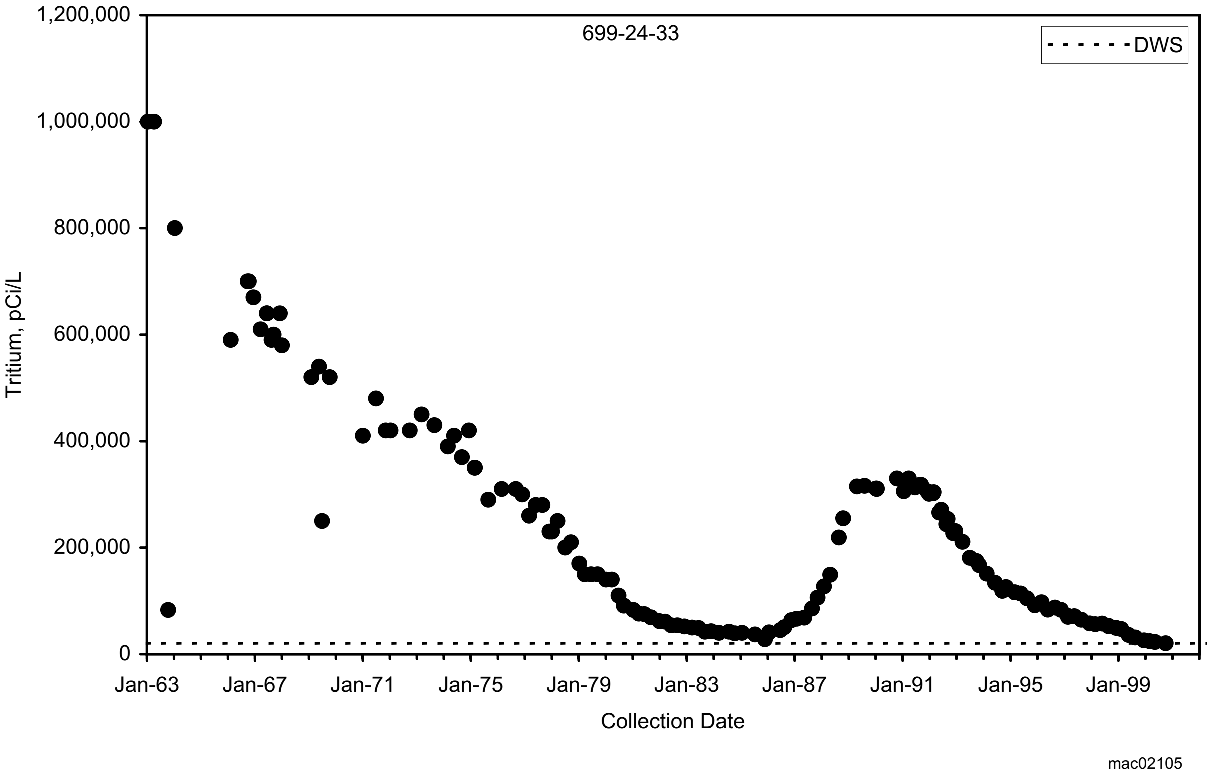

Figure 2.9-33. Tritium Concentrations Within the 200 East Area Plume Near the Central Landfill

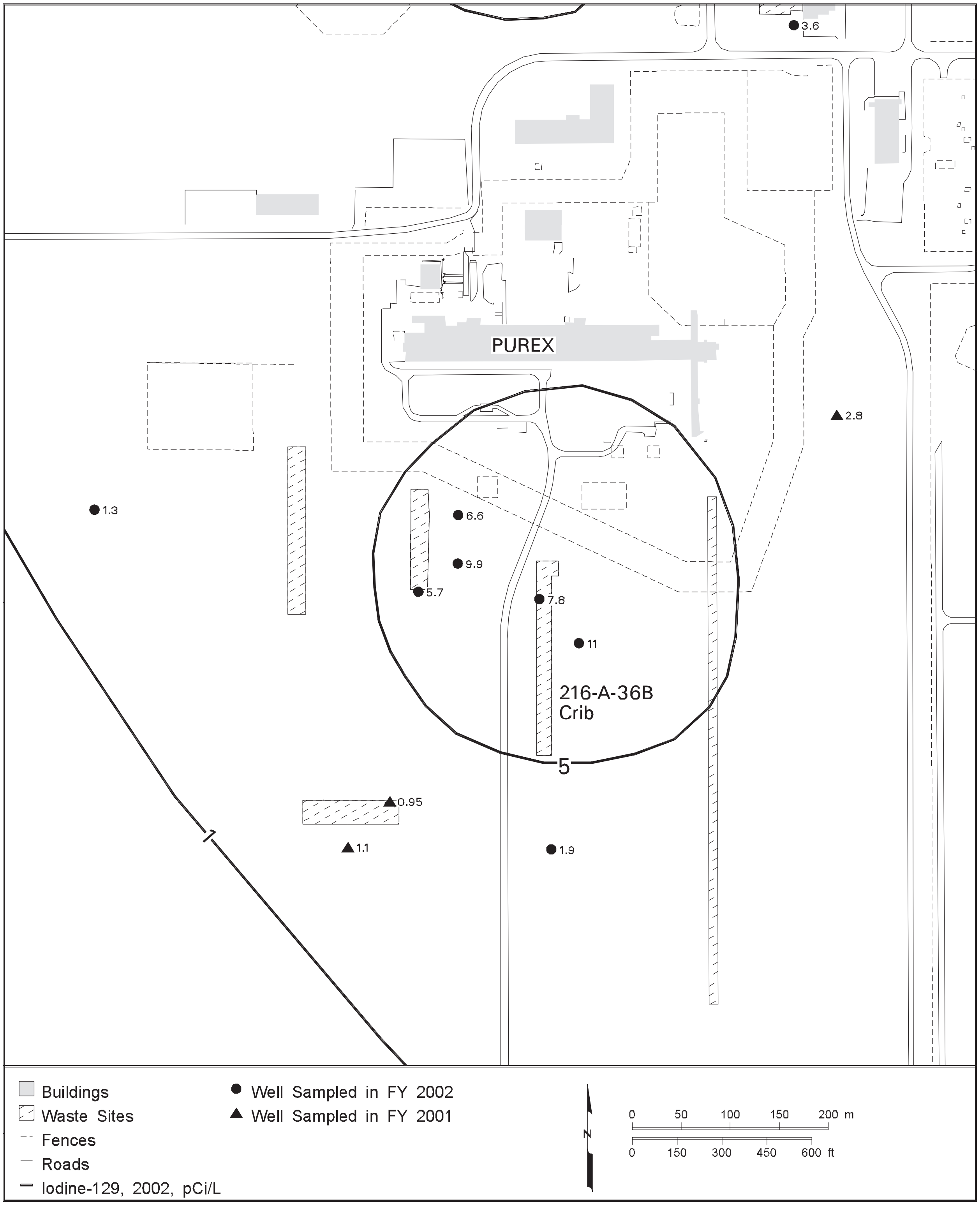

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Figure 2.9-34. Average Iodine-129 Concentrations Near the PUREX Plant, Top of Unconfined Aquifer

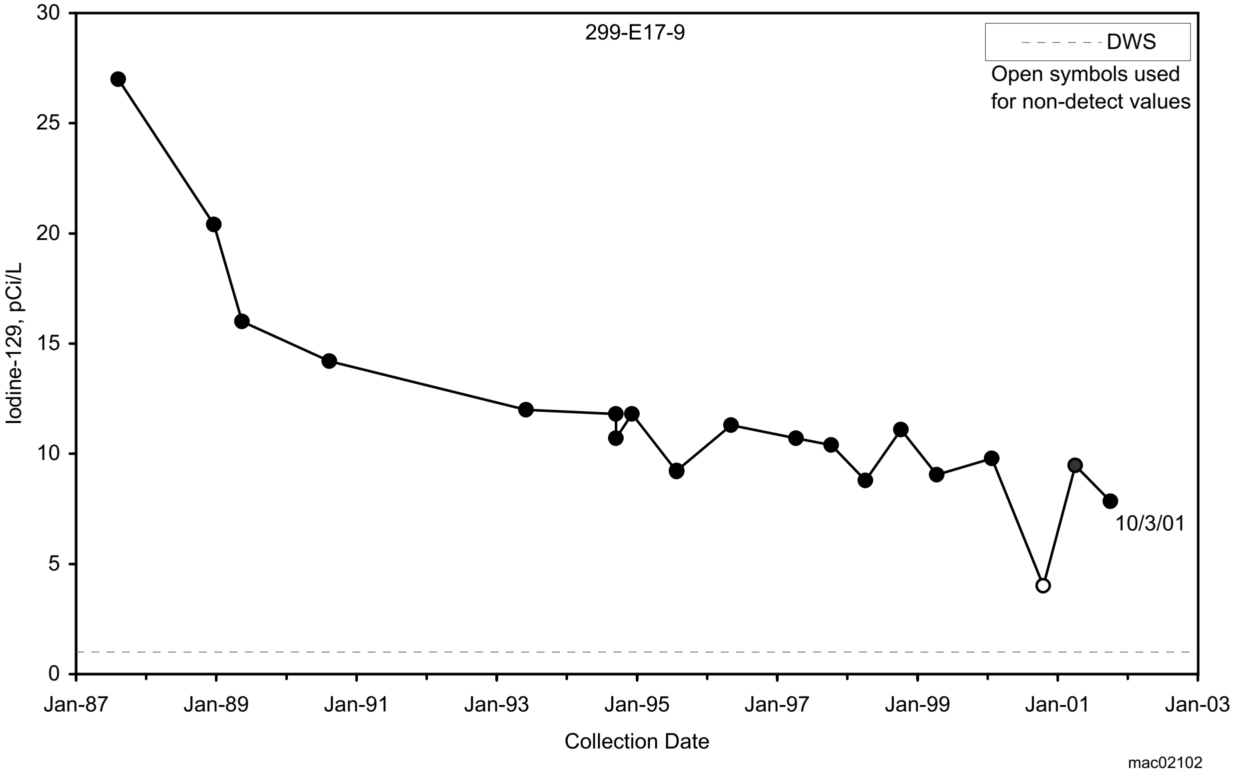

Figure 2.9-35. Iodine-129 Concentrations at the 216-A-36B Crib

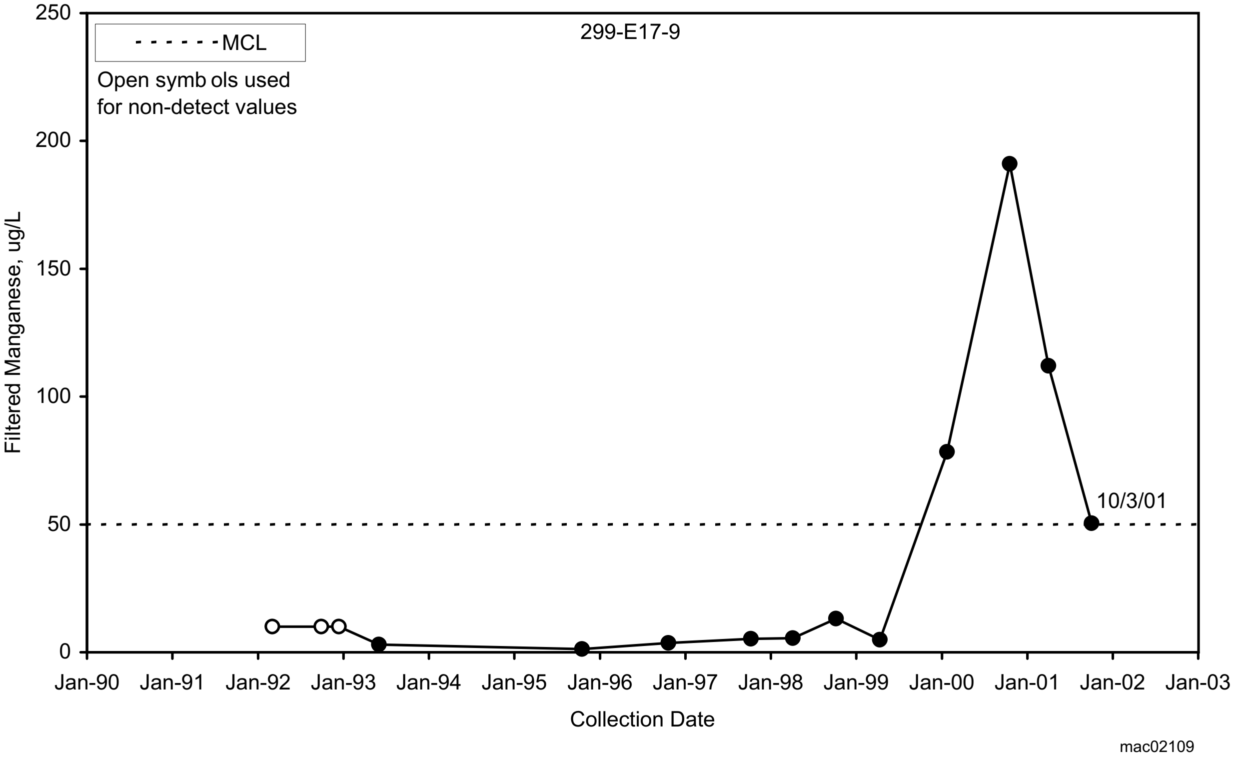

Figure 2.9-36. Manganese Concentrations Near the 216-A-36B Crib

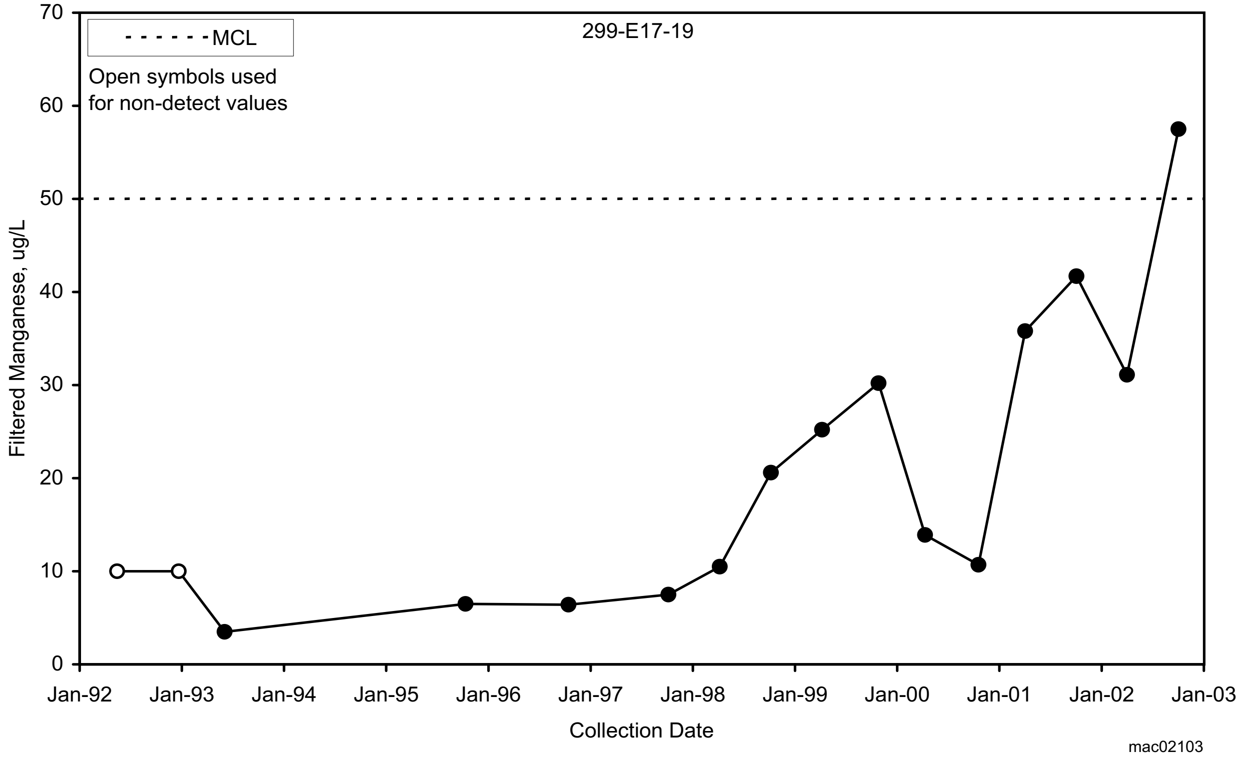

Figure 2.9-37. Manganese Concentrations in Well 299-E17-19 Near the 216-A-10 Crib

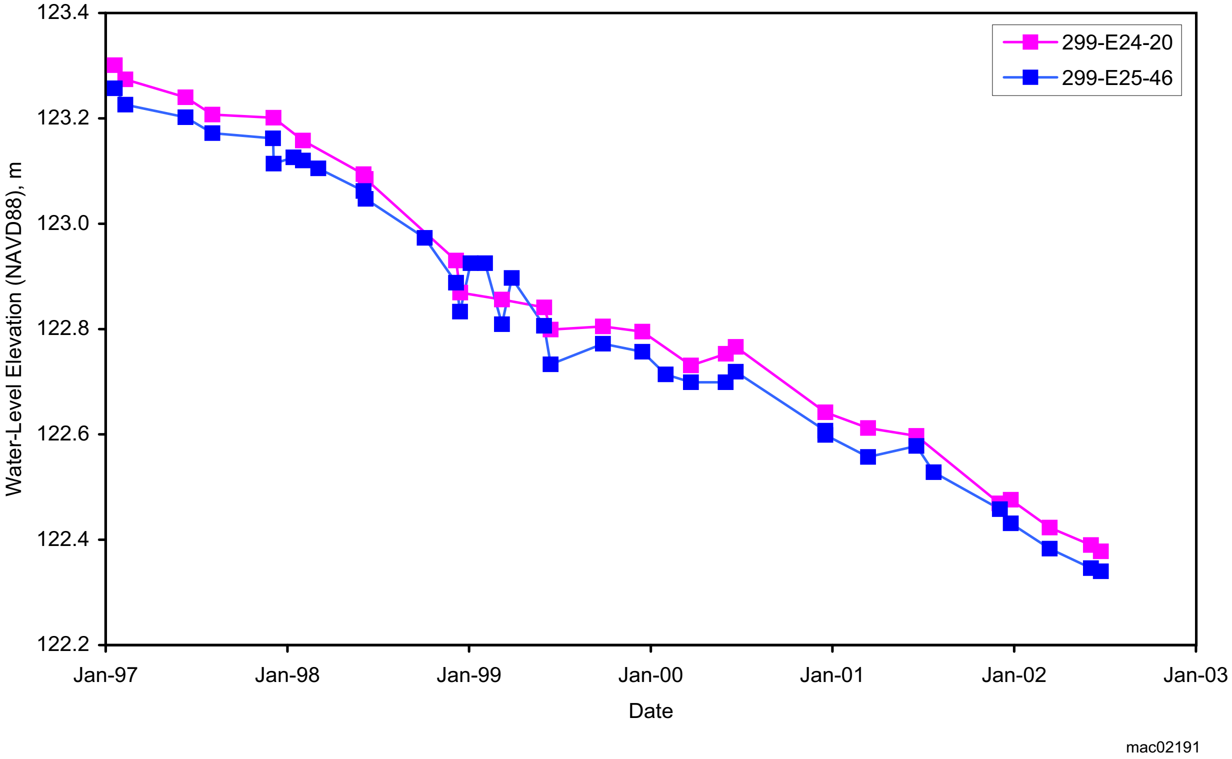

Figure 2.9-38. Water Levels at Waste Management Area A-AX. Well 299-E24-20 is west (upgradient) of well 299-E25-46.

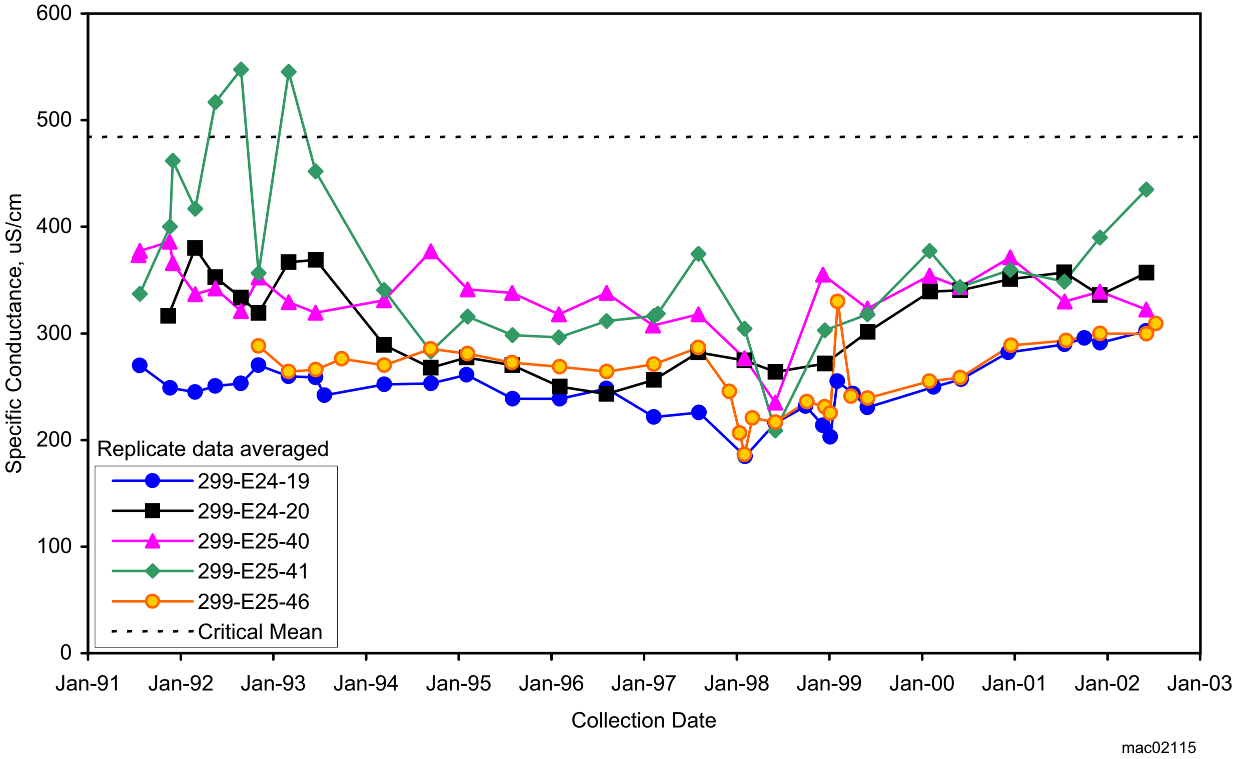

Figure 2.9-39. Specific Conductance in Wells Monitoring Waste Management Area A-AX

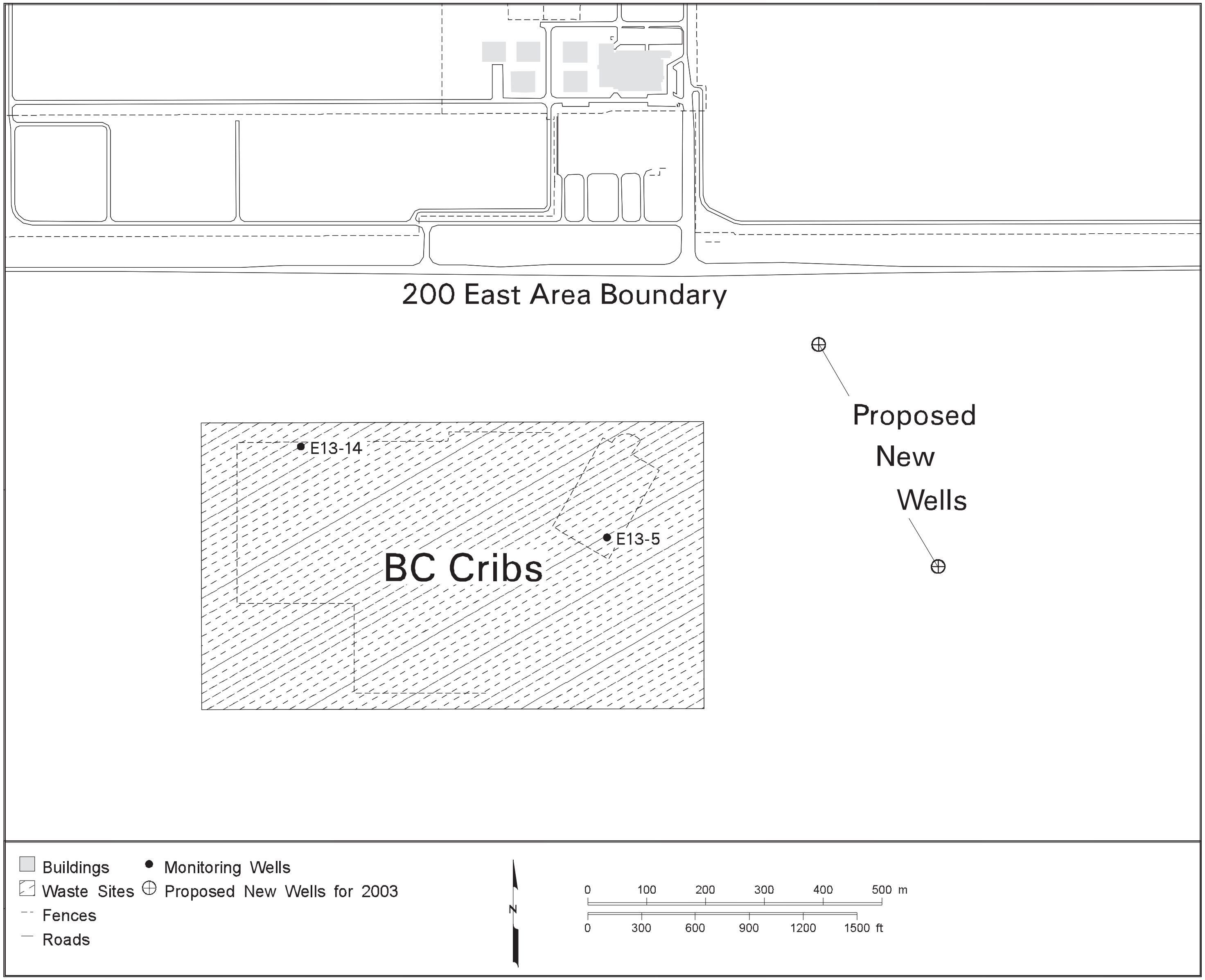

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Figure 2.9-40. Map Showing Location of BC Cribs and Trenches, Two Existing Wells, and Two Proposed New Well Locations

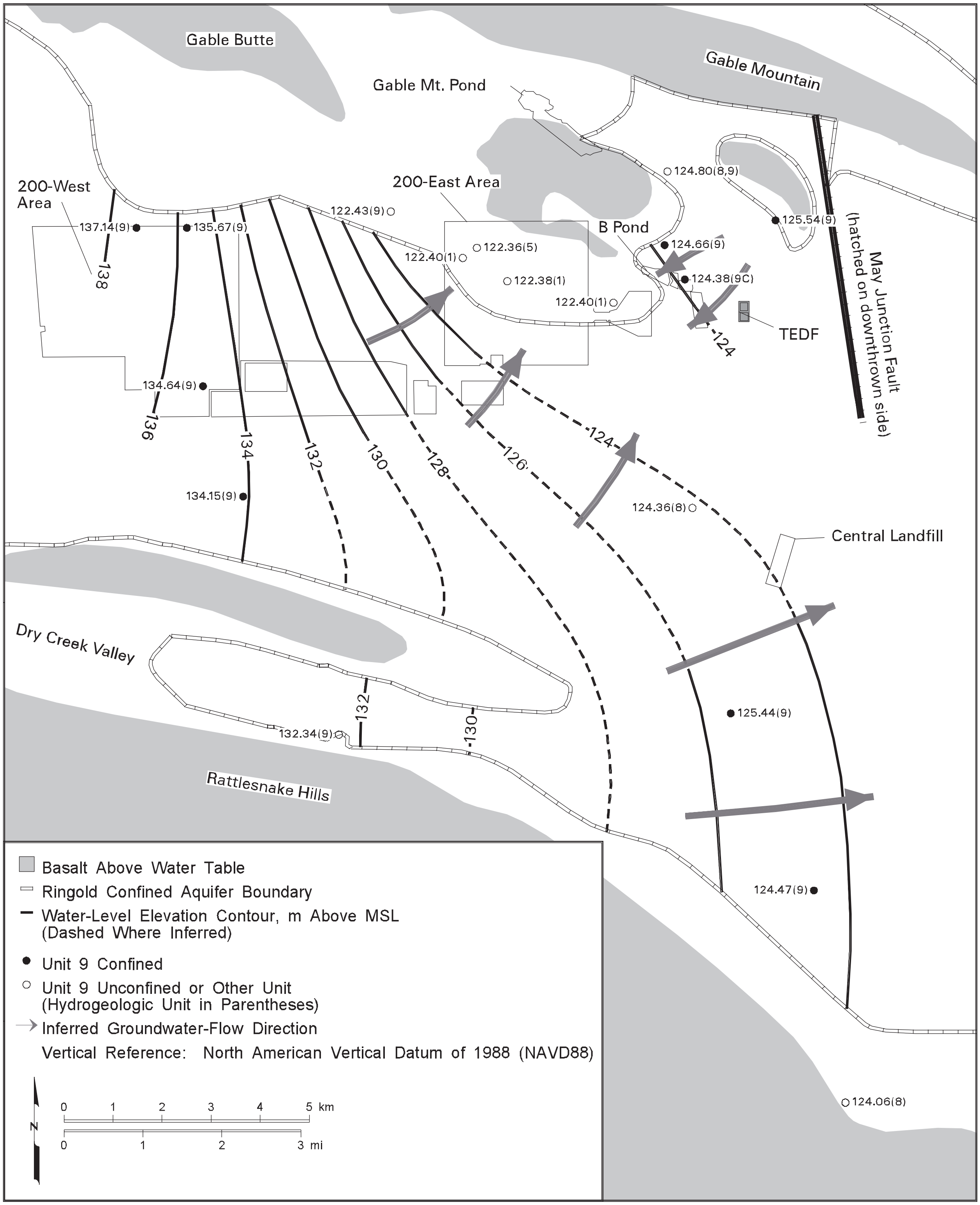

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Figure 2.9-41. Potentiometric Surface Map of Ringold Formation Confined Aquifer (Unit 9), Central Hanford Site, March 2002

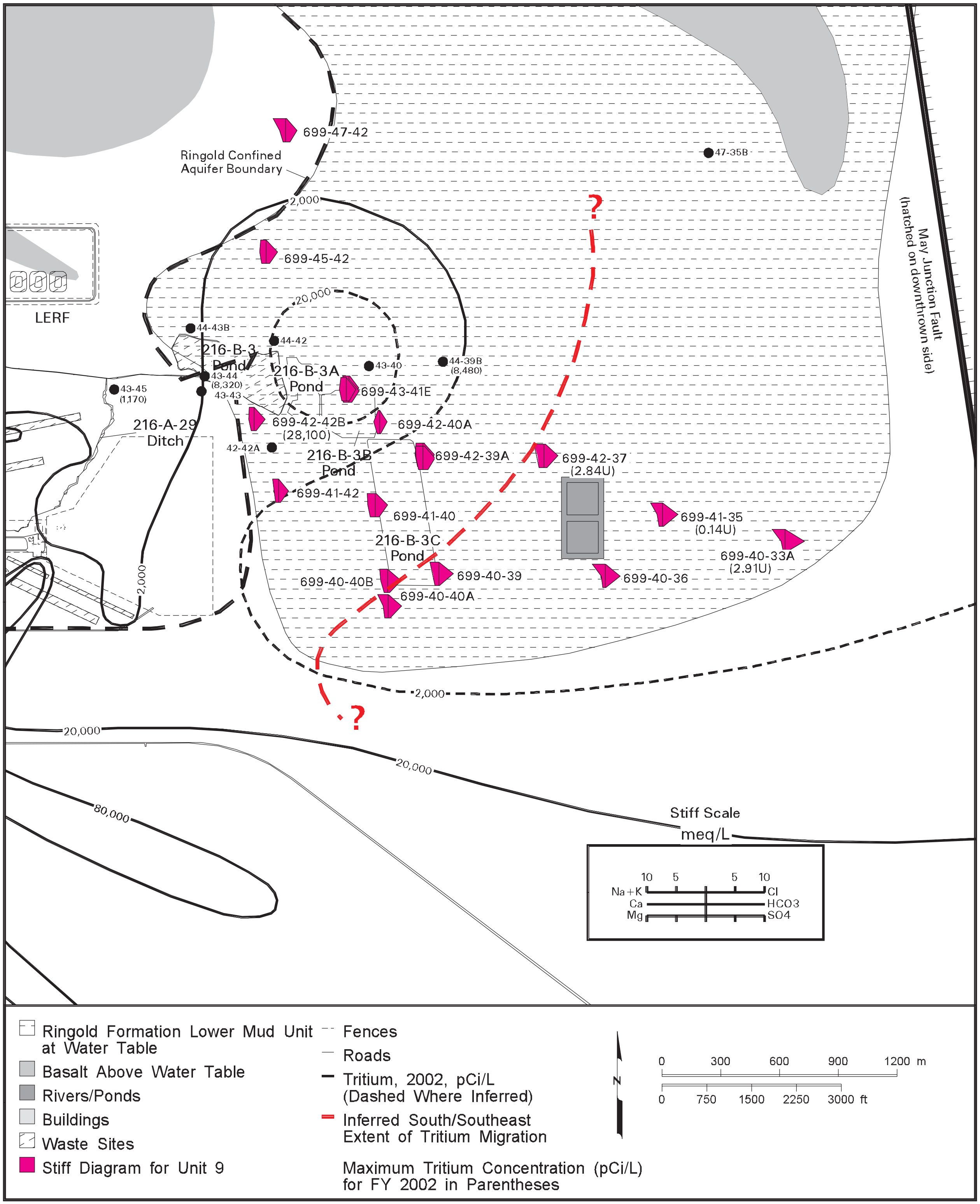

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Figure 2.9-42. Major Ion Chemistry in Wells Completed in the Confined Aquifer

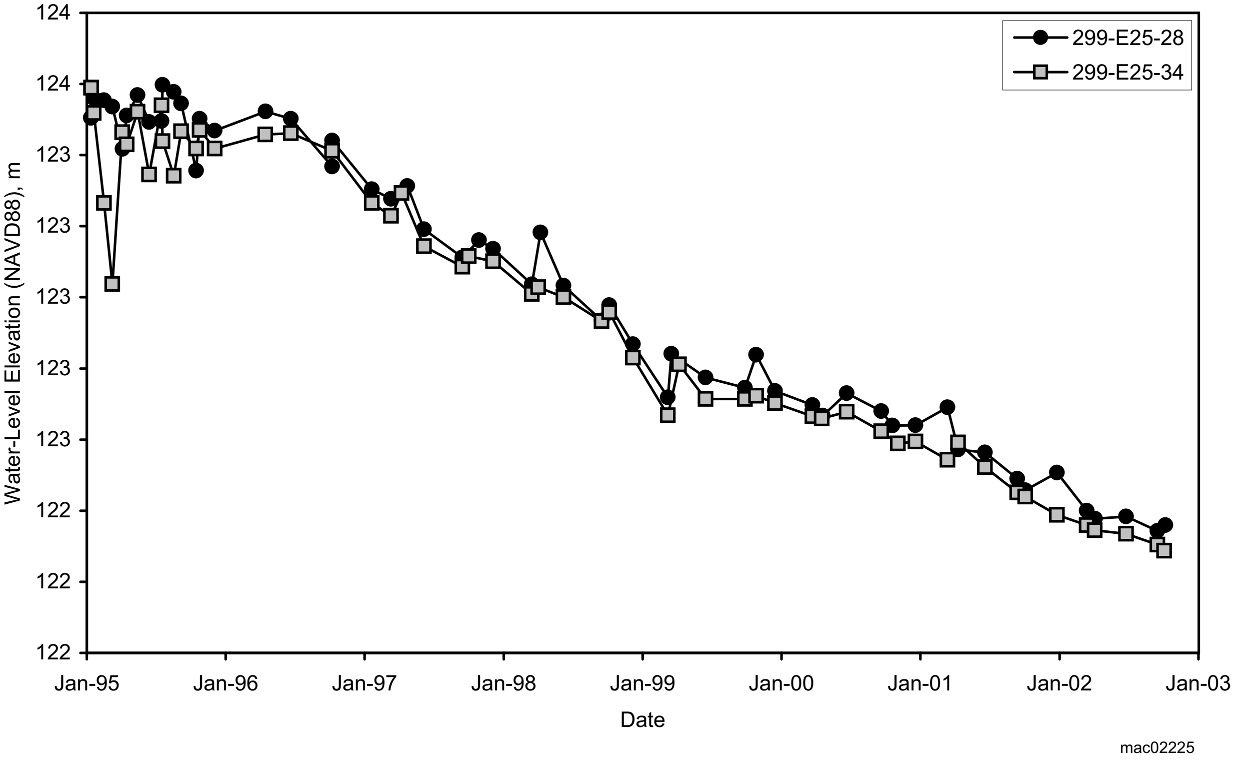

Figure 2.9-43. Water Levels in Well 299-E25-28 in Ringold Formation Unit 9 and Well 299-E25-34 in the Overlying Hanford Formation

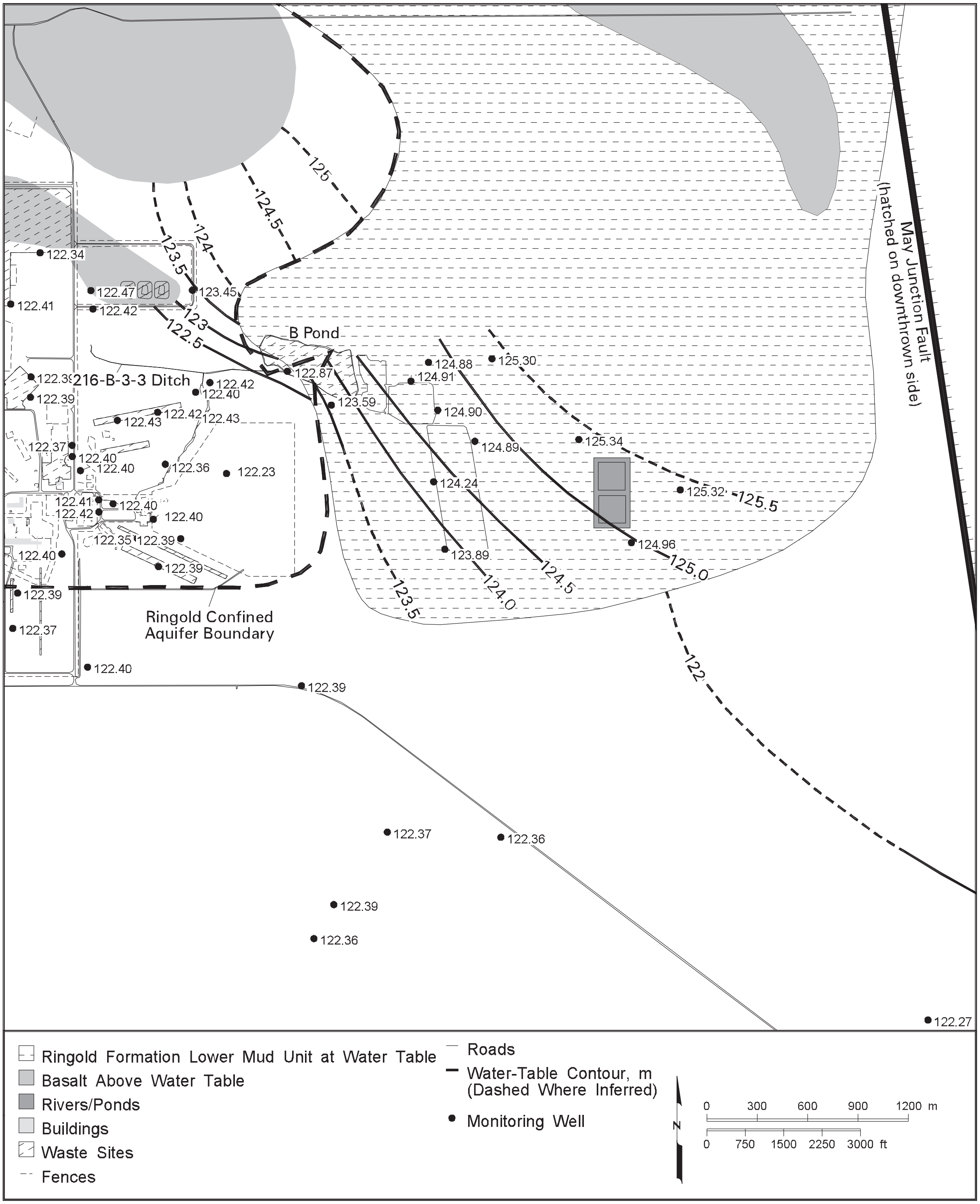

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Figure 2.9-44. Potentiometric Surface Map for the Confined and Unconfined Aquifers Near B Pond, March 2002

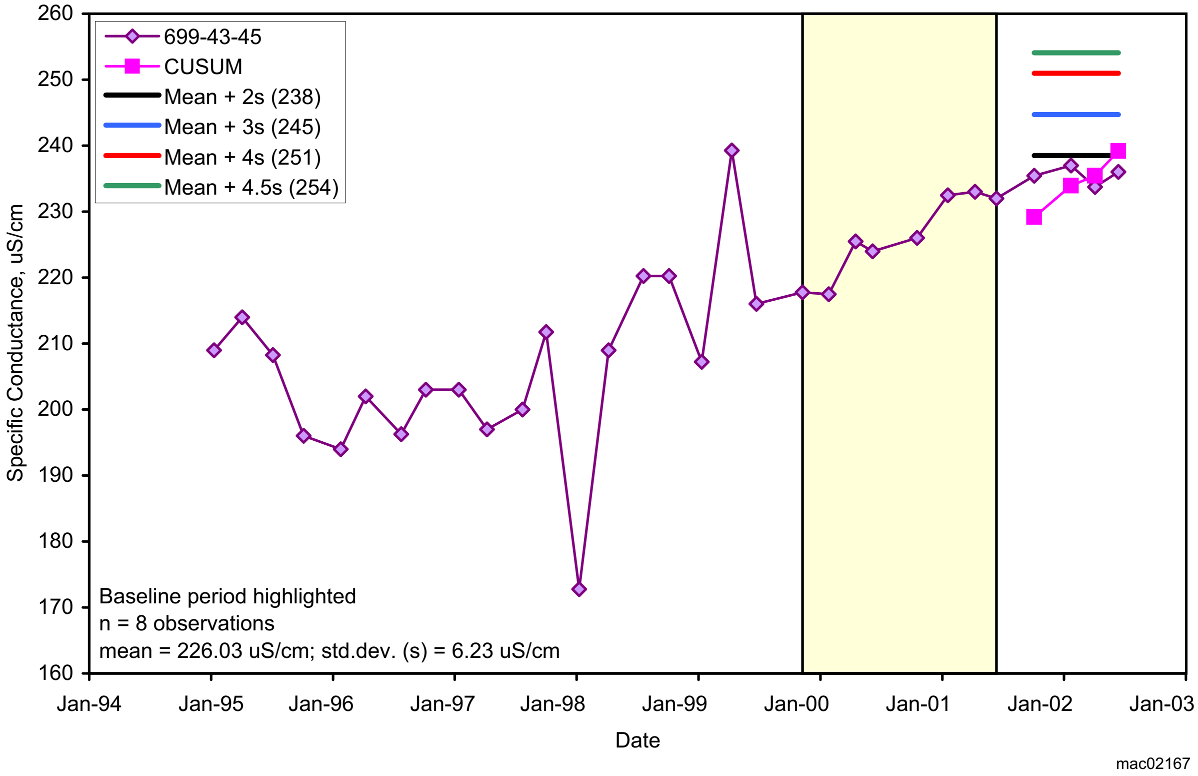

Figure 2.9-45. Shewhart CUSUM Control Chart for Specific Conductance in Well 699-43-45

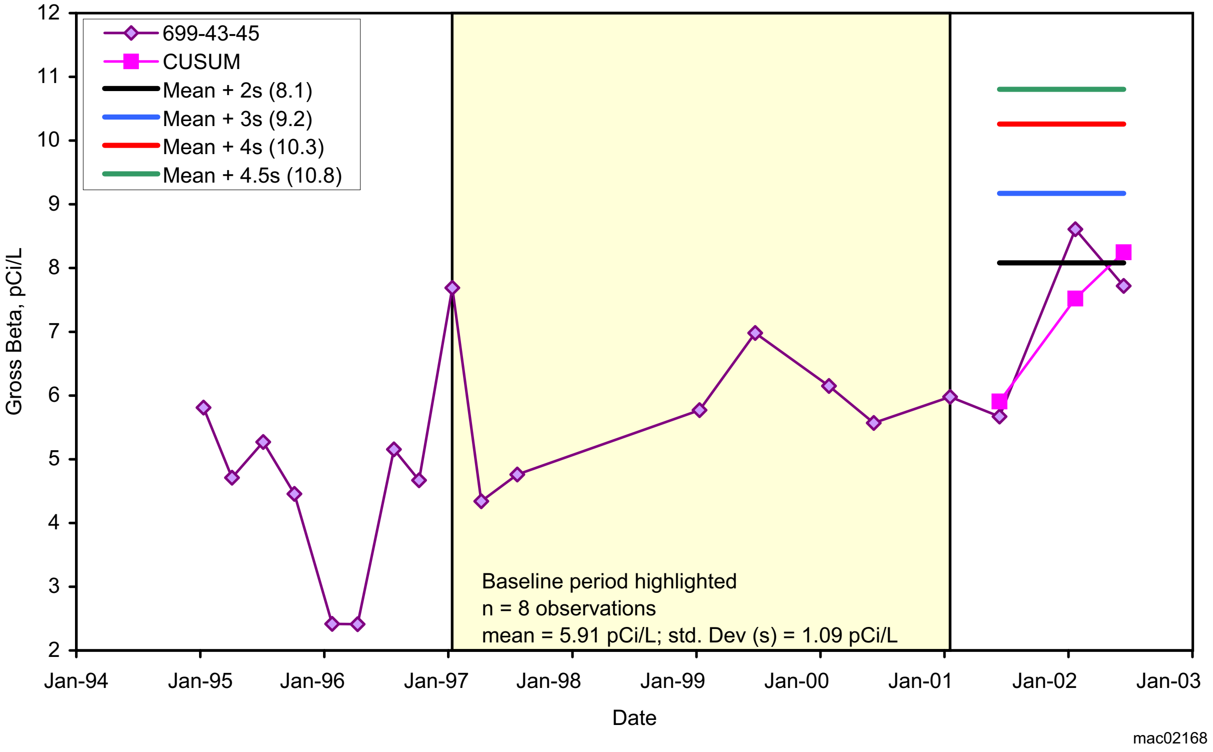

Figure 2.9-46. Shewhart CUSUM Control Chart for Gross Beta in Well 699-43-45

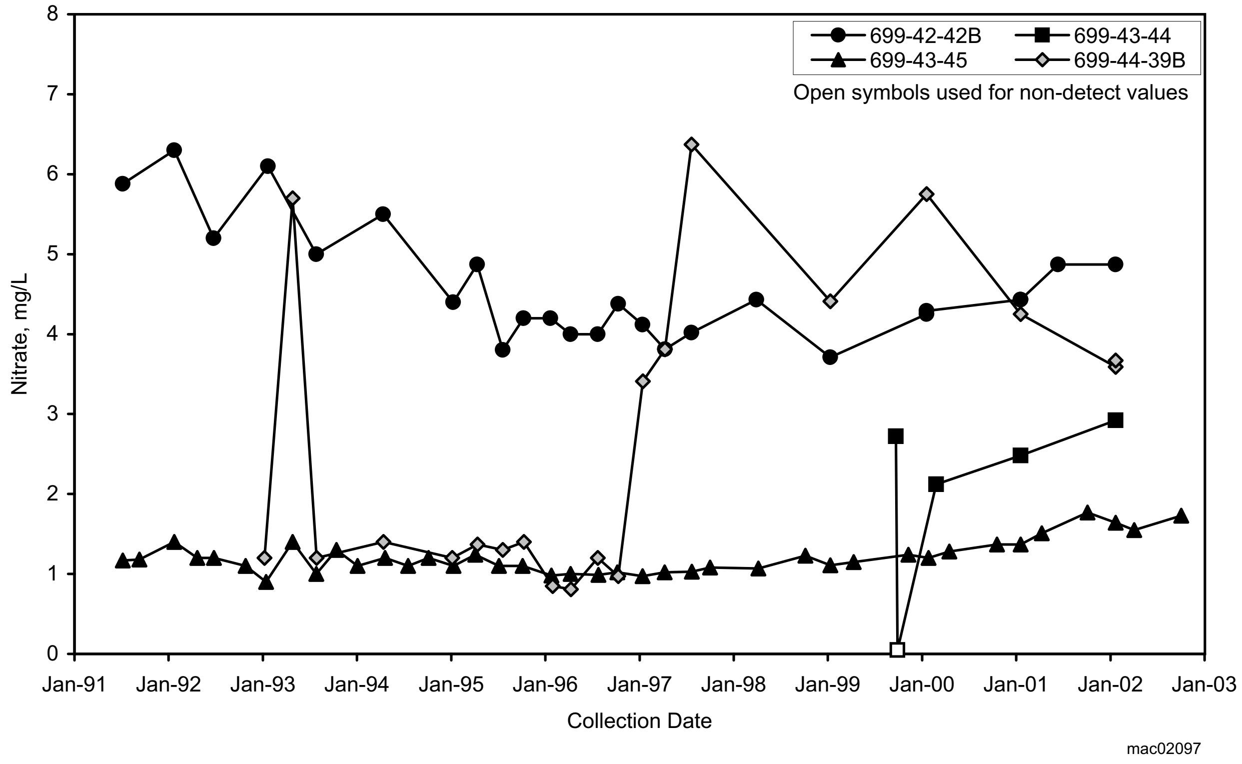

Figure 2.9-47. Nitrate Concentrations at B Pond in Wells Illustrating Significant Trends

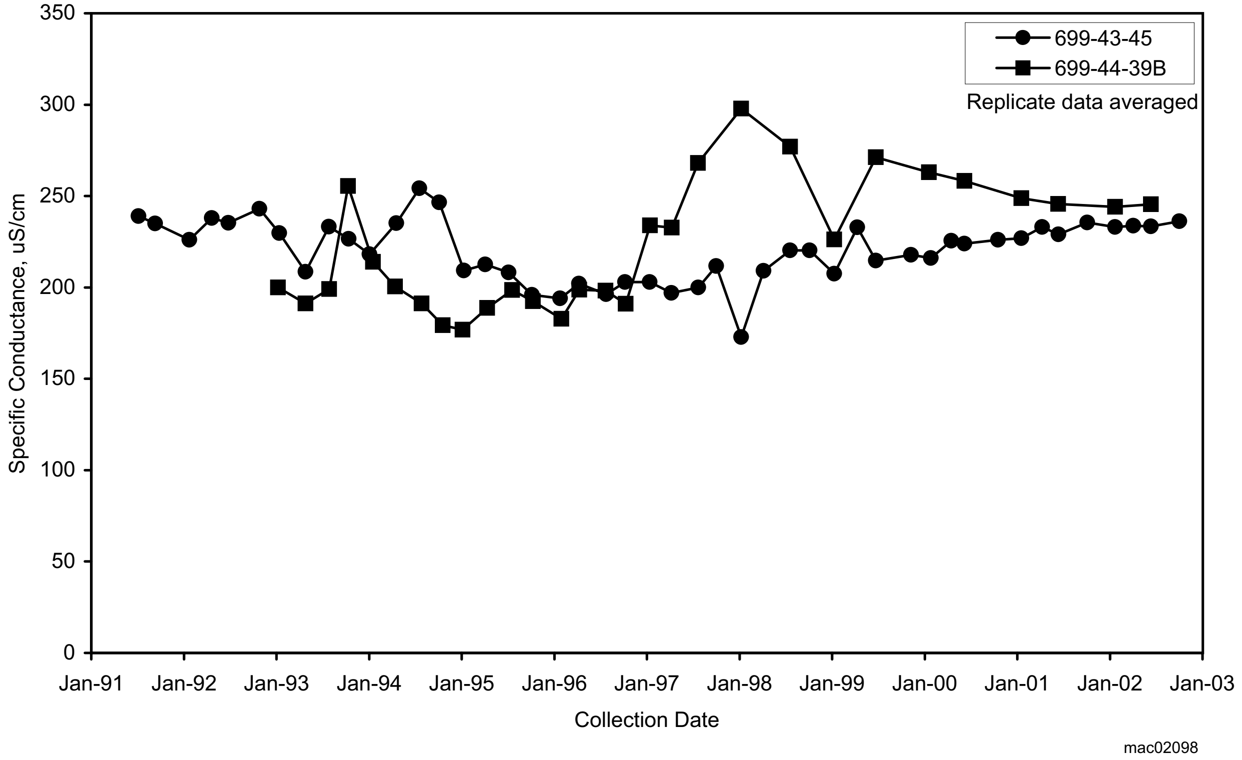

Figure 2.9-48. Specific Conductance in Wells Monitoring B Pond

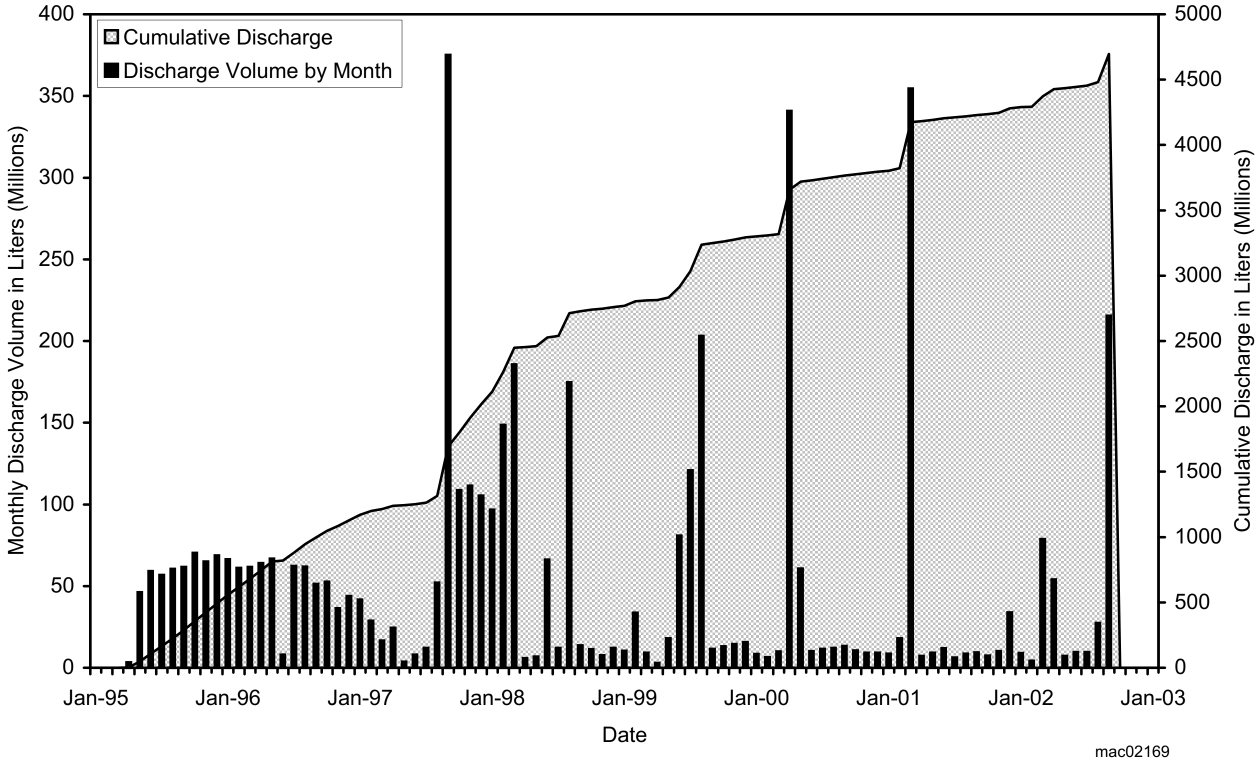

Figure 2.9-49. Discharge Volume History in the 200 Areas Treated Effluent Disposal Facility, April 1995 through September 2002

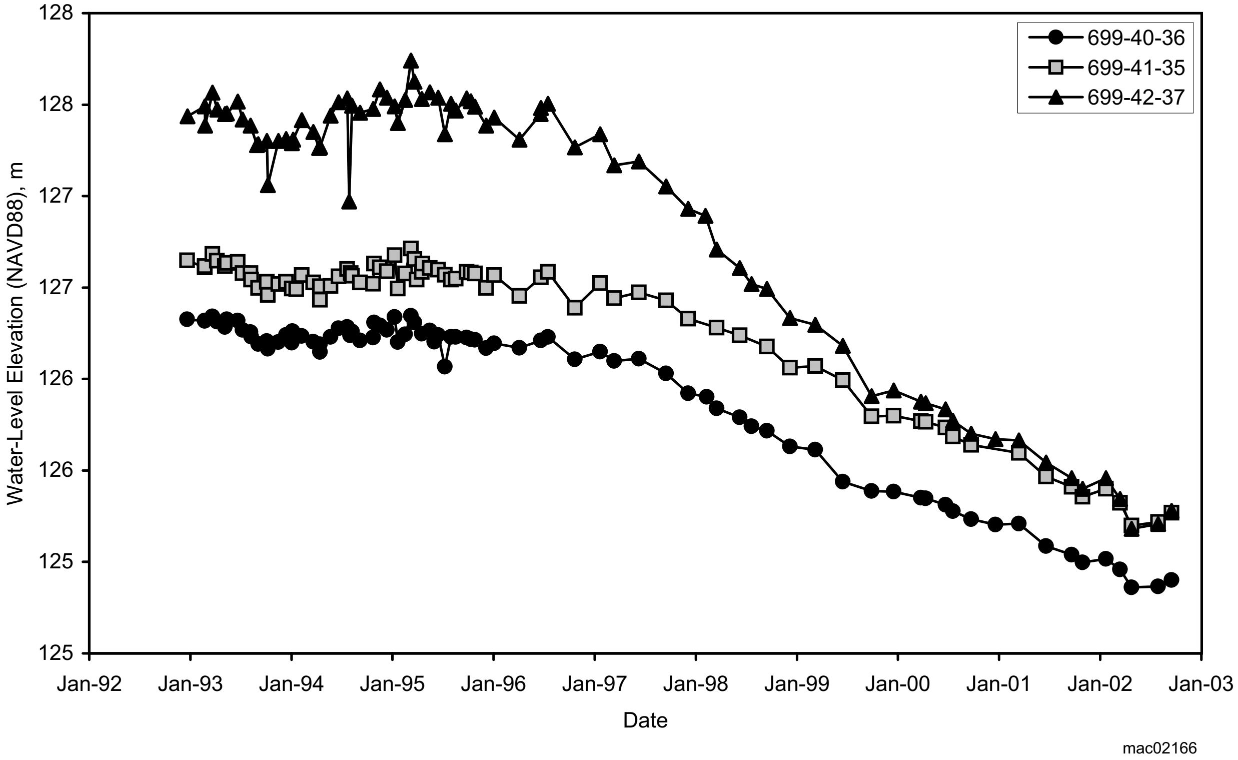

Figure 2.9-50. Water Levels in Wells at the Treated Effluent Disposal Facility

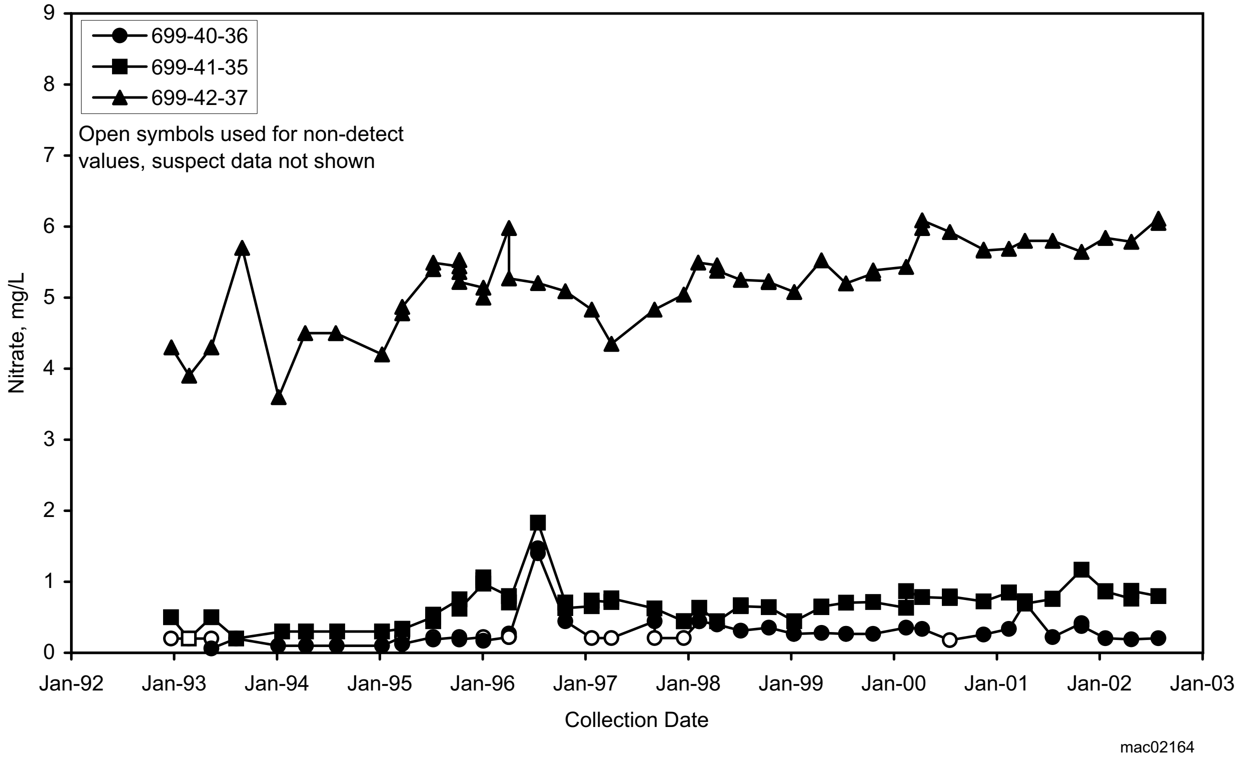

Figure 2.9-51. Trends for Nitrate in Wells at the Treated Effluent Disposal Facility

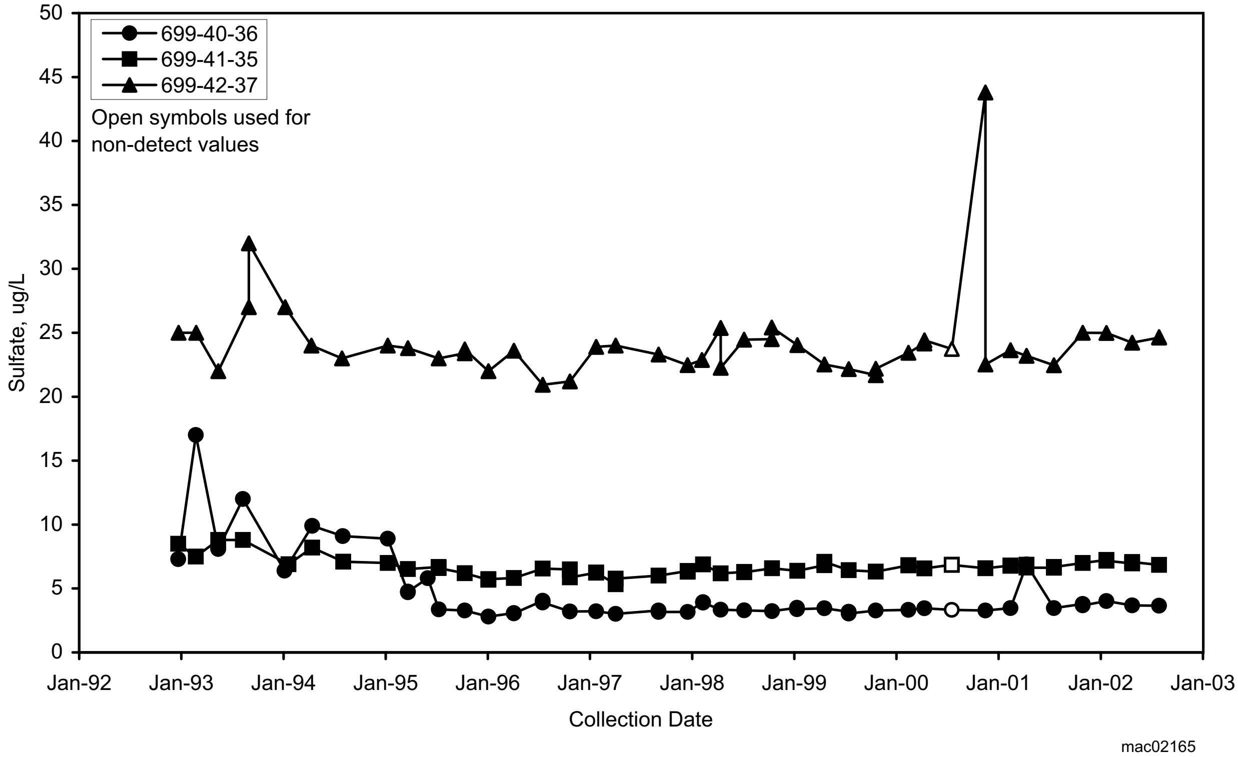

Figure 2.9-52. Sulfate Trends in Wells at the Treated Effluent Disposal Facility. (High values for 2000 is a suspected error in analysis.)

2.10 400 Area

E. C. Thornton

The 400 Area on the Hanford Site is the location of the Fast Flux Test Facility, a liquid sodium-cooled reactor. In December 2001, the U.S. Department of Energy (DOE) announced that restart of the facility is impractical and plans to proceed with deactivation of the facility. Deactivation activities have currently been halted pending resolution of a legal challenge to DOE's shutdown decision. Resolution of the matter is expected during the first half of 2003.

Primary groundwater monitoring activities in the 400 Area include monitoring of the 4608-B/C ponds (also called the 400 Area process ponds) for compliance with a waste discharge permit, and monitoring of the 400 Area water supply wells. Monitoring is also conducted to provide information needed to describe the nature and extent of site-wide contamination. The location of groundwater monitoring wells in the 400 Area is shown in Figure 2.10-1.

Wells in the 400 Area supply water and serve as emergency backup. The wells are monitored quarterly to ensure that tritium levels remain low.

2.10.1 Groundwater Flow

The Hanford Site water-table map (see Figure 2.1-1) indicates that flow is generally to the east-southeast across the 400 Area. The water table is located near the contact of the Hanford and Ringold Formations, which is ~49 meters below ground surface (WHC-EP-0587). Hanford formation sediment dominates groundwater flow in the 400 Area because of its relatively high permeability compared to that of sediment in the Ringold Formation.

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Technicians collect groundwater samples and prepare them for transport to an analytical laboratory, as shown above. The types of bottles used are determined by the type of contaminant that is being investigated.

2.10.2 Nitrate and Nitrite

Nitrate is the only significant contaminant attributable to 400 Area operations. A large area of relatively low nitrate concentrations north of the 400 Area appears to be related to discharge of effluent to the process ponds (Figure 2.10-2). However, elevated nitrate concentrations up to 81 mg/L (45-mg/L maximum contaminant level) were found in downgradient well 699-2-7 during fiscal year 2002 and are attributed to a sanitary sewage lagoon formerly located immediately west and upgradient of the process ponds and later to a drainfield associated with septic tanks located west of the ponds (see Figures 2.10-2 and 2.10-3). Groundwater samples associated with this well are also frequently elevated with respect to nitrite (Figure 2.10-4), which may have been generated by reduction of nitrate to nitrite due to the natural breakdown of nitrate in the aquifer. All nitrite values are below the 3.3-mg/L maximum contaminant level, however. Disposal to the lagoon was discontinued in 1983 or 1984 and to the drainfield in April 1997. Thus, groundwater contamination from these sources is expected to diminish with time and the average concentration of nitrate in samples collected from well 699-2-7 was, in fact, observed to decrease from 82 to 73 mg/L between fiscal years 2001 and 2002. Nitrate and nitrite concentrations in samples obtained from the new downgradient well 699-2-6A were not significantly elevated relative to the upgradient well 699-8-17.

Nitrate is the only groundwater contaminant attributable to 400 Area operations. The contamination is believed to have come from a sanitary sewage lagoon that is no longer in use.

2.10.3 Tritium

Elevated levels of tritium associated with the groundwater plume from the vicinity of the Plutonium-Uranium Extraction Plant in the 200 East Area were identified in 400 Area wells as in previous years (Figure 2.10-5). The lower concentrations of tritium north of the 400 Area are probably related to discharge at the process ponds. This source of groundwater contamination is relevant to the water-supply wells, which provide drinking water and emergency supply water for the 400 Area. Well 499-S1-8J serves as the main water supply well, while wells 499-S0-7 and 499-S0-8 are backup supply wells. Well 499-S1-8J has lower tritium concentrations because it is screened at a greater depth than the other two water supply wells. The tritium concentrations in wells 499-S0-7, 499-S0-8, and 499-S1-8J are compared in Figure 2.10-6 to that of the 400 Area drinking water supply. Tritium was found at levels below the 20,000 pCi/L-drinking water standard in samples from well 499-S0-7 during fiscal year 2002. Samples collected from well 499-S0-8 exceeded the drinking water standard during the latter part of fiscal year 1999, but all samples collected during fiscal years 2000, 2001, and 2002 were well below the drinking water standard. All samples collected from well 499-S1-8J in fiscal year 2002 were below the drinking water standard. The sampling of the water-supply wells was reduced from monthly to quarterly in fiscal year 2002.

Monitoring Objectives in 400 Area

Groundwater monitoring is conducted in the 400 Area:

- triennially to annually to describe the nature and extent of contamination
- quarterly to detect possible impacts of 400 Area process ponds
- quarterly to monitor tritium trends in water-supply wells

Tritium remained below the 20,000-pCi/L drinking water standard and the 4-millirem-per-year dose equivalent in the drinking water supply, sampled at a tap for all sampling events in fiscal year 2002 (see Figure 2.10-6). Nitrate remained below the maximum contaminant level in fiscal year 2002 for the water-supply wells. Data from fiscal year 2002 and earlier from 400 Area and surrounding wells indicates no other constituents are present at levels above their maximum contaminant levels or drinking water standards.

2.10.4 400 Area Process Ponds

The 400 Area process ponds are regulated under a WAC 173-216 state waste discharge permit, which was issued on August 1, 1996, and modified on February 10, 1998. This permit defines groundwater enforcement limitations for the facility. Groundwater monitoring is provided by upgradient well 699-8-17 and downgradient wells 699-2-6A and 699-2-7, and is undertaken quarterly per the requirements presented in Appendix A, Table A.41. Groundwater quality met permit conditions in fiscal year 2002.

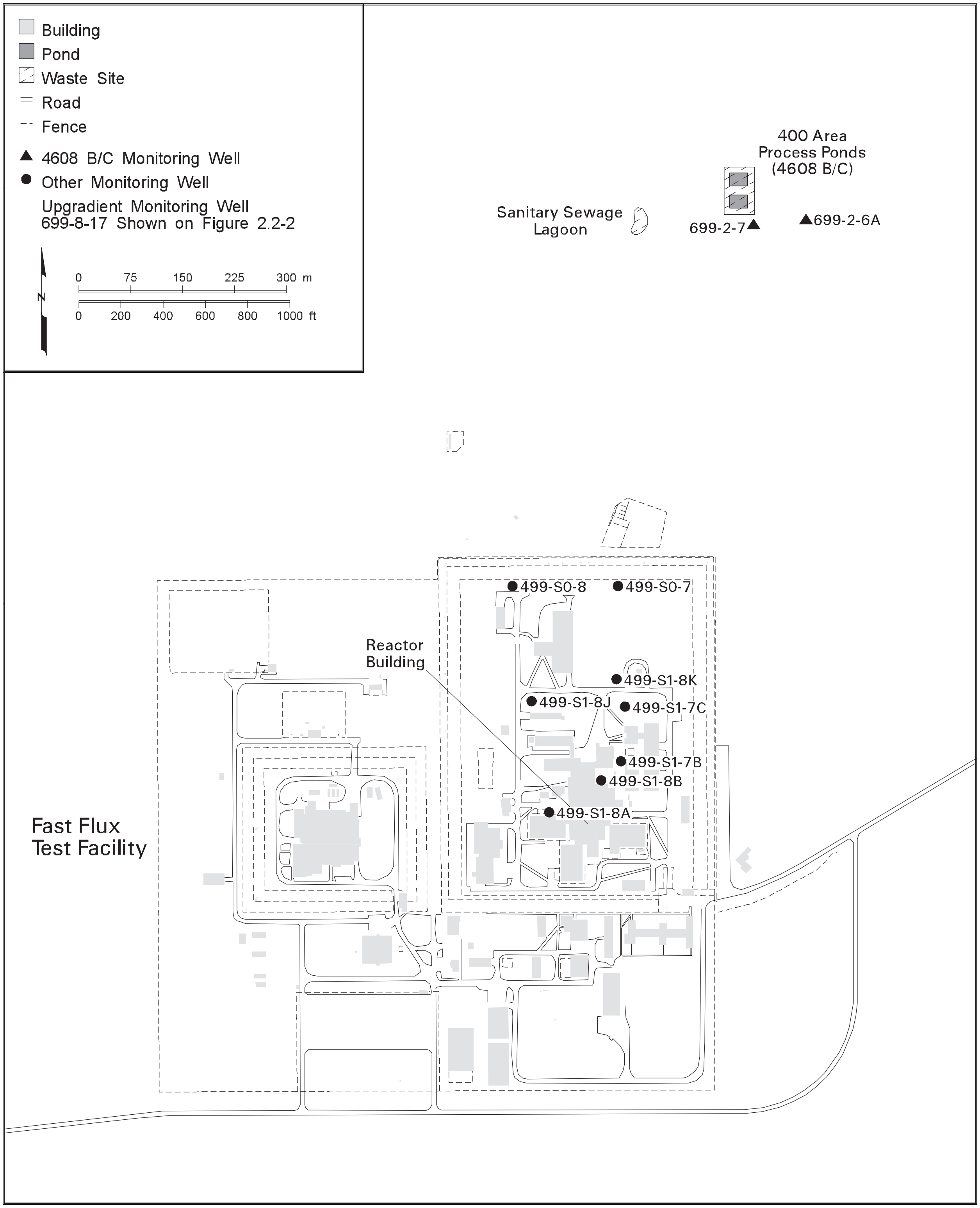

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Figure 2.10-1. Groundwater Monitoring Wells in the 400 Area

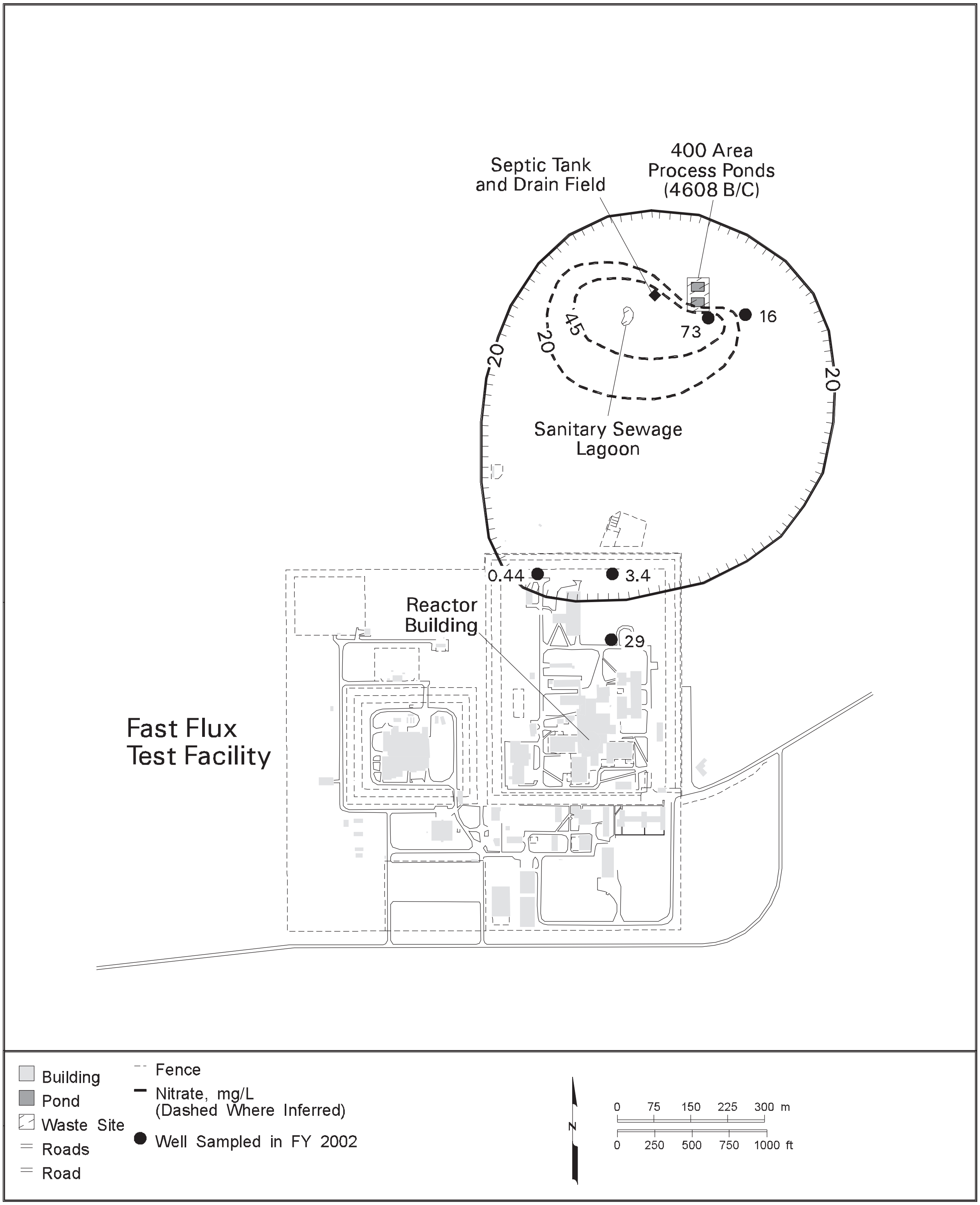

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Figure 2.10-2. Average Nitrate Concentrations in the 400 Area, Top of the Unconfined Aquifer

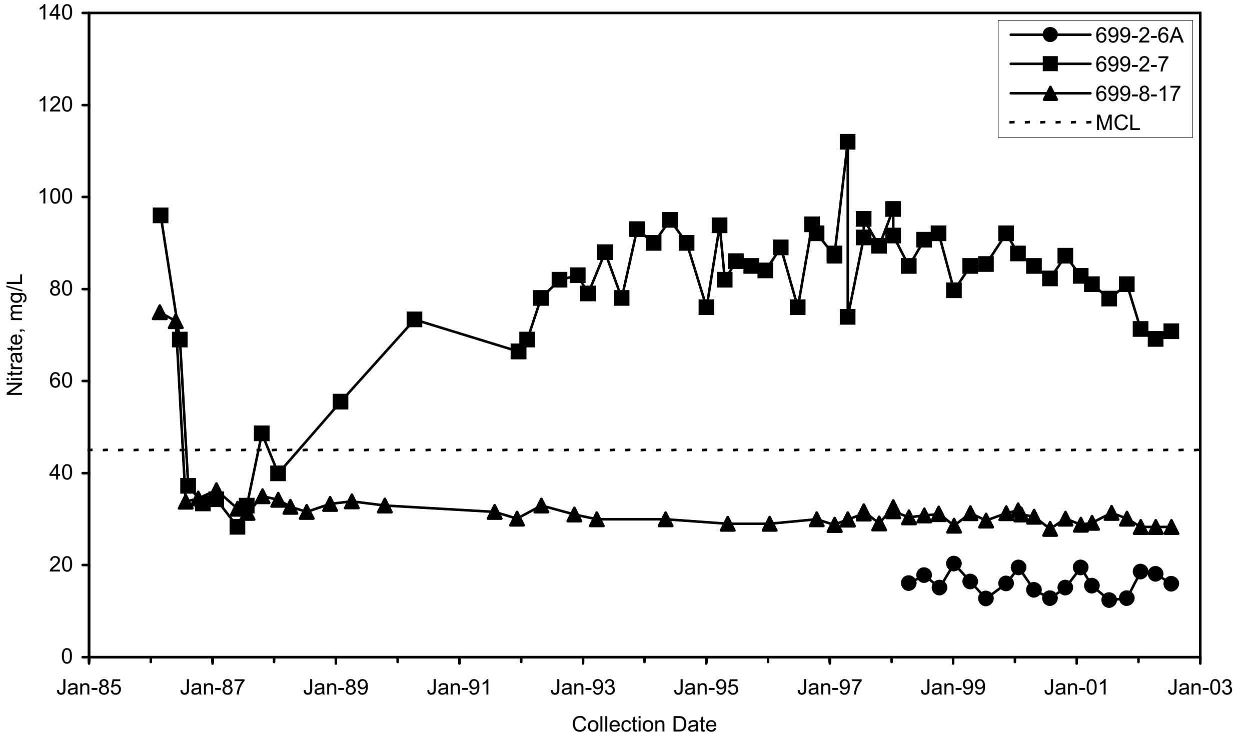

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Figure 2.10-3. Nitrate Concentrations in Wells Monitoring the 400 Area Process Ponds

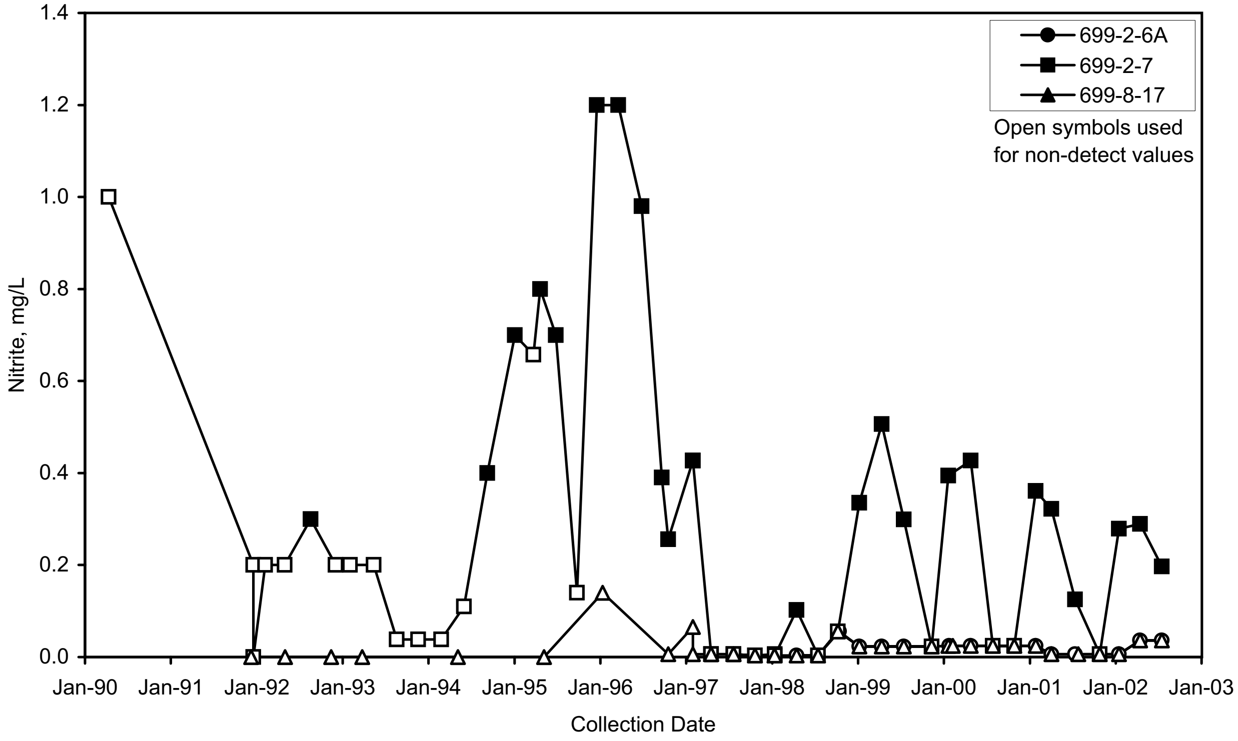

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Figure 2.10-4. Nitrite Concentrations in Wells Monitoring the 400 Area Process Ponds

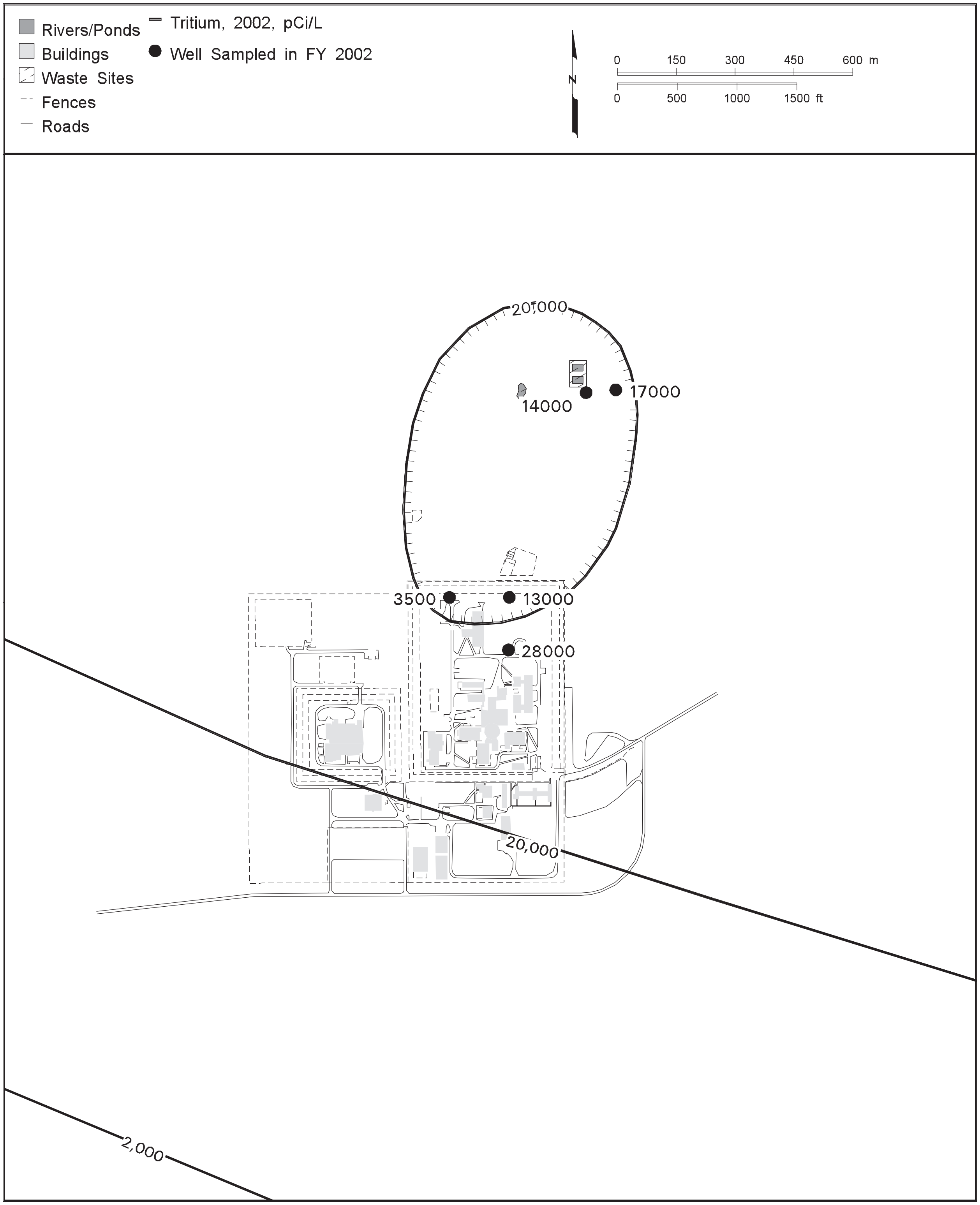


Figure 2.10-5. Average Tritium Concentrations in 400 Area, Top of Unconfined Aquifer

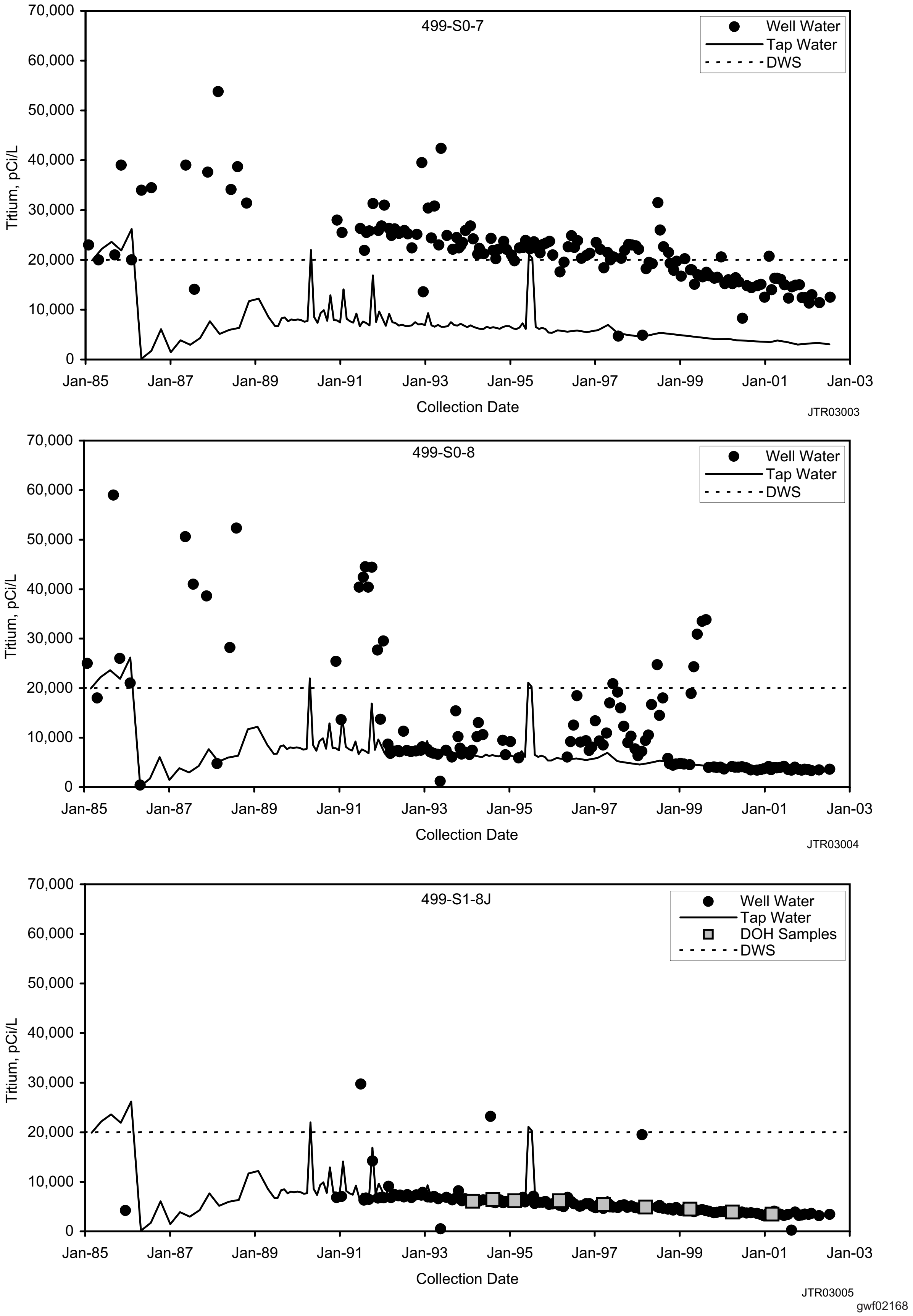


Figure 2.10-6. Comparison of Tritium Concentrations in 400 Area Drinking Water System

2.11 600 Area

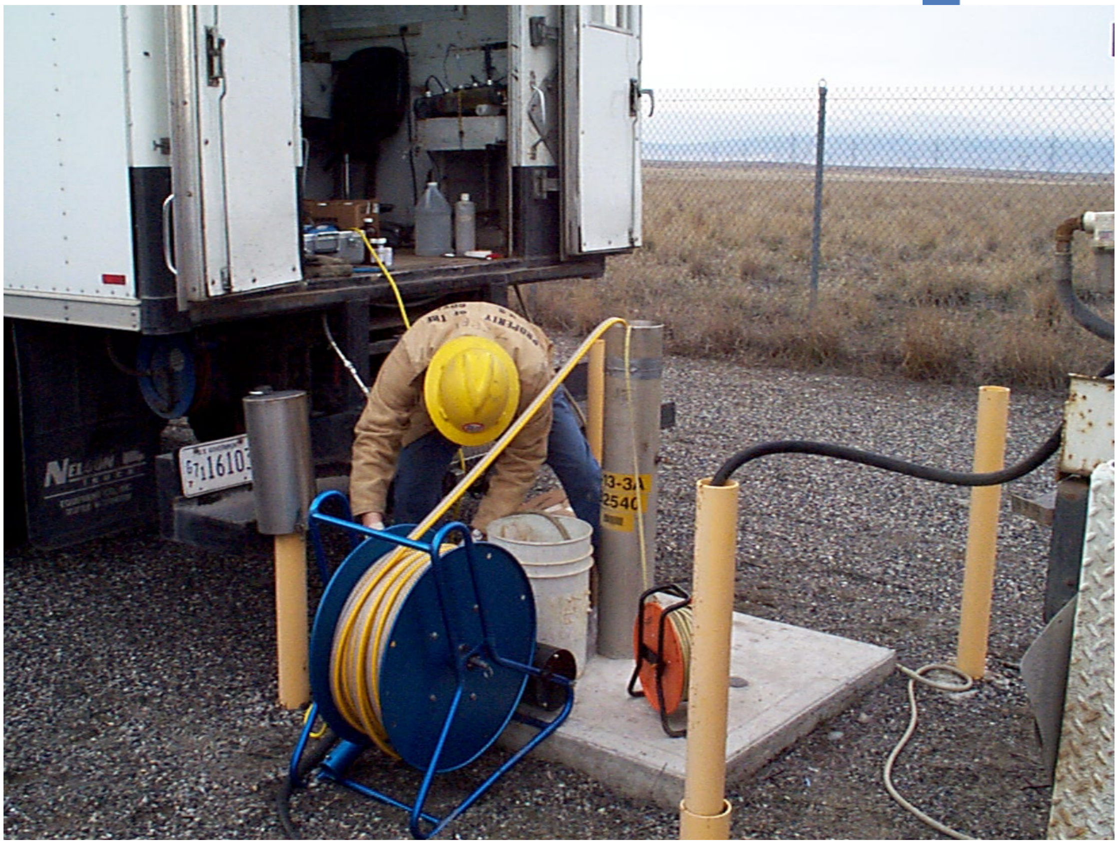
J. W. Lindberg

This section discusses groundwater contamination in the Central Landfill. Other facilities located in the 600 Area are described in the sections relating to their waste sources or operable units (i.e., 618-10 burial ground, 618-11 burial ground, and 316-4 cribs are in Section 2.12; Gable Mountain Pond in Section 2.9; Plutonium-Uranium Extraction (PUREX) Plant cribs plumes in Section 2.9).

Most of the groundwater contaminants in the 600 Area originated at waste sites in other areas.

2.11.1 Central Landfill

The Central Landfill is located ~5 kilometers southeast of the southeast corner of the 200 East Area (see Figure 2.2-2) and is composed of two separate landfills: the Nonradioactive Dangerous Waste Landfill and the Solid Waste Landfill. The Nonradioactive Dangerous Waste Landfill is an interim status *Resource Conservation and Recovery Act* (RCRA) land disposal facility that is monitored under indicator-evaluation requirements. The Solid Waste Landfill is regulated by the Washington State Department of Ecology under WAC 173-304. Originally, in 1973, the area occupied by the two landfills was designated as the Central Landfill. However, in order to segregate "regulated dangerous wastes" such as asbestos and non-radioactive chemical waste, the north portion of the Central Landfill was isolated from the south portion, i.e., the Solid Waste Landfill. Groundwater monitoring wells at the Central Landfill are shown on Figure 2.11-1.



Groundwater sampling is performed at well 699-13-3A, which has the highest tritium values on the Hanford Site. The portable reel holds a pump on the end of a hose.

2.11.1.1 Groundwater Flow

Monitoring Objectives in 600 Area

Groundwater monitoring is conducted in the 600 Area:

- triennially to annually to describe the nature and extent of contamination
- semiannually to detect possible impacts of the Nonradioactive Dangerous Waste Landfill RCRA Site
- quarterly to detect possible impacts of the Solid Waste Landfill

Groundwater flow beneath the Central Landfill in fiscal year 2002 was virtually the same as in recent years. The direction and rate of groundwater flow at the Central Landfill are difficult to determine from water-table maps because of the extremely low hydraulic gradient. The best indicators of flow direction are the major plumes of iodine-129, nitrate, and tritium. These plumes flow to the southeast (~125 degrees east of north; see Section 17.0 in DOE/RL-91-03) in the vicinity of the Central Landfill. The decrease in nitrate and tritium concentrations in a southwest-northeast trend across the Central Landfill is due to the location of the Central Landfill on the south edge of the plumes. The rate of groundwater flow is ~0.026 to 0.23 meter per day (see Appendix A) based on measurements of the hydraulic gradient from water-table maps and current understanding of the local hydraulic conductivity and effective porosity.

March 2002 water-level data from one well pair, sampling the top of the unconfined aquifer and the aquifer immediately above the low-permeability unit, indicate that the vertical gradient within the upper portion of the unconfined aquifer is negligible.

2.11.1.2 RCRA Parameters for the Nonradioactive Dangerous Waste Landfill

Monitoring of the Nonradioactive Dangerous Waste Landfill focuses on the RCRA interim status indicator parameters: pH, specific conductance, total organic carbon, and total organic halides (see Appendix A). Volatile organic compounds are monitored because they may represent groundwater contamination originating from this landfill. Nitrate is present in groundwater and has a source in the 200 East Area (see Section 2.9.2.4). The groundwater quality parameters (chloride, iron, manganese, phenols, sodium, and sulfate) are monitored but are either not detected or not found in concentrations significantly above background concentrations.

Wells at the Nonradioactive Dangerous Waste Landfill (see Figure 2.11-1) are sampled semiannually, usually in February and August. The August 2002 sampling was late in some wells, and these wells were sampled in September 2002. Well 699-25-34B was not sampled during fiscal year 2002 because of mechanical problems with the pump. Efforts are being made to remedy the faulty pump.

RCRA monitoring at the Nonradioactive Dangerous Waste Landfill in fiscal year 2002 indicated the site has not had a significant impact on groundwater.

The values for RCRA indicator parameters did not exceed their critical means (or critical range for pH) in fiscal year 2002 for three of the indicator parameters: pH, total organic carbon, and total organic halides. However, the critical mean for specific conductance (564 µS/cm) was exceeded at three downgradient wells: 699-25-34A, 699-25-34D, and 699-26-33. The highest values reported were at well 699-25-34A where the September 2002 quadruplicate samples averaged 625 µS/cm. This exceedance was first discovered and reported in fiscal year 2000. An assessment plan and assessment report were submitted to the regulator (Washington State Department of Ecology) at that time. The increased specific conductance is most likely caused by increases in the concentrations of non-hazardous constituents (bicarbonate, calcium, manganese, and sulfate) from the adjacent Solid Waste Landfill.

During fiscal year 2002, seven volatile organic compounds were detected in wells at the Nonradioactive Dangerous Waste Landfill, but six of the seven were detected at levels considered "estimates" because the concentrations were too low for certainty. The volatile organic compound that was detected at high enough concentrations to provide certainty of detection was 1,1,1-trichloroethane. The highest concentration reported during fiscal year was 1.3 µg/L at well 699-26-35A (an upgradient well) for a sample collected in March 2002; the drinking water standard for 1,1,1-trichloroethane is 200 µg/L. A duplicate sample collected at the same time had a reported result of 1.0 µg/L. The six volatile organic compounds with uncertain detections were: 1,1-dichloroethane, acetone, chloroform, methylene chloride, tetrachloroethene, and trichloroethene. The source of the volatile organic compounds could either be from the Solid Waste Landfill (to the south) or from the Nonradioactive Dangerous Waste Landfill (bottom of trenches is ~35 meters above the water table). For example, tetrachloroethene is present in vadose zone vapor beneath the Solid Waste Landfill (PNL-7147) and also is the principal contaminant in vadose zone vapor around the chemical disposal trenches at the Nonradioactive Dangerous Waste Landfill (see Section 5.2 of DOE/RL-93-88). It is possible that both of these sources contribute to the contamination.

Nitrate continues to be detected in wells at the Nonradioactive Dangerous Waste Landfill during fiscal year 2002. Its source is upgradient in the 200 East Area. Nitrate concentrations continue to decrease with time.

2.11.1.3 Groundwater Monitoring at the Solid Waste Landfill

The Solid Waste Landfill is regulated by the Washington State Department of Ecology under WAC 173-304. WAC 173-304 constituents and site-specific constituents (including volatile organic compounds and filtered arsenic) are analyzed on groundwater samples collected quarterly (see Appendix A). Compliance is determined by comparing results from monitoring downgradient wells with statistically derived background threshold values from upgradient wells. Exceedance indicate results that are out of compliance with WAC 173-304. Groundwater flow was described in Section 2.11.1.1. The well locations in the Solid Waste Landfill are shown in Figure 2.11-1.

The Solid Waste Landfill is regulated under state law. Groundwater monitoring has detected only very low levels of chlorinated hydrocarbons.

The Solid Waste Landfill has had little impact on Hanford Site groundwater, except minor chlorinated hydrocarbon contamination (Table 2.11-1) below federal maximum contaminant levels but above levels defined in WAC 173-200, which are generally lower. Some downgradient wells show higher specific conductance, chloride, sulfate and coliform bacteria levels, and lower pH than upgradient wells. This apparently is a result of high concentrations of carbon dioxide in the vadose zone resulting from the degradation of sewage material disposed to the Solid Waste Landfill (see Section 5.3 of DOE/RL-93-88; PNL-7147; and WHC-SD-EN-TI-199).

WAC 173-304 Parameters

Each WAC 173-304 parameter is discussed separately below. See Appendix A for a complete list of all results for required constituents at the Solid Waste Landfill during fiscal year 2002. Table 2.11-1 shows the results for the volatile organic compounds during the same period.

- Temperature – Groundwater temperatures measured during sampling in downgradient wells ranged from 17.1°C to 20.7°C. (Note: One temperature exceeded the background threshold value of 20.7°C; it was 26°C at well 699-24-33 in August 2002. This reported value is presumed to be a measurement error because it varies significantly from the historical trend.) See Appendix A for a total list of fiscal year 2002 background threshold values for WAC 173-304 required parameters.
- Specific conductance – Specific conductance measurements on samples taken from all wells downgradient of the Solid Waste Landfill exceeded the

background threshold value of 583 µS/cm. The range in downgradient wells was 640 to 866 µS/cm. Seven of the eight downgradient wells also exceed the 700-µS/cm maximum contaminant level (WAC 246-290-310) in fiscal year 2002.

- Field-measured pH – Measured values ranged from 6.58 to 7.69. Reported results were lower than the background threshold range (6.68 to 7.84) in four downgradient wells: 699-23-34A, 699-23-34B, 699-24-34A, and 699-24-34B.
- Total organic carbon – The reported values of total organic carbon ranged from <120 to 680 µg/L. None exceeded the 1,090-µg/L background threshold value.
- Chloride – Chloride concentrations in the downgradient wells ranged from 5,500 to 8,300 µg/L. The reported results for August 2002 exceeded the background threshold value of 7,800 µg/L in two downgradient wells (699-23-34B had a reported value of 8,300 µg/L and 699-25-34C had a reported value of 8,200 µg/L).
- Nitrate – Nitrate concentrations in downgradient wells ranged from 11.5 to 16.4 mg/L. Neither the 29-mg/L background threshold value nor the 45-mg/L maximum contaminant level were exceeded in any well downgradient of the Solid Waste Landfill. The source of nitrate contamination at the Solid Waste Landfill is from upgradient sources in the 200 East Area (see Figure 2.1-4).
- Nitrite – Nitrite concentrations in all downgradient wells were less than the method detection limit (0.0351 mg/L).
- Ammonium – Ammonium concentrations in all downgradient wells were less than the method detection limit (15.7 µg/L).
- Sulfate – Reported sulfate concentrations in downgradient wells ranged from 40.1 to 52.7 mg/L. Results exceeded the background threshold value of 47.2 mg/L in wells 699-22-35, 699-23-34A, 699-23-34B, and 699-24-34A. None of the samples exceeded the 250-mg/L standard (WAC 173-200).
- Filtered iron – Reported values for filtered iron ranged from less than the method detection limit (<8.2 µg/L in well 699-24-33 in May 2002 to 80.6 µg/L at well 699-25-34C in October 2001). None of the reported values exceeded the 160-µg/L background threshold value in any of the downgradient wells.
- Filtered zinc – Reported values for filtered zinc ranged from less than the method detection limit (<2 µg/L) to 15.2 µg/L. None of the reported values exceeded the background threshold value of 34.9 µg/L.
- Filtered manganese – Reported values for filtered manganese ranged from less than the method detection limit (0.5 µg/L) to 8.4 µg/L in downgradient wells. None of the reported values exceeded the background threshold value of 10 µg/L.
- Chemical oxygen demand – None of the reported results exceeded the method detection limit of 7.5 µg/L or the background threshold value of 10 µg/L.
- Coliform bacteria (most probable number) – Reported results for coliform bacteria for fiscal year 2002 were generally zero colonies per 100 milliliters, and, therefore, less than the background threshold value of 3.7 colonies per 100 milliliters. However, results for one downgradient well and one upgradient well exceeded the background threshold value in August 2002. The downgradient well with the exceedance was well 699-23-34A with a reported value of 52 colonies per 100 milliliters, and the upgradient well with the exceedance was well 699-24-35 with a reported value of 260 colonies per 100 milliliters. Well 699-24-35 had the highest report result of coliform bacteria at the Solid Waste Landfill during fiscal year 2001 also. The reason for coliform bacteria in an upgradient well is not known, but perhaps this well is not far

enough upgradient to escape contamination from the Solid Waste Landfill. The presence of coliform bacteria is not surprising because sewage was deposited in trenches at the landfill.

Site-Specific Parameters

Site-specific parameters at the Solid Waste Landfill include chlorinated hydrocarbons and two constituents (1-4 dioxane and filtered arsenic) detected in the system to collect leachate from the landfill. Slightly elevated concentrations of chlorinated hydrocarbons continued to be detected at the Solid Waste Landfill during fiscal year 2002. Four constituents exceeded the groundwater criteria set forth in WAC 173-200. The range of reported concentrations of chlorinated hydrocarbons is given in Table 2.11-1.

Chlorinated hydrocarbons were detected in all of the monitoring wells at the Solid Waste Landfill, including the upgradient wells. The chlorinated hydrocarbons detected were

- carbon tetrachloride
- chloroform
- 1,1-dichloroethane
- 1,2-dichloroethane
- 1,4-dichlorobenzene
- tetrachloroethene
- trichloroethene
- 1,1,1-trichloroethane

1,1-dichloroethane (1.0 µg/L) and tetrachloroethene (0.8 µg/L) exceed applicable regulatory limits at the Solid Waste Landfill. The maximum concentration for 1,1-dichloroethane was 1.1 µg/L and for tetrachloroethene was 2.2 µg/L.

Of those detected, only carbon tetrachloride, 1,1-dichloroethane, tetrachloroethene, and trichloroethene exceeded the WAC 173-200 concentration limits (0.3, 1.0, 0.8, and 3.0 µg/L, respectively) during fiscal year 2002. However, only one reported value for carbon tetrachloride and trichloroethene exceeded the WAC 173-200 limits and at two different wells. These two results are anomalous, do not fit the historical trend for these two wells, and are most likely due to errors in sampling or analysis. Therefore, the exceedances of WAC 173-200 actually occurred with only two constituents (1,1-dichloroethane and tetrachloroethene). The 1,1-dichloroethane limit was reached or exceeded at wells 699-22-35, 699-23-34A, and 699-23-34B. The tetrachloroethene limit was exceeded at all Solid Waste Landfill wells except for one upgradient well (699-26-35A). None of the reported results exceeded the maximum contaminant level (drinking water standards) for any of the detected chlorinated hydrocarbons with the possible exception of the single result for trichloroethene at well 699-25-34C, which is most likely due to sampling or analysis error.

The most likely cause of the widespread, low-level chlorinated hydrocarbon contamination at the Solid Waste Landfill, including the upgradient wells and the adjacent Nonradioactive Dangerous Waste Landfill, is the dissolution of vadose zone vapors into groundwater. However, the source of the vapors is uncertain. The most probable source is chlorinated hydrocarbon dissolved in liquid sewage that was discharged to trenches at that site.

Filtered arsenic (maximum contaminant level 10 µg/L; WAC 173-200 limit 0.05 µg/L) is detected at all 10 Solid Waste Landfill wells. The highest concentration detected was 5.3 µg/L at well 699-24-35 (an upgradient well) in a sample collected November 2001. All detections were below the contractually required detection limit of the laboratory (the instrument detection limit was 1.38 µg/L). Although arsenic was discovered in the leachate collection system at the trenches, the occurrence of arsenic in groundwater at the Solid Waste Landfill is probably due to natural processes (i.e., occurs naturally in Hanford Site groundwater – Hanford Site background is ~10 µg/L – DOE/RL-92-23), or there is an upgradient source (e.g., 200 East Area). The concept that the arsenic may be from a source other than the Solid Waste Landfill is supported by (1) the occurrence of arsenic at very low concentrations in all of the Solid Waste Liquid network wells, and (2) the occurrence of arsenic at both upgradient wells.

Another constituent, 1,4-dioxane, was discovered in the leachate collection system at the Solid Waste Landfill trenches. Therefore, groundwater samples were specifically tested for this constituent also. It was not detected in any of the network wells. However, the instrument detection limit for 1,4-dioxane in the analytical method used was 13 µg/L. The WAC 173-200 limit is 7.0 µg/L.

Table 2.11-1. Ranges of Reported Chlorinated Hydrocarbon Concentrations in Solid Waste Landfill Wells During Fiscal Year 2002

Constituent	Limit (µg/L)(a)	699-22-35	699-23-34A	699-23-34B	699-24-33	699-24-34A
Carbon tetrachloride	WAC 0.3	<0.33	<0.33	<0.33	<0.33	<0.33
Chloroform	WAC 7.0	<0.12-0.3	<0.21	<0.12 - 0.22	<0.21	<0.21
1,1-Dichloroethane	WAC 1.0	<0.25 - **1.0**	<0.23 - **1.1**	<0.86 - **1.1**	<0.28 - 0.76	0.42 - 0.82
1,2-Dichloroethane	WAC 0.5	<0.27	<0.27	<0.27	<0.27	<0.27
1,4-Dichlorobenzene	WAC 4.0	<0.25	0.04 - 0.27	<0.25	<0.25	<0.25
cis-1,2-Dichloroethene	MCL 70	<0.24	<0.24	<0.24	<0.24	<0.24
trans-1,2-Dichloroethene	MCL 100	<0.23	<0.23	<0.23	<0.23	<0.23
Tetrachloroethene	WAC 0.8	**<0.97 - 1.2**	**1.3 - 1.7**	**0.92 - 1.3**	**1.9 - 2.2**	**1.5 - 1.9**
Trichloroethene	WAC 3.0	0.49 - 0.7	0.4 - 0.7	0.36 - 0.62	0.68 - 0.97	0.55 - 0.77
1,1,1-Trichloroethane	WAC 200	2.9 - 3.5	2.0 - 2.8	2.5 - 3.0	1.5 - 2.0	1.9 - 2.5
1,1,2-Trichloroethane	MCL 5.0	<0.27	<0.27	<0.27	<0.27	<0.27
1,4-Dioxane	WAC 7.0	<13.0	<13.0	<13.0	<13.0	<13.0

Constituent	Limit (µg/L)(a)	699-24-34B	699-24-34C	699-24-35	699-25-34C	699-26-35A
Carbon tetrachloride	WAC 0.3	<0.33	<0.33	<0.33	<0.33 - **4.9**(b)	<0.33
Chloroform	WAC 7.0	<0.21	<0.21	<0.21	<0.12 - 4.0	<0.12 - 0.21
1,1-Dichloroethane	WAC 1.0	0.46 - 0.89	<0.23 - 0.7	<0.23 - 0.47	<0.23 - 0.43	<0.25
1,2-Dichloroethane	WAC 0.5	<0.27	<0.27	<0.27	<0.27	<0.18 - 0.3
1,4-Dichlorobenzene	WAC 4.0	<0.25	<0.25	<0.25	<0.25	<0.25
cis-1,2-Dichloroethene	MCL 70	<0.24	<0.24	<0.24	<0.24	<0.24
trans-1,2-Dichloroethene	MCL 100	<0.23	<0.23	<0.23	<0.23	<0.23
Tetrachloroethene	WAC 0.8	**1.9 - 2.2**	**1.0 - 2.0**	**0.94 - 1.2**	<0.17 - **1.2**	0.48 - 0.87
Trichloroethene	WAC 3.0	0.62 - 0.84	0.41 - 0.84	0.33 - 0.54	0.5 - **5.5**(b)	0.23 - 0.5
1,1,1-Trichloroethane	WAC 200	1.6 - 2.4	0.74 - 1.7	1.8 - 2.3	<0.09 - 1.1	0.75 - 1.4
1,1,2-Trichloroethane	MCL 5.0	<0.27	<0.27	<0.27	<0.27	<0.27
1,4-Dioxane	WAC 7.0	<13.0	<13.0	<13.0	<13.0	<13.0

(a) MCL = Maximum contaminant level.
WAC = Washington Administrative Code.
(b) Probable error in sampling or analysis; request for data review filed.
Values in **bold** type equal or exceed WAC 173-200-40.

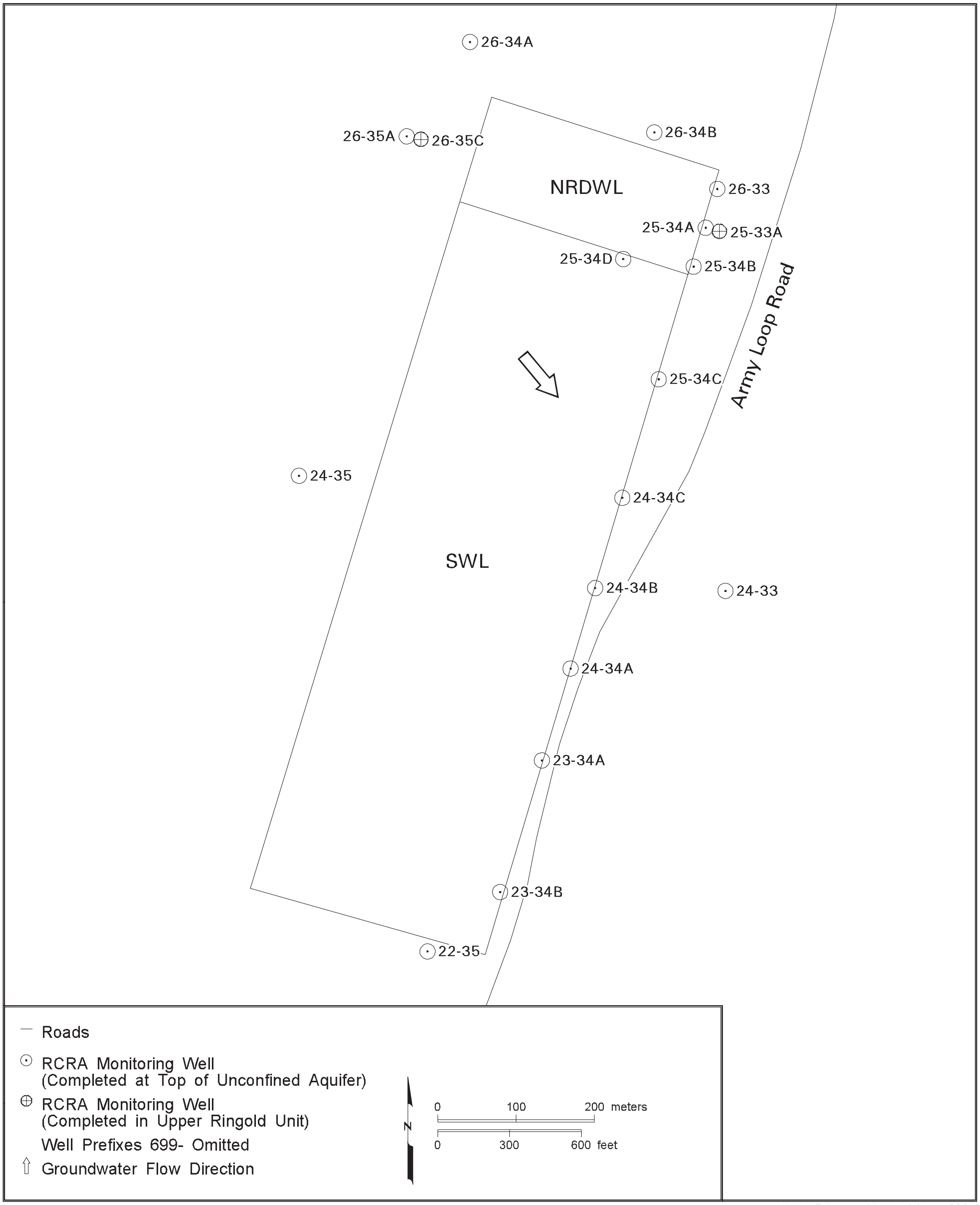


Figure 2.11-1. Groundwater Monitoring Wells at the Central Landfill and Vicinity

2.12 300 Area

J. W. Lindberg and R. E. Peterson

This discussion on the 300 Area is mainly about the 300 Area proper, which includes a *Resource Conservation and Recovery Act* (RCRA) site (the 316-5 process trenches) and is part of a larger groundwater operable unit (300-FF-5). The chapter also includes smaller areas to the north of the 300 Area that are included in the 300-FF-5 Operable Unit. These satellite areas to the north (Figure 2.12-1) include the 618-11 burial ground, 618-10 burial ground, and 316-4 cribs and are discussed in Sections 2.12.7.2 and 2.12.7.3.

Uranium in the 300 Area and tritium at the 618-11 burial ground are the major groundwater contaminants of concern in the 300-FF-5 Operable Unit.

Uranium is the principal contaminant of concern in the 300 Area. A discussion of uranium contamination follows in Section 2.12.2. Tritium contamination from the 200 East Area affected the 300 Area at levels less than the drinking water standard of 20,000 pCi/L (see Section 2.13.2). The 2,000-pCi/L-isopleth line extends through the 300 Area and is in approximately the same position as last year in the west part of the 300 Area. In the east part, the 2,000-pCi/L-isopleth line receded slightly. The major tritium plume flowing southeast from the 200 East Area is discussed in Section 2.9.2.2, and how it affects the Richland North Area is discussed in Section 2.13.2. Additional constituents detected during fiscal year 2002 include nitrate, cis-1,2-dichloroethene, and trichloroethene. Figure 2.12-2 shows the locations of groundwater monitoring wells in the 300 Area and Richland

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Remediation of contaminated burial grounds and liquid waste disposal sites continued in the 300 Area during fiscal year 2002, where uranium is a principal contaminant of concern. Most of the major soil excavation activities are completed, though some backfilling of excavations and ground surface restoration activities remain to be completed. A more comprehensive investigation of uranium along the river shoreline began in summer 2001 and continued in fiscal year 2002, with greater focus on all media (i.e., water, sediment, and biota) through which uranium may be dispersed.

North Area. Contaminants of concern in the groundwater beneath the 618-10 burial ground and 316-4 cribs include uranium, various hydrocarbons, and tributyl phosphate. At the 618-11 burial ground, the contaminant of concern in groundwater is tritium.

2.12.1 Groundwater Flow

Water-table contours in the vicinity of the 300 Area are somewhat concentric, indicating that the 300 Area is a low point or "sink" in the local unconfined aquifer. Groundwater enters the 300 Area from the northwest, west, and southwest (Figure 2.12-3), flows through the 300 Area, and then into the Columbia River. In the immediate vicinity of the 316-5 process trenches, the flow direction was southeast during March 2002 based on the water-table contours (see Figure 2.12-3). Flow rate at the 316-5 process trenches was 0.16 to 46 meters per day (see Appendix A, Table A.2) based on the March 2002 gradient and calculated hydraulic conductivity from aquifer tests (PNL-6716). The southeast flow direction is typically the direction of groundwater flow in the north portion of the 300 Area when the river stage is in a low-to-normal stage. During higher river stages (as in June 2002), the direction of groundwater flow tends to be more south to southwest in the vicinity of the 316-5 process trenches. A water-table map for June 2002 is not shown because the June 2002 water-level measurements were collected from 300 Area wells over an 11-day period (measured at time of groundwater sampling). Water-table maps of the 300 Area are easier to interpret when the water levels are collected in a relatively short period of time such as one day. Over an 11-day period, the 300 Area can experience large and multiple changes in water-table configurations as it did during June 2002.

Monitoring Objectives in 300 Area

Groundwater monitoring is conducted in the 300 Area:

- annually to describe the nature and extent of contamination
- annually to determine if contaminants in the groundwater operable unit are reducing in concentration
- semiannually to determine if contaminants at one RCRA site are reducing in concentration
- semiannually for special studies to describe the nature and extent of groundwater contamination at CERCLA operable unit satellite areas to the north of the 300 Area

The primary influence on water-table elevation in the 300 Area is the fluctuation in Columbia River stage. Changes in river-stage elevation can be correlated to changes in water-level elevations at wells as far as ~360 meters from the river (PNL-8580). During fiscal year 2002, river-stage fluctuations were typical for an average year throughout the majority of the year, and the water-table elevations and corresponding configuration of the water-table map for March 2002 (see Figure 2.12-3) were similar to March water-table maps of previous years. However, the high river stage, typical of June and the spring runoff each year, was higher during June 2002 than it had been since 1997.

During the high river stage of June 2002, the gradient of the water table was reversed along the riverbank for a distance of several hundred meters from the river. In the area of the reversed gradient, groundwater flowed in a nearly reversed direction (southwest) from its normal direction (southeast), and river water moved into the riverbank and mixed with groundwater.

During the high river stage in June 2002, river water flowed into the aquifer and mixed with groundwater near the Columbia River.

The degree of river water/groundwater mixing and the distance from the river that the bank storage extended can be interpreted from measurements of specific conductance. Typically, specific conductance of Columbia River water near the 300 Area is in the range of 120 to 150 µS/cm, whereas groundwater in the upper portion of the unconfined aquifer of the 300 Area typically has a range of 300 to 500 µS/cm. Specific conductance measurements at 300 Area wells during June 2002 showed that mixing was greatest at wells along the shoreline, such as well 399-1-10A, which experienced a change (from a March 2002 measurement) in specific conductance from 466 to 172 µS/cm (see Figure 2.12-2 for well locations). Specific conductance measurements at wells farther from the Columbia River (such as well 399-1-17A near the 316-5 process trenches) dropped only slightly due to only a small amount mixing. The specific conductance lowering at well 399-1-17A from the March to June 2002 measurements was 468 to 315 µS/cm. Wells farther from the river had no significant changes in specific conductance and probably did not experience any mixing with river water.

2.12.2 Uranium

The distribution of uranium in the unconfined aquifer at the beginning of fiscal year 2002 was similar to the August through September 2001 distribution shown in Figure 2.12-4. This map was in last year's annual report and is shown again for comparison with the changes that occurred in June 2002 (Figure 2.12-5). This distribution is the result of several years of relatively stable water-table surfaces in the 300 Area because the river level remained relatively constant throughout that period. However, in June 2002, the spring runoff produced a substantial rise in river level that had a significant impact on the uranium distribution in the 300 Area.

The 316-5 process trenches and 316-1 process pond were waste sites that contaminated groundwater with uranium. The sites have been excavated and contaminant concentrations in groundwater have declined in recent years.

The reported results for uranium from June 2002 sampling showed the effects of the high river stage that was occurring at the same time. The distribution of uranium in the unconfined aquifer changed from the situation shown in Figure 2.12-4 (August through September 2001) to that shown in Figure 2.12-5. Changes to the uranium plume were similar to the changes that occurred in specific conductance in wells near the Columbia River. That is, in areas where there was substantial mixing of groundwater with river water (as near the river at well 399-1-16A), there was a corresponding decrease in uranium concentration (Figure 2.12-6). However, in areas where there was little or no mixing of groundwater with river water (farther from the river as near well 399-3-11), the concentration of uranium increased (Figure 2.12-7). Figure 2.12-8 shows the location of various 300 Area wells and the net increase or decrease in uranium concentration over the previous measurement. The wells closer to the river tend to have a net decrease in uranium concentration, whereas wells farther away show net increases in uranium concentration.

The decrease in uranium concentration in the unconfined aquifer along the Columbia River is caused by dilution of groundwater with river water as river water flows westward and away from the river under the reversed gradient established during the high river stage (see Section 2.12.1). Consistent with this observation is a recent study (PNNL-14022) that reports the mobility of uranium in groundwater/river water mixtures compared to full-strength groundwater is lower. Conversely, PNNL-14022 also reports that uranium mobility in full-strength groundwater (with higher concentrations of calcium carbonate and bicarbonate) is higher than in groundwater/river water mixtures. This could help explain the increased concentration of uranium in June 2002 sampling in areas farther from the river. The higher-than-normal river stage in June 2002 allowed groundwater to enter what formerly was the lower vadose zone and remobilize uranium sequestered there. The water table also rises along the river during high river stages, but the uranium mobility is decreased in the groundwater-river water mixtures, with the result of lower uranium concentration. The two areas of higher concentration of uranium on Figure 2.12-5 correspond to two areas of known disposal of contaminated and radioactive waste liquids, where the vadose zone sediment is likely to be contaminated. The higher concentration to the north corresponds to the 316-5 process trenches, and the higher concentration to the south corresponds to the area of the 307 trenches (316-3) (EMO-1026).

2.12.3 Strontium-90

Strontium-90 has been found as an isolated occurrence at well 399-3-11 in previous years (PNNL-13404). The highest concentration measured in recent years was 8.7 pCi/L in 1995. Since then the concentration levels measured at well 399-3-11 have varied between 3 and 8 pCi/L. Results of sampling well 399-3-11 during fiscal year 2002 ranged from 3.4 and 3.6 pCi/L. The source of strontium-90 is unknown, but it may be the former 307 trenches (316-3) located north-northwest of well 399-3-11.

2.12.4 Chlorinated Hydrocarbons

Trichloroethene, tetrachloroethene, and cis-1,2-dichloroethene were detected at 300 Area wells during fiscal year 2002, but only cis-1,2-dichloroethene exceeded the maximum contaminant level (70 µg/L).

Trichloroethene was detected at 21 wells in the 300 Area in fiscal year 2002, and there are two sources:

- a localized plume confined to one well (399-1-16B), which is downgradient of the 316-5 process trenches and at the bottom of the unconfined aquifer (the source is presumed to be the 316-5 process trenches)
- a plume extending into the 300 Area from a source off the Hanford Site to the southwest and situated in the upper portion of the unconfined aquifer (Figure 2.12-9)

The 316-5 process trenches contaminated groundwater with chlorinated hydrocarbons. Trichloroethene and tetrachloroethene concentrations are declining; however, cis-1,2-dichloroethene exceeded the drinking water standard in one well.

The plume downgradient of the 316-5 process trenches (well 399-1-16B) had a maximum concentration of 2.4 µg/L trichloroethene in March 2002. The concentration has mostly decreased in the well since 1997 and remained steady below 3.0 µg/L for the last 2 years (Figure 2.12-10). The drinking water standard is 5µg/L.

The other plume of trichloroethene, the one extending into the 300 Area from the southwest (see Figure 2.12-9), is detected at wells screened at the water table. The highest concentration in this plume within the 300 Area during fiscal year 2002 was 4.3 µg/L at well 399-4-1. Since 1997, the concentration of trichloroethene at well 399-4-1 has been variable with a range of 2 to 5 µg/L (Figure 2.12-11). The current major source of the trichloroethene in this plume is from offsite, southwest of the Horn Rapids Landfill (see also Section 2.13.4).

A plume of cis-1,2-dichloroethene was detected at five 300 Area wells during fiscal year 2002, but the reported concentrations exceeded the 70 µg/L-maximum concentration limit at only one of those wells, 399-1-16B, screened at the bottom of the unconfined aquifer. The source of the cis-1,2-dichloroethene was probably the 316-5 process trenches and is a degradation product of trichloroethene (Morrison 1998). The concentration is variable in this well with no discernible increase or decrease in trend since 1999 (Figure 2.12-12). During fiscal year 2002, the concentration at well 399-1-16B ranged from 140 to 160 µg/L, which is within the range of the reported values in fiscal year 2001 (130 to 190 µg/L).

The plume of tetrachloroethene (5.0-µg/L maximum contaminant level) is virtually gone from the unconfined aquifer in the 300 Area. From the high concentration of 38 µg/L in 1988, it decreased in concentration to the point where it was detected in only two wells in the 300 Area during fiscal year 2002. Those reported detections were 0.41 µg/L at well 399-3-6 and 0.38 µg/L at well 399-4-11.

2.12.5 Nitrate

Nitrate above background levels (WHC-EP-0595, Table A-1-2) was detected in all wells in the 300 Area that sampled the upper portion of the unconfined aquifer during fiscal year 2002 (Figure 2.12-13). However, only two wells had reported nitrate results greater than the 45-mg/L maximum contaminant level.

Those wells were 399-5-1 and 699-S27-E14 in the southwest part of the 300 Area. The highest reported result for that well in fiscal year 2002 was 89.9 mg/L in a sample collected March 2002. The source of the nitrate is probably offsite industry and agriculture (see also Section 2.13.3).

2.12.6 RCRA Parameters for the 316-5 Process Trenches

Since 1997, the 316-5 process trenches have been monitored by a RCRA final status corrective-action network (WAC 173-303-645). Corrective action is in conjunction with the *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA) (see Section 2.12.7). The 316-5 process trenches modified closure/post-closure plan (DOE/RL-93-73) was approved and incorporated into the Hanford Site RCRA Permit (DOE/RL-88-21) in fiscal year 1997. In May 1998, closure activities at the 316-5 process trenches were completed, and post-closure care began. Post-closure care will continue for a 30-year period, culminating in post-closure certification in fiscal year 2028. The purpose of groundwater monitoring is to examine the trend of the contaminants of concern to determine if they decrease in concentration as expected. Eleven wells were monitored during fiscal year 2002 for uranium and volatile organics (including as a minimum, the contaminants of concern, trichloroethene, cis-1,2-dichloroethene, and tetrachloroethene) (see also Appendix A, Section A.1.10 and Table A.18). Additional information about groundwater contamination is in the general discussion of contaminants earlier in this chapter.

RCRA corrective-action groundwater monitoring at the 316-5 process trenches employs an alternative monitoring approach. A 2-year demonstration of the alternative approach will determine whether it will be used in the future.

During fiscal year 2002, uranium remained above the maximum contaminant level (30 µg/L) in 6 of the 11 wells that monitor the upper portion of the unconfined aquifer near the water table. Those wells are 399-1-7, 399-1-10A, 399-1-11, 399-1-16A, 399-1-17A, and 399-1-21A. Regardless of the temporary changes in the distribution of uranium in the 300 Area due to river-stage fluctuations, the overall trend in most 316-5 process trenches network wells is decreasing concentrations. Trichloroethene and tetrachloroethene exceeded maximum contaminant levels in previous years but not in fiscal year 2002. Tetrachloroethene is no longer detected in any 316-5 process trenches network wells. For more information about uranium and volatile organics in 300 Area wells, see Sections 2.12.2 and 2.12.4.

2.12.7 300-FF-5 Operable Unit

Groundwater monitoring at the 300-FF-5 Operable Unit continued in fiscal year 2002 under a revised operation and maintenance plan for the 300-FF-5 Operable Unit (DOE/RL-95-73) and a sampling and analysis plan that implements requirements for fiscal year 2002 (DOE/RL-2002-11). The operable unit includes groundwater beneath the 300 Area, the 618-10 burial ground and adjacent 316-4 cribs, and the 618-11 burial ground (EPA 2000; see Figure 2.12-1).

The record of decision for the operable unit (ROD 1996b) includes as interim action characterizing the level of contamination and how natural processes are affecting the level. The scope for groundwater activities has been expanded in the revised operations and maintenance plan (DOE/RL-95-73) to include gathering more information on (1) the recharge of mapped plumes because of release from the vadose zone, (2) the characteristics of discharge from the aquifer to the Columbia River, and (3) dispersal of contaminants in the river environment via biotic pathways. The intent during the interim action period is to build a technical basis for including monitored natural attenuation as a component in a future record of decision for final groundwater remedial action.

The CERCLA process includes a requirement for the U.S. Environmental Protection Agency (EPA) to review the effectiveness of their records of decision every 5 years. The results of the first 5-year review (EPA 2001) indicated that the remedial actions at 300 Area source waste sites were proceeding in an effective manner to protect human health and the environment. EPA re-affirmed that the cleanup goals and remedy selection for groundwater are still appropriate at the time the 5-year review was released. The next 5-year review by EPA will be conducted during fall 2004 through spring 2005.

2.12.7.1 300 Area Plumes

New studies during fiscal year 2002 at the 300 Area provided a greater understanding of the distribution of uranium. The results of the studies will benefit future contaminant modeling of uranium movement through the vadose zone and aquifer.

The 300-FF-5 Operable Unit contaminants of concern beneath the 300 Area proper are uranium, chlorinated hydrocarbons (e.g., trichloroethene), and nitrate. Strontium-90 is detected at one location (well 399-3-11). The current distribution of these contaminants is described in Sections 2.12.2 through 2.12.5. Also, the results of RCRA-prescribed monitoring of the 316-5 process trenches are described in Section 2.12.6; uranium and volatile organic compounds are the RCRA constituents tracked.

New work involving the mobility of uranium in 300 Area soil was completed during fiscal year 2002 (PNNL-14022). The results provide an understanding of distribution coefficients for uranium, which vary depending on the geochemical environment and on whether uranium is being adsorbed or desorbed from sediment. The immediate application of these results involves predicting the exposure caused by residual amounts of uranium that remain after source excavation and backfill (BHI-01667). The new information will also benefit future contaminant transport modeling of uranium movement through the vadose zone and aquifer. This type of modeling will begin during fiscal year 2003 to support characterizing the change in the level of uranium contamination with time.

Also new for fiscal year 2002 are the results of a detailed investigation of contaminants at the groundwater/river interface along the 300 Area shoreline. This investigation was a joint effort involving the Washington State Department of Health and Pacific Northwest National Laboratory's Surface Environmental Surveillance Project (PNNL-13692). The investigation tracked 300 Area contaminants along the pathway that includes groundwater near the river, riverbank springs, nearshore river water, shoreline sediment, and nearshore biota. Key findings include

- No apparent impact to people using the river or shoreline from external radiation originating at the 300 Area. External radiation exposure along the 300 Area shoreline comes from background radiation.
- Contaminants transported by groundwater away from 300 Area sources can be identified in water, solids, and biota along the 300 Area shoreline, but at concentrations that are below applicable standards for nearly all samples collected.
- Clams were shown to be particularly effective indicators of chromium, selenium, and uranium.

This investigation (PNNL-13692) was not designed to directly support the objectives of the 300-FF-5 operations and maintenance plan (DOE/RL-95-73), though the results do provide significant new information that is relevant to future monitoring at the interface, and to assessing the risk posed to the river ecosystem. Additional description of this investigation is provided in Section 2.12.8.

Groundwater samples from a well near the 618-10 burial ground and 316-4 cribs contain uranium and petroleum products. In fiscal year 2002, concentrations generally declined and are below the relevant drinking water standards.

2.12.7.2 618-10 Burial Ground and 316-4 Cribs

The 618-10 burial ground and 316-4 cribs are waste sites within the 300-FF-2 Operable Unit. The sites are located ~3.6 kilometers southeast of the 400 Area (see Figure 2.12-1). Groundwater flow is generally to the east as inferred from the regional scale water-table map (see Figure 2.1-1). A location map for the area near these waste sites is shown in Figure 2.12-14. In addition to groundwater monitoring wells, two cone penetrometer boreholes were advanced to groundwater in 1995, and soil-gas sampling tubes were installed along the southeast perimeter of the burial ground in 2002 (see Section 3.3.8). Two new groundwater monitoring wells are planned for installation during early 2003 along the downgradient side of the 618-10 burial ground.

A description of each of these past-practices facilities is presented in the technical baseline report completed in 1994 for the 300-FF-2 Operable Unit (BHI-00012). The 618-10 burial ground operated between 1954 and 1963, and the 316-4 cribs operated between 1948 to 1956. The characterization history includes a limited field investigation (DOE/RL-96-42) that occurred during the period 1994 through 1996, which included groundwater sampling and refurbishment of well 699-S6-E4A. In 1995, a relatively high concentration of uranium (768-µg/L, unfiltered sample) was detected in well 699-S6-E4A, along with hydrocarbons (possibly diesel), and tributyl phosphate. This well is adjacent to the 316-4 cribs, which are the most likely source for these contaminants. The limited field investigation report noted that the levels of contamination observed at that time may not accurately represent aquifer conditions because of refurbishment activities in the well. (The vadose zone in the vicinity of the crib and well is very likely to contain uranium, organic solvents, and petroleum hydrocarbons as a result of past disposal practices.) No direct evidence of groundwater contamination as a consequence of releases from the burial ground was found. The limited field investigation also included a surface geophysical survey in 1995 of the 316-4 cribs (BHI-00212) and of the 618-10 burial ground in 1997 (BHI-00291).

In 2002, soil-gas investigations at the 618-10 burial ground detected some tritium but not at levels found near the 618-11 burial ground in 1999.

There is essentially no monitoring well coverage for a large portion of the area immediately downgradient from the burial ground. Because of discoveries made at the 618-11 burial ground (PNNL-13228) and the possibility for similar conditions to exist at 618-10 burial ground, additional investigations were conducted in 2002, along with a decision to install two new groundwater monitoring wells. In September 2002, a survey of helium isotopes in soil gas along the southeast perimeter of the burial ground was conducted. If tritium is being released from the vertical pipe units in the burial ground, or if a plume exists in groundwater, either situation should be revealed by anomalously high ratios of helium-3 (decay product of tritium) to helium-4 (stable natural background). The results indicated the presence of some tritium, but at levels much lower than those found near the 618-11 burial ground (Section 3.3.8 provides a more detailed account of this vadose zone survey).

Groundwater conditions near the 316-4 cribs are monitored by well 699-S6-E4A, which was refurbished in 1995. Contaminants of concern for this waste site (e.g., uranium, volatile organic compounds, and petroleum hydrocarbons) were anomalously high immediately following maintenance activities; since then, concentrations show a long-term general decline (Figures 2.12-15 and 2.12-16). Current concentrations at the well include the following:

- uranium (~15 µg/L)
- tributyl phosphate (undetected)
- total petroleum hydrocarbons (diesel range, undetected; gasoline range, undetected)

Oil and grease was detected in several samples in 2000 and 2001, but there are quality control questions with the results, which were variable; the most recent analysis indicates undetected concentrations. Gross beta is somewhat elevated in samples, with current concentrations ~20 pCi/L. The 316-4 cribs, with tritium concentrations ~17,000 pCi/L, are at the edge of the site-wide tritium plume, which originates in the 200 East Area.

The uranium at well 699-S6-E4A is highly depleted in uranium-234 and uranium-235 (PNNL-13404). Although details of disposal to the burial ground and cribs are sketchy (WHC-MR-0415), the waste is known to have come from 300 Area operations, and depleted uranium is known to have been used there. The presence of uranium-236 suggests that a portion of the uranium has been irradiated in a reactor.

2.12.7.3 618-11 Burial Ground

The 618-11 burial ground is located a short distance west of the Energy Northwest reactor complex (see Figure 2.12-14). The burial ground was active from 1962 to 1967 and received a variety of low and high activity solid waste from the 300 Area. The Waste Information Data System description of this site identifies numerous contaminants of concern (e.g., cesium, cobalt, curium, plutonium, strontium, uranium, and zirconium). Other contaminants that might be encountered include aluminum-lithium, beryllium, carbon tetrachloride, hydrogen gas, sodium-potassium eutectic, and thorium.

The tritium concentrations in a well downgradient of the 618-11 burial ground continued to decline during fiscal year 2002. The narrow tritium plume extends ~900 meters east-northeast from the burial ground.

The water-table gradient beneath the 618-11 burial ground suggests movement of groundwater toward the east (see Figure 2.1-1). Lithologic variability suggests that groundwater flow may be diverted to the northeast or southeast from the easterly direction indicated by gradient alone. The presence of low permeability sediment is believed to explain the area of low tritium concentrations surrounding this region (see Figure 2.1-3).

Tritium was detected at a level up to several million pCi/L immediately downgradient of the 618-11 burial ground at well 699-13-3A in early 1999 (Figure 2.12-17). Prior to this time, monitoring for radionuclide contamination consisted of analyzing for gross alpha, gross beta, and uranium (the burial ground was not expected to be a source of tritium). A special investigation of the groundwater near the site followed the unexpected discovery of high tritium concentrations (PNNL-13228). It was determined that the burial ground was the likely source for the tritium plume, which is shown in Figure 2.12-18. Other radionuclides detected during the initial investigation included carbon-14, nickel-63, and technetium-99 though all were at very low concentrations. For chemical constituents, nitrate is the only contaminant other than tritium that exceeds the drinking water standard, with several wells downgradient of the burial ground revealing nitrate concentrations in the range 40 to 90 mg/L. One Energy Northwest monitoring well (well C3079; ENW #9) shows anomalously high concentrations, with recent results at ~145 mg/L. Traces of carbon tetrachloride were also found during the initial investigation.

The investigation of tritium at the 618-11 burial ground during fiscal year 2001 defined the lateral and vertical extent of the groundwater contamination. The investigation relied on collecting groundwater samples, and also on collection of soil-gas samples. Helium-3/helium-4 ratios were determined for these samples and excess helium-3 was interpreted as an indication of a nearby tritium source. The excess helium-3, a decay product of tritium, is believed to have come from buried tritium sources in the burial ground and from the underlying groundwater plume (PNNL-13675).

The fiscal year 2001 study defined a plume that is narrow and extends ~900 meters east-northeast of the burial ground (see Figure 2.12-18). Tritium was detected throughout the unconfined aquifer above a silt layer, which occurs at a depth of ~14 meters below the water table in well 699-13-2D. Based on the mapped extent of the plume, its approximate thickness, and concentrations during fiscal year 2001, the plume is estimated to contain 190 to 285 curies of tritium (0.020 to 0.029 gram).[(a)]

Water supply wells east of the 618-11 burial ground probably played a large role in determining the shape of this tritium plume. Wells 699-13-1A and 699-13-1B were used for water supply during construction of the Columbia Generating Station in the 1970s and early 1980s. Tritium was detected at concentrations up to 1.4 million pCi/L in well 699-13-1A in the late 1970s. The narrow plume tracks directly through the location of this well so it appears that the well drew the plume over from the burial ground. The gradients induced by the pumping would cause the transport of tritium down through the unconfined aquifer. The supply wells, in this scenario, would have captured the contamination until the wells were replaced by an alternate source for water, i.e., river water was subsequently used for reactor complex needs. Following shutdown of the water supply wells, the plume would be able to move further east under natural gradients. Groundwater velocity under the natural gradient is considerably slower than under the well pumping.

Estimates indicate a travel time in the range 43 to 166 years for the 618-11 tritium plume to reach the Columbia River. Most or all of the tritium will likely decay to less than the drinking water standard before the plume reaches the river.

The conceptual model described above has been used as a basis to estimate travel time from the burial ground to the Columbia River, with a resulting estimate of 166 years.[(b)] Additional methods were used that involved alternative assumptions, and provided a range of 43 to 129 years for travel time. The calculations indicate that tritium concentrations will most likely decay to less than the drinking water standard by the time the plume reaches the Columbia River. The plume is not expected to affect active water supply wells in the vicinity because none are operating in the plume's flow path.

2.12.8 Monitoring at the River Shoreline

During the late summer and fall of 2001, an extensive investigation of contamination along the 300 Area shoreline was conducted as a cooperative effort involving the Washington State Department of Health and Pacific Northwest National Laboratory's Public Safety and Resource Protection Program. The investigation involved sampling near-river groundwater, riverbank seepage, shoreline sediment, riverbed pore water, river water, and biota. The objective was to search for contaminants in the various media sampled and, if found, to determine if the contaminants presented a risk to humans and to plant and animal life. The study found no indication of previously undetected sources that may pose such a risk. A description of the investigation methods, the data obtained, and interpretations are presented in PNNL-13692, from which the following summary is taken.

The Washington State Department of Health and Pacific Northwest National Laboratory recently conducted an extensive investigation of contamination along the 300 Area shoreline. The study found no indication of previously undetected sources that may pose such a risk.

The wide variety of media sampled and the increased geographic coverage of the shoreline environment provided a more detailed understanding of contamination from groundwater to the 300 Area river environment. Although some constituents carried by groundwater to the shoreline were measured above background levels, most did not exceed applicable human health and ecological safety

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(a) Letter report from J. V. Borghese, W. J. McMahon, and R. W. Ovink (CH2M HILL Hanford Group, Inc.) to the U.S. Department of Energy, Richland, Washington, *Tritium Groundwater Investigation at the 618-11 Burial Ground, September 2001*, dated September 2001.

(b) Letter report from P. E. Dresel and M. P. Bergeron (Pacific Northwest National Laboratory) to U.S. Department of Energy, Richland, Washington, *Evaluation of the Impact of Tritium Contamination in Groundwater from the 618-11 Burial Ground at the Hanford Site*, dated December 20, 2001.

criteria. The exceptions are water samples from prominent riverbank seepage sites, which are monitored regularly by the Surface Environmental Surveillance Project (seepage sites S3-42-2 and S3-DR-42-2). At these sites, uranium and gross alpha exceeded the relevant standards (i.e., 30 µg/L for uranium and 15 pCi/L for gross alpha). Within the river itself, only a single sample revealed uranium and gross alpha above standards; this was at a river sampling site adjacent to seepage site S3-DR42-2. The low concentrations measured in river water samples reflect the rapid mixing that occurs between groundwater and river water at the interface. Uranium and gross alpha have been identified previously as contaminants of concern in groundwater beneath the 300 Area.

Many constituents of concern in 300 Area groundwater were not detected in plants and animals collected from the shoreline, even when specialized analysis methods were used to achieve very low detection levels. Clams were determined to be a good indicator of where contaminated groundwater discharges to the riverbed environment, because they do not move around very much and live for a relatively short period of time (i.e., ~2 years).

Data from the study appear to verify that groundwater discharges to identifiable zones of the riverbed. As a generalization, groundwater from the Hanford aquifer discharges to the riverbed through half (or less) of the channel, i.e., from the shoreline out to the deepest part of the channel. Flow-path modeling also indicates that groundwater discharge is not evenly spread along the Hanford half of the riverbed, but is focused in the area immediately offshore. The impact of 300 Area groundwater discharge on Columbia River water quality was determined by collecting samples from a cross-river transect. All results showed concentrations that were lower than applicable ambient surface water quality criteria levels for radionuclides, anions, and metals. The highest uranium concentration was found in a sample collected near the Franklin County shoreline. Elevated uranium concentrations at this location are most likely caused by leaching of fertilizers applied to nearby fields (uranium is commonly present in the minerals used for fertilizer).

Uranium concentrations continued to exceed the drinking water standard in fall 2001 at aquifer tubes along the 300 Area shoreline.

Constituents of interest in 300 Area groundwater that appear at shoreline monitoring sites are summarized in Table 2.12-1. The data span the period of late summer 2001 to early fall 2002, which includes the time frame for the shoreline investigation described above. The results presented in the table are consistent with expectations based on observations in near-river monitoring wells. Additional samples of riverbank seepage and river water were obtained in October 2002, and results will be reported in the next Hanford Site Environmental Surveillance report.

Table 2.12-1. Shoreline Monitoring Data for the 300 Area, Fiscal Years 2001 and 2002

Location Name	Sample From[a]	Sample Date[b]	Specific Conductance (µS/cm)[c]	Gross Alpha (pCi/L)	Gross Beta (pCi/L)	Nitrate (mg/L)	Strontium-90 (pCi/L)	Technetium-99 (pCi/L)	Tritium (pCi/L)	Uranium (µg/L)[d]
300 SPR 7-1										
(2.5 ft)	Tube	09/18/01	360					U	7,560	192
(4 ft)	Tube	09/18/01	358					9.9	8,020	95
(6 ft)	Tube	09/18/01	390					25.9	8,390	98
300 SPR 7-2										
(2 ft)	Tube	09/18/01	384					9.1	8,420	95
(4.2 ft)	Tube	09/18/01	390					U	8,660	106
300 SPR 9-1										
(2 ft)	Tube	09/17/01	344					9.4	6,060	101
(4 ft)	Tube	09/17/01	387					20.2	7,590	149
300 SPR 9-2										
(2 ft)	Tube	09/17/01	388					12.0	7,800	163
(4.5 ft)	Tube	09/17/01	387					11.4	7,620	162
300 SPR 9-3										
(5.5 ft)	Tube	09/17/01	360					10.7	7,160	210
S3-42-2 (SPR 7)	Seep	08/27/01	327	27.0	16.0				6,300	42
S3-42-2 (SPR 7)	Seep	09/18/01	353					10.6	7,410	50
S3-DR42-2 (SPR 9)	Seep	08/27/01	390	86.8	32.7				8,380	152
S3-DR42-2 (SPR 9)	Seep	09/17/01	357					10.1	6,940	105
R3-431-T1	River	09/13/01				0.23	0.1		43	1
R3-431-T1	River	09/10/02				0.30	0.1		43	1
R3-415-SHR	River	09/13/01				0.30	0.1		135	1
R3-415-SHR	River	09/10/02				0.30	0.1		65	1
R3-421-SHR	River	09/13/01				1.10	0.1		547	1
R3-421-SHR	River	09/10/02				0.32	0.1		70	1
R3-425-SHR	River	09/13/01				0.29	0.1		103	1
R3-425-SHR	River	09/10/02				0.30	0.1		45	1
R3-429-SHR	River	09/13/01				0.24	0.1		49	1
R3-429-SHR	River	09/10/02				0.26	0.1		34	1
R3-421-SHR (42-2)	River	08/27/01		9	9		U	7.0	4,540	15
R3-424-SHR (DR42-2)	River	08/27/01		70	25		U	15.0	4,850	87
R3-427-SHR (Spr-11)	River	08/27/01		9	4		U	1.3	450	14

U = Below detection limit.

(a) Tube = aquifer sampling tube near shoreline; Seep = riverbank seepage; River = nearshore river water.

(b) Data from August through September 2001 (fiscal year 2001) included to provide comparison for October 2001 (fiscal year 2002).

(c) Specific conductance provides an indication of the amount of river water in the sample; uncontaminated groundwater is typically in the range of 350 to 450 µS/cm and river water in the range of 120 to 150 µS/cm.

(d) Sum of individual isotope concentrations (^{234}U, ^{235}U, and ^{238}U) in pCi/L, divided by 0.68 to convert activity to mass.

Data sources: Hanford Environmental Information System, various project records, and the Washington State Department of Health.

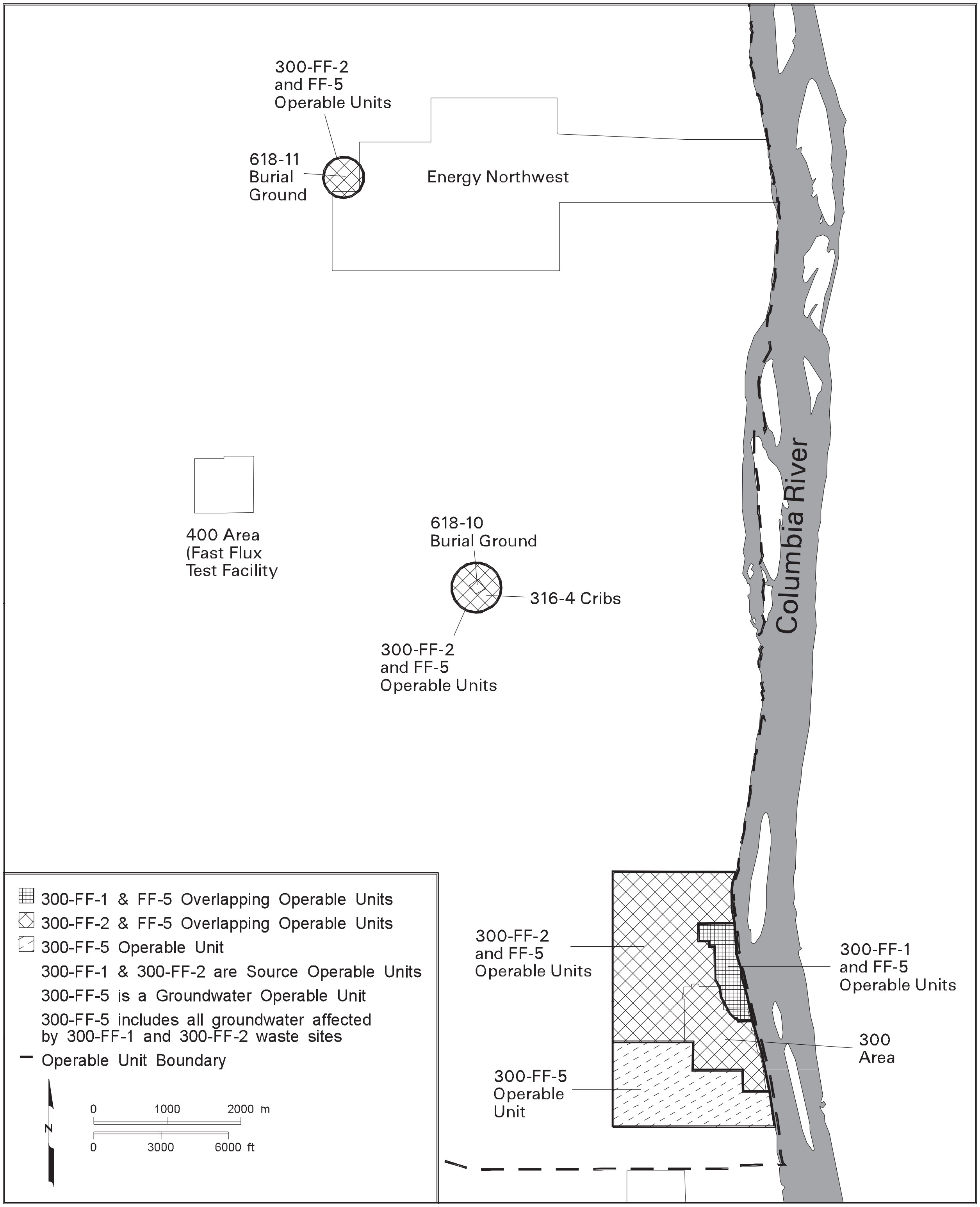

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Figure 2.12-1. Locations of the 300-FF-1, 300-FF-2, 300-FF-5 Operable Units; 618-10 Burial Ground; 316-4 Cribs; and 618-11 Burial Ground

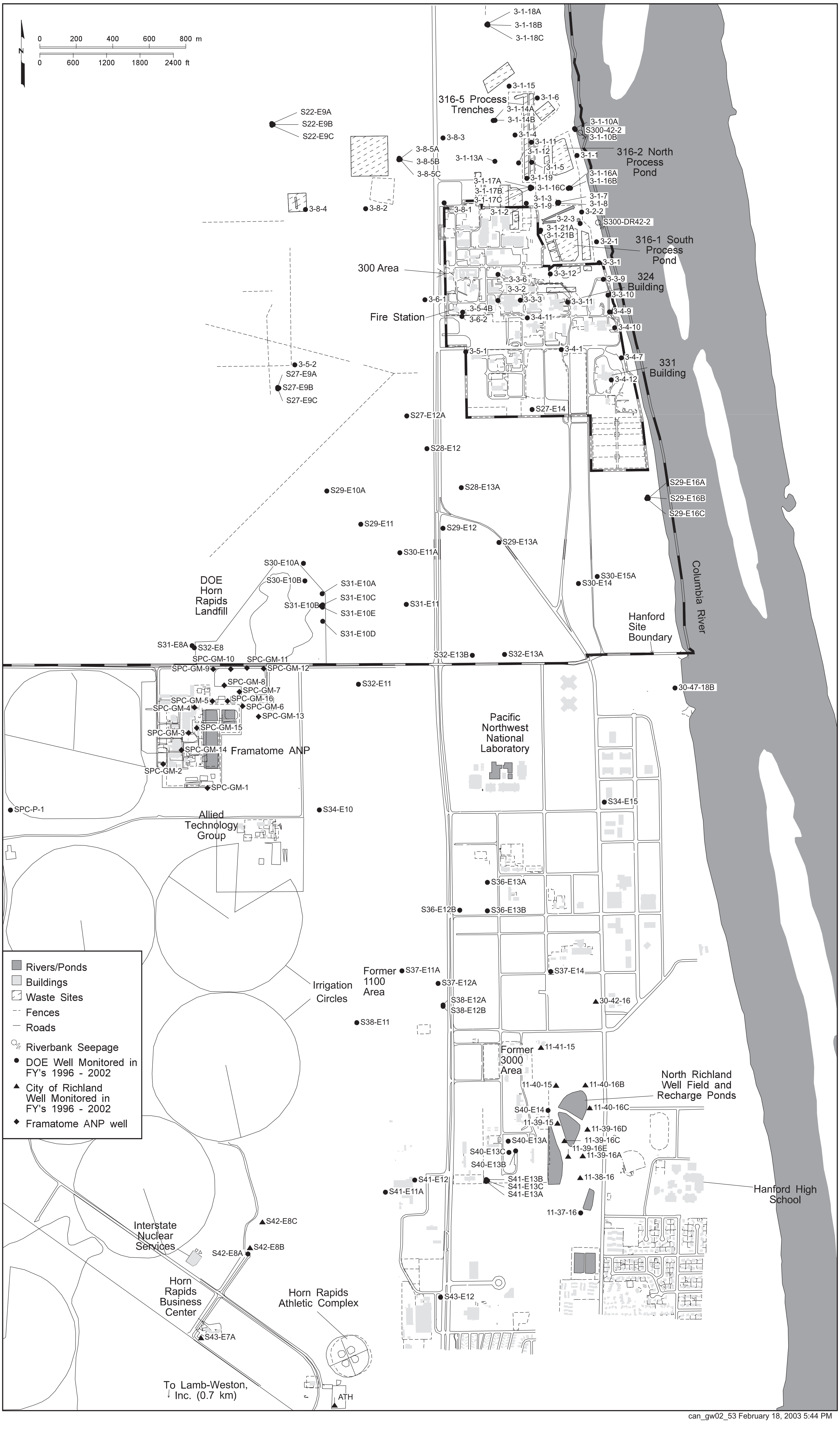

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Figure 2.12-2. Groundwater Monitoring Wells at the 300 and Richland North Areas

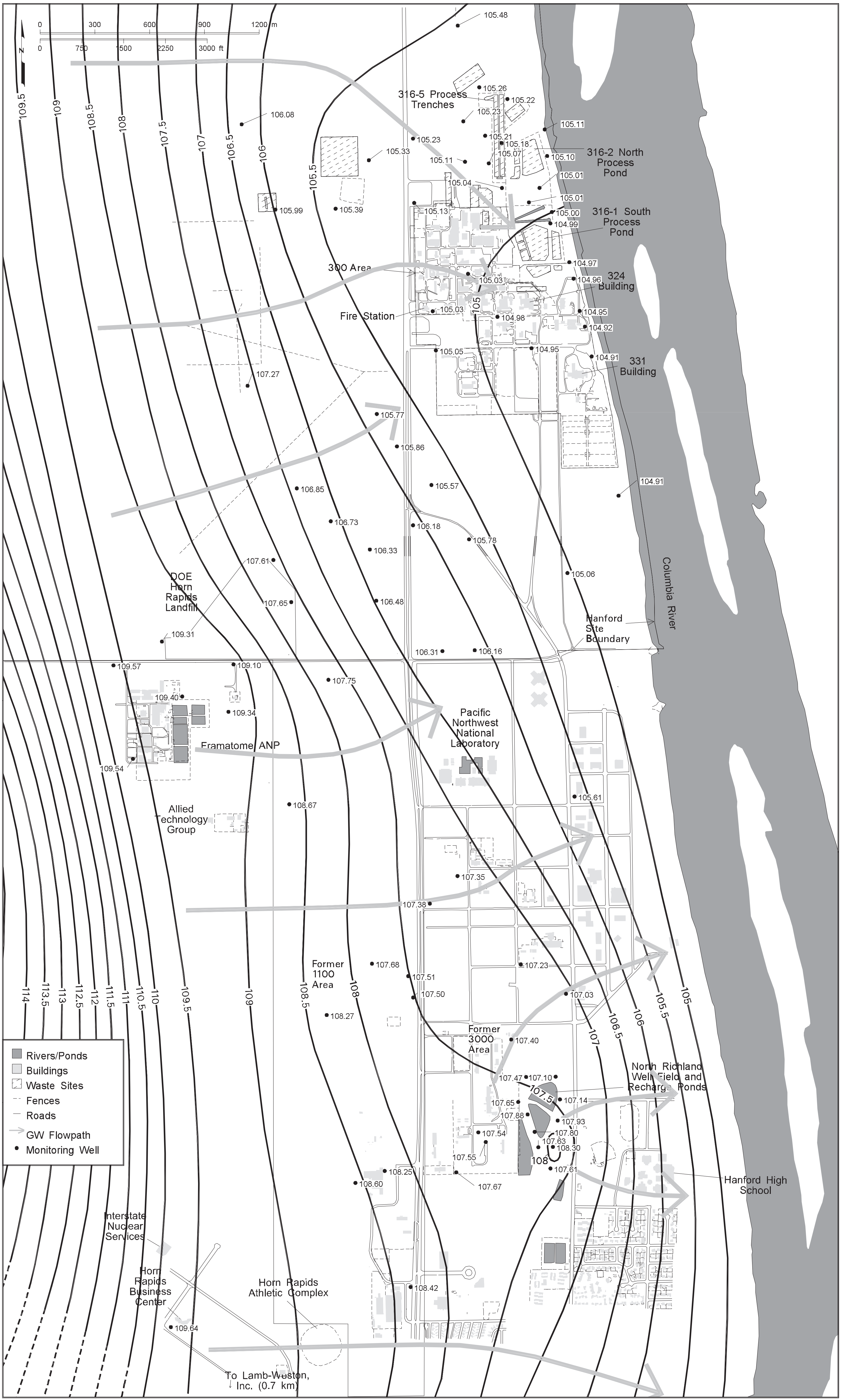

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Figure 2.12-3. Water-Table Map of the Richland North and 300 Areas, March 2002

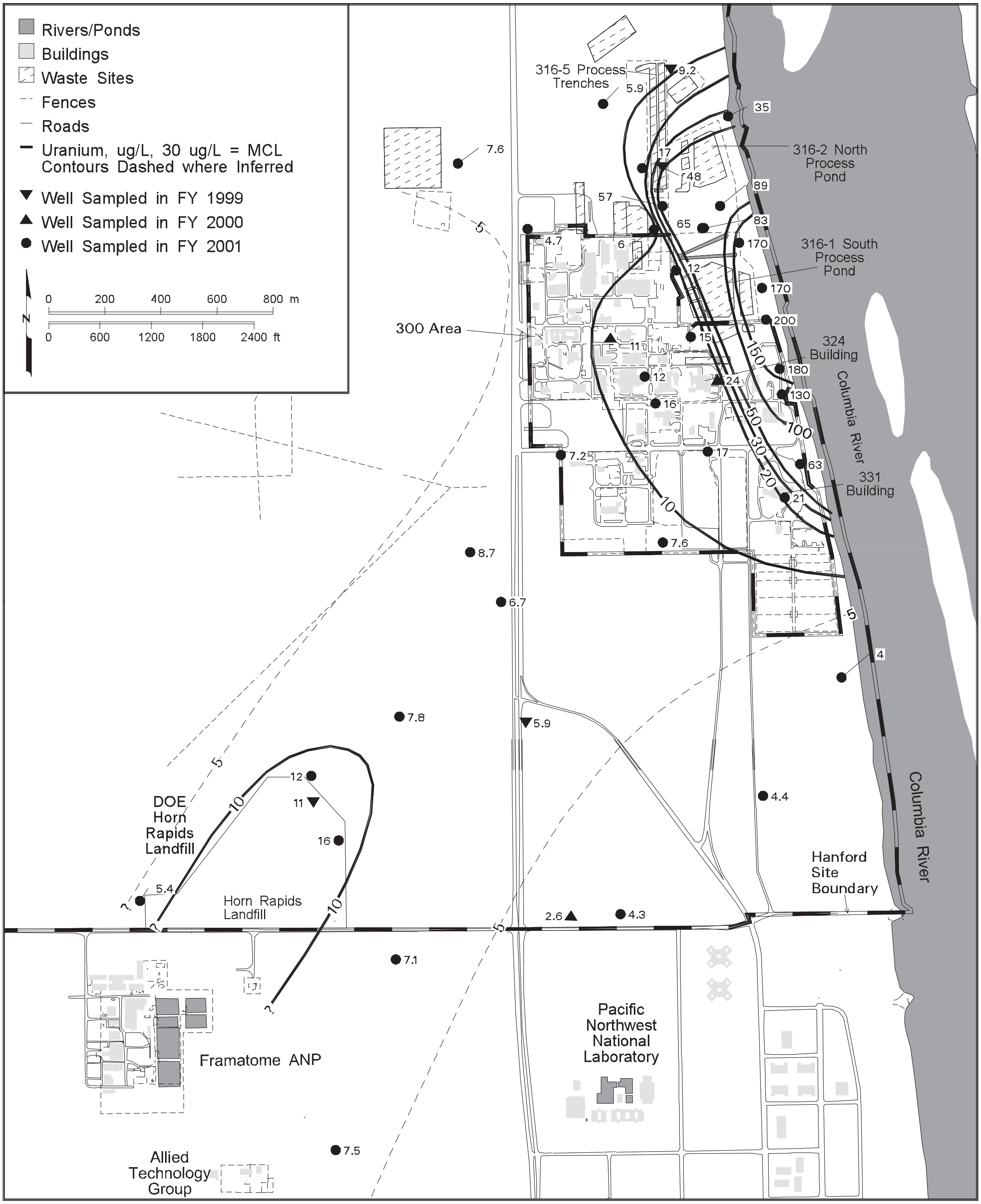

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Figure 2.12-4. Uranium Concentrations in the 300 Area, Top of Unconfined Aquifer, August Through September 2001

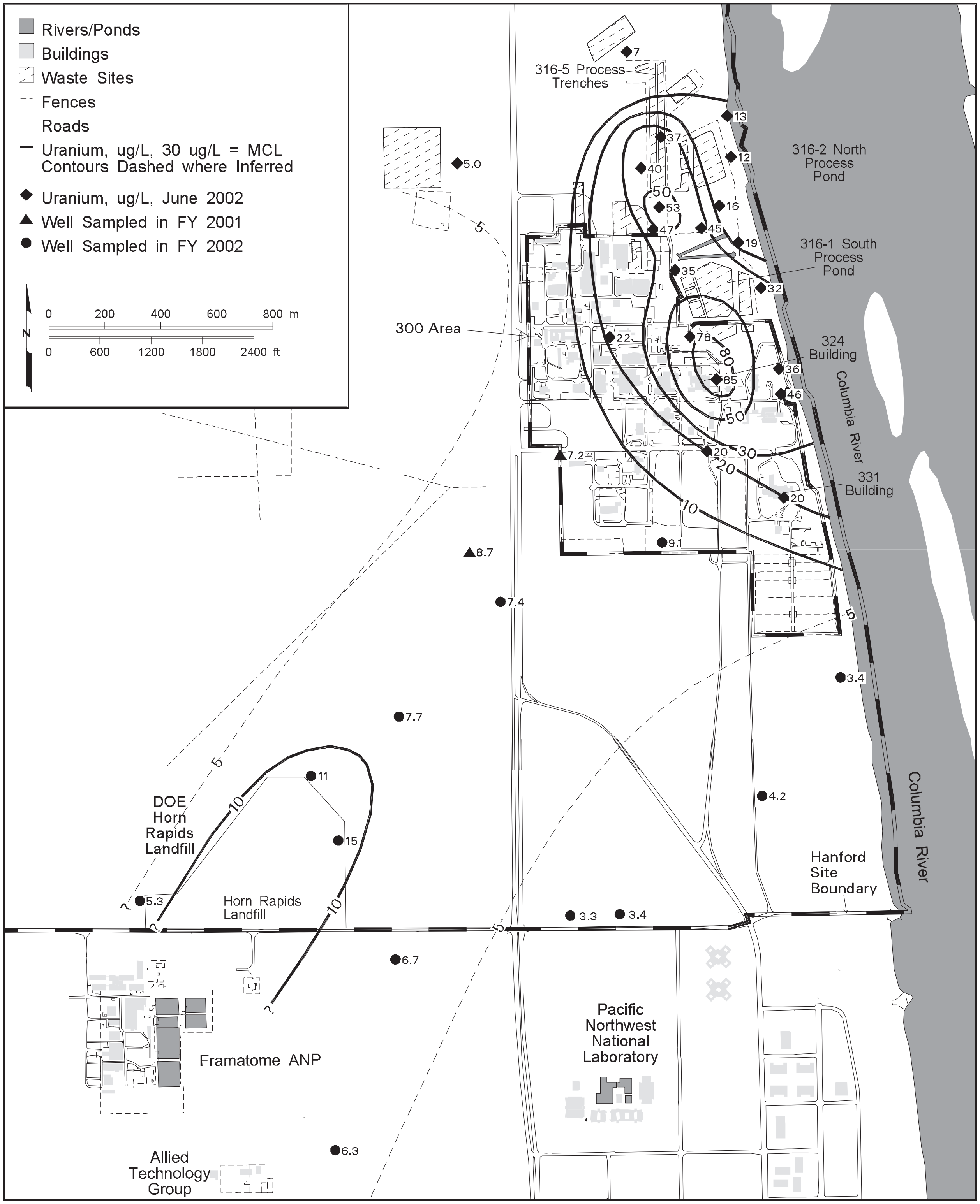

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Figure 2.12-5. Uranium Concentrations in the 300 Area, Top of Unconfined Aquifer, June 2002

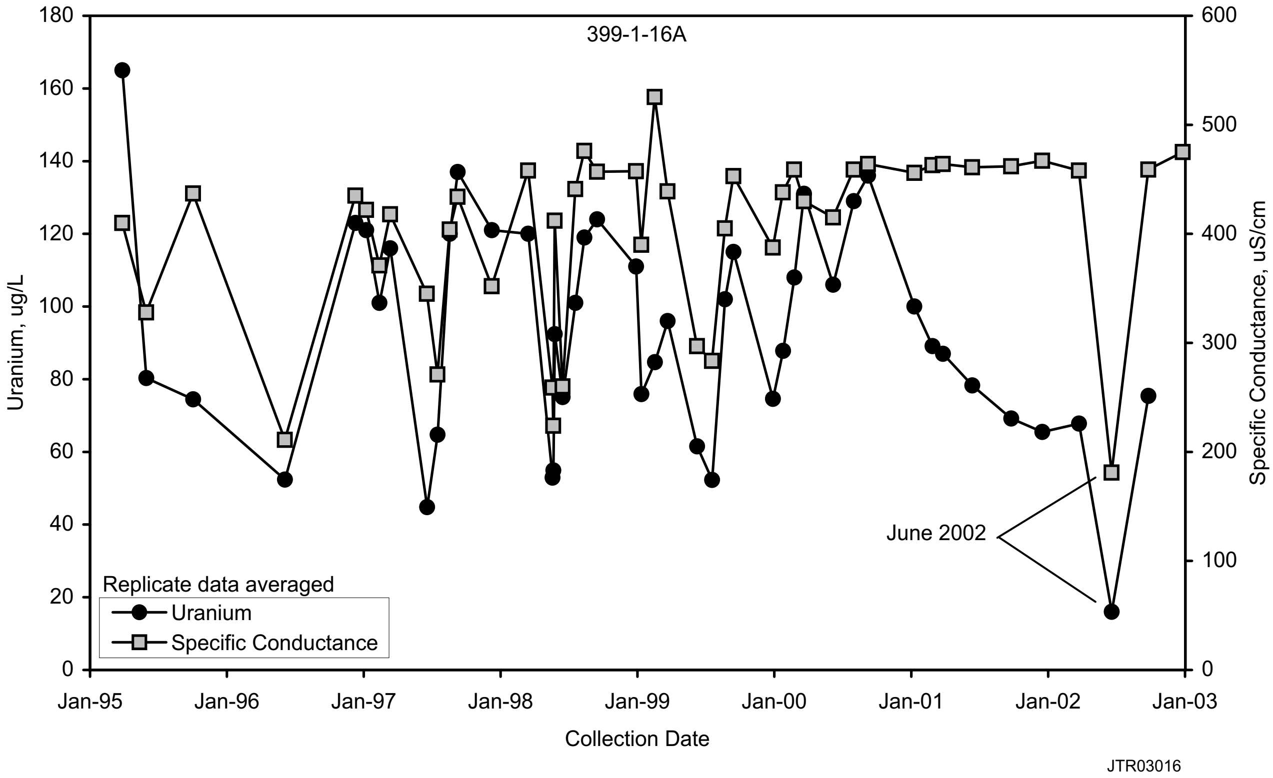

Figure 2.12-6. Uranium Concentrations Downgradient of the 316-5 Process Trenches

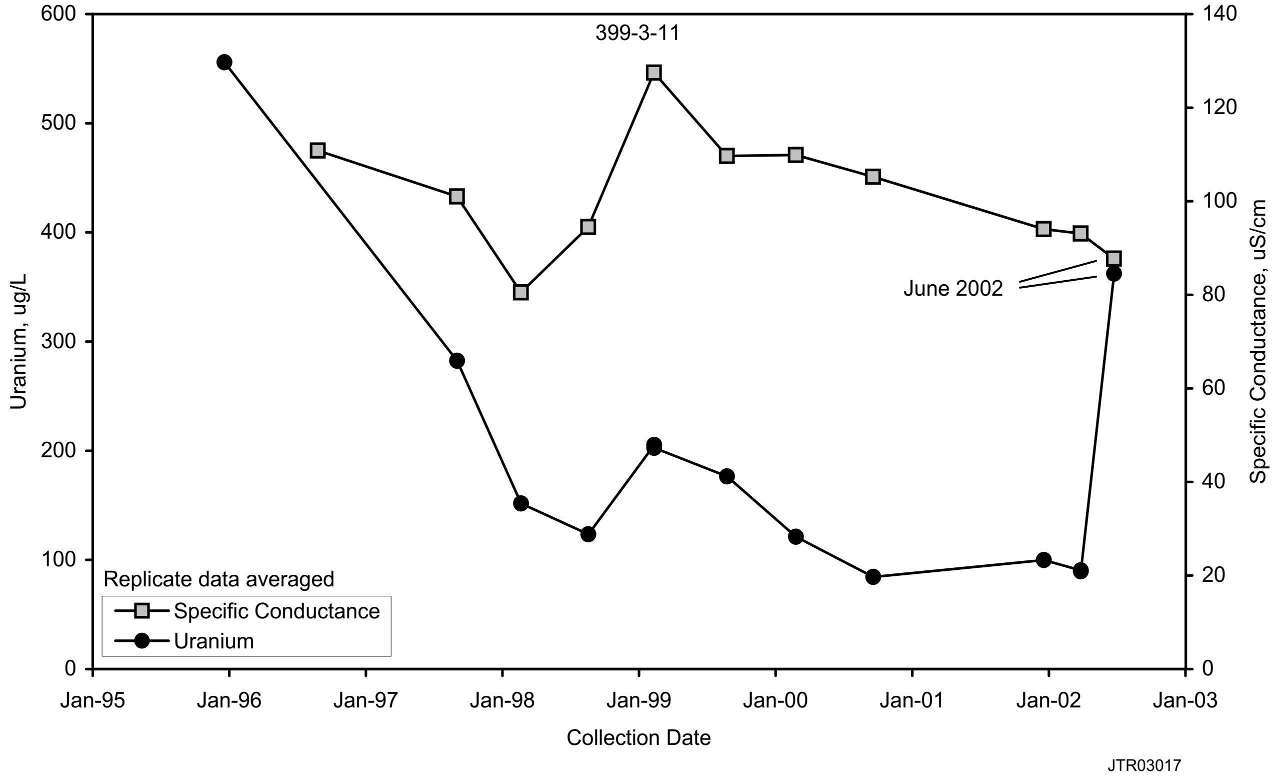

Figure 2.12-7. Uranium Concentrations Near the 324 Building

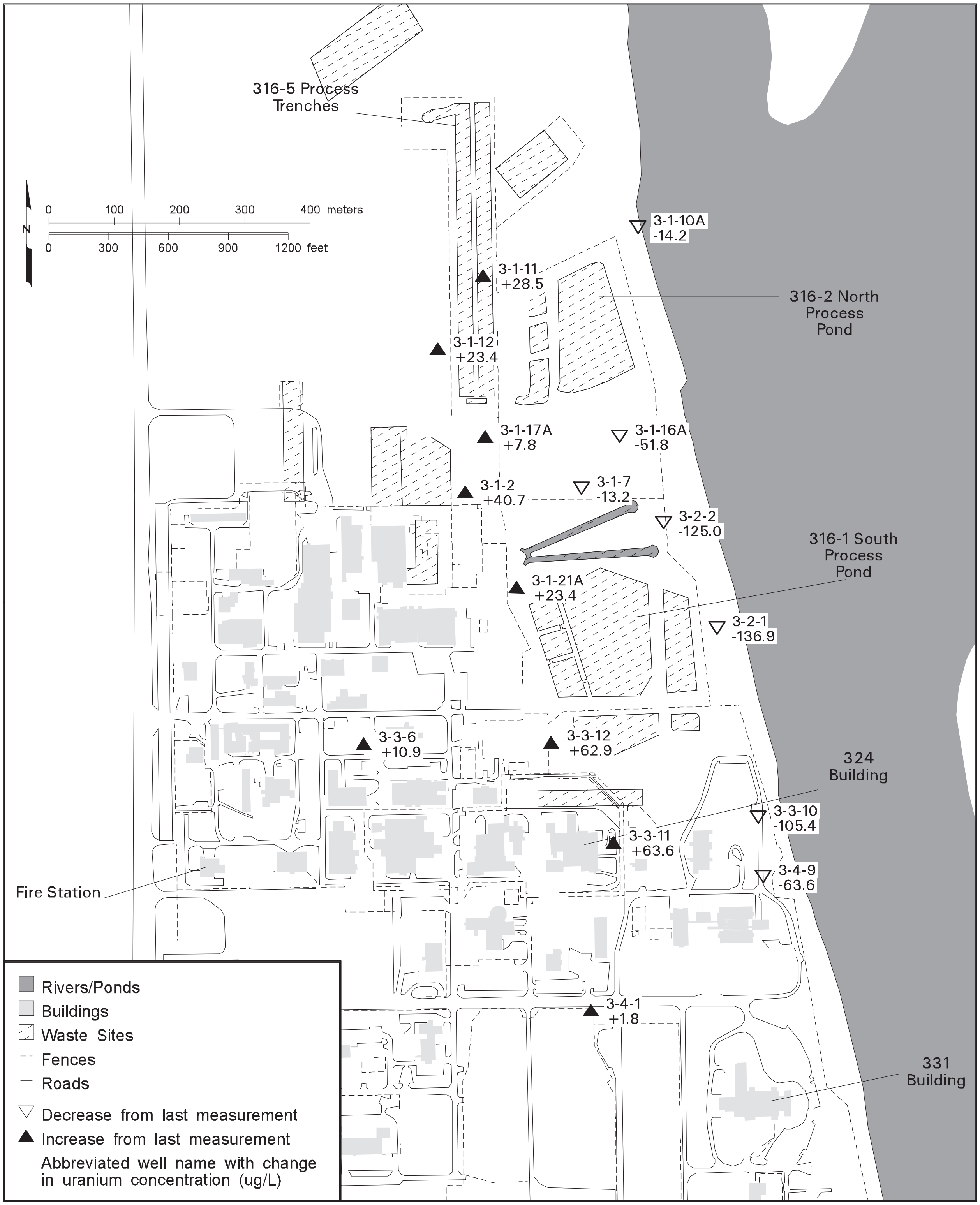

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Figure 2.12-8. Net Change in Uranium Concentrations at 300 Area Wells Between June 2002 and Previous Sampling

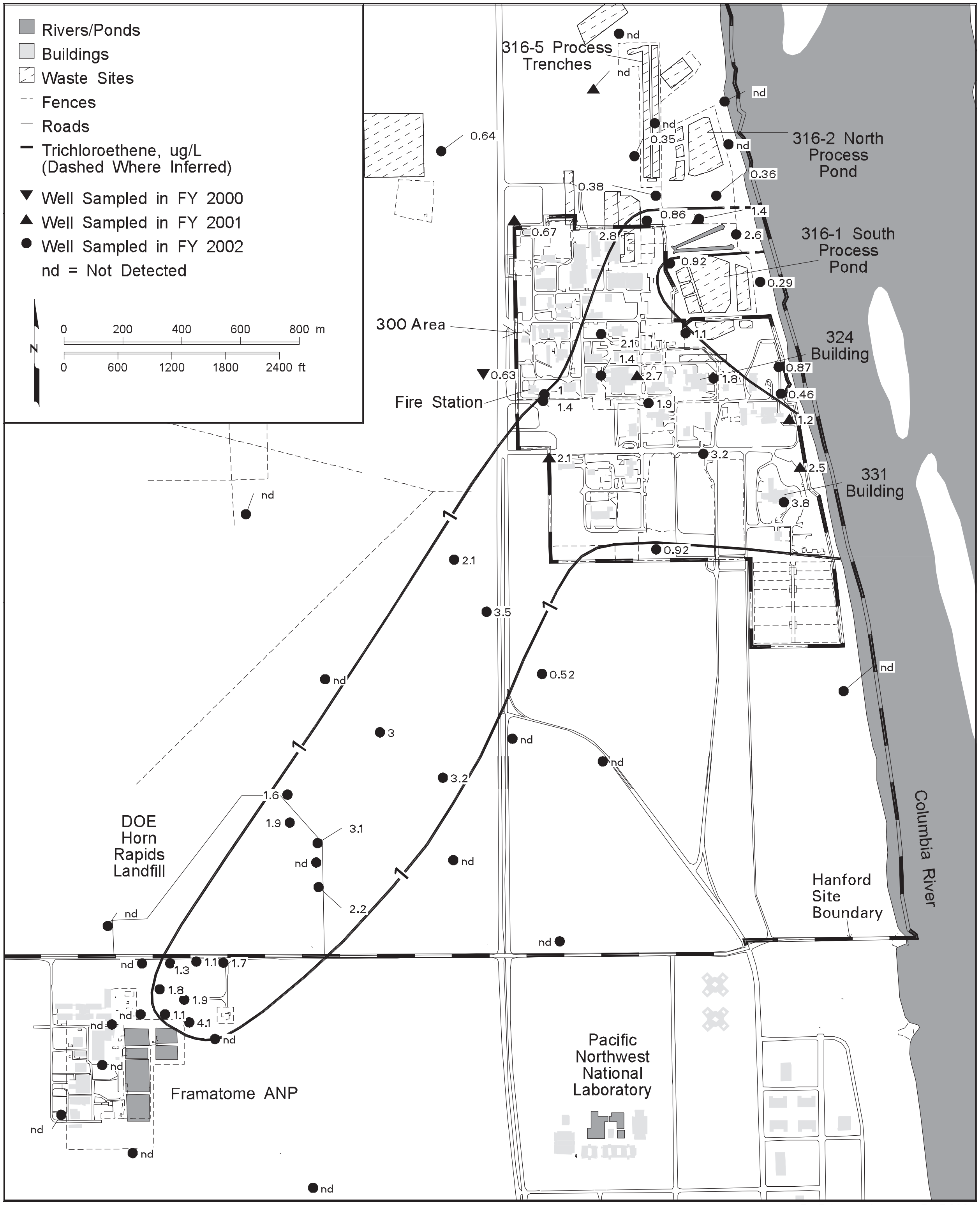

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Figure 2.12-9. Average Trichloroethene Concentrations in the 300 and Richland North Areas, Top of the Unconfined Aquifer

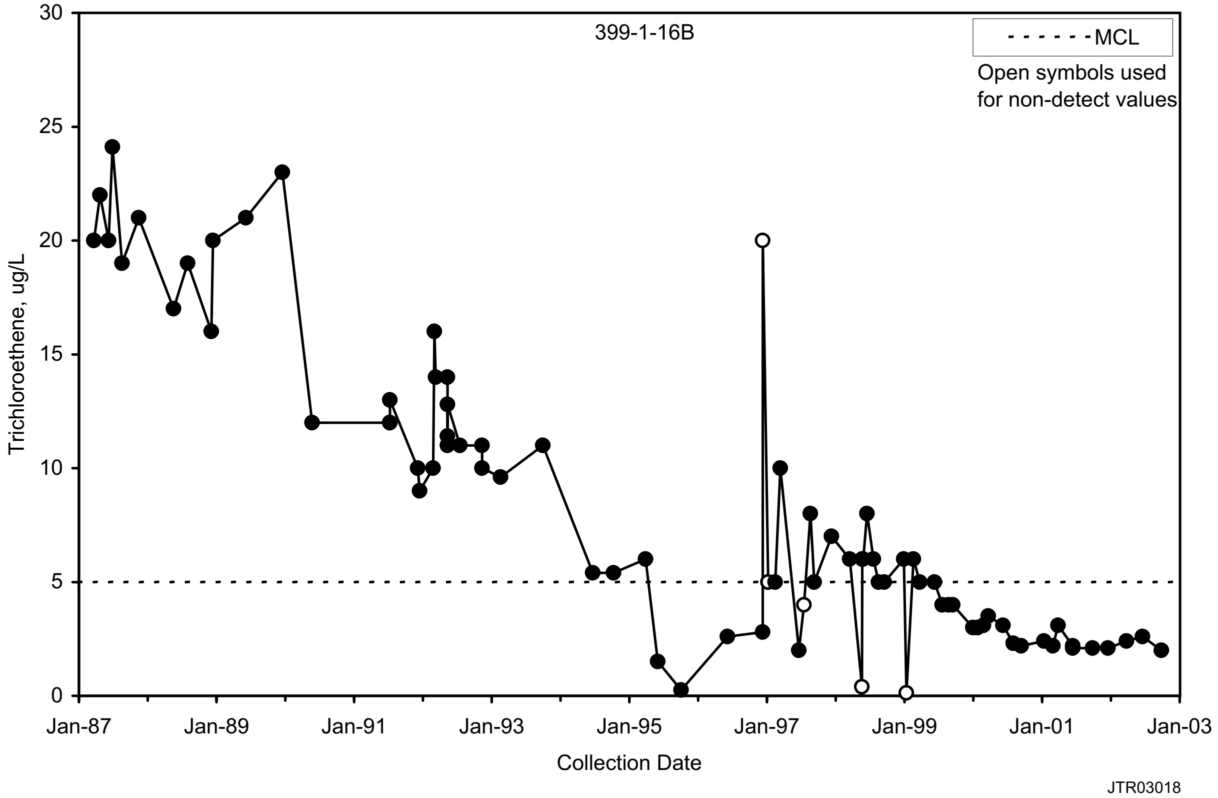

Figure 2.12-10. Trichloroethene Concentrations Near the 316-5 Process Trenches

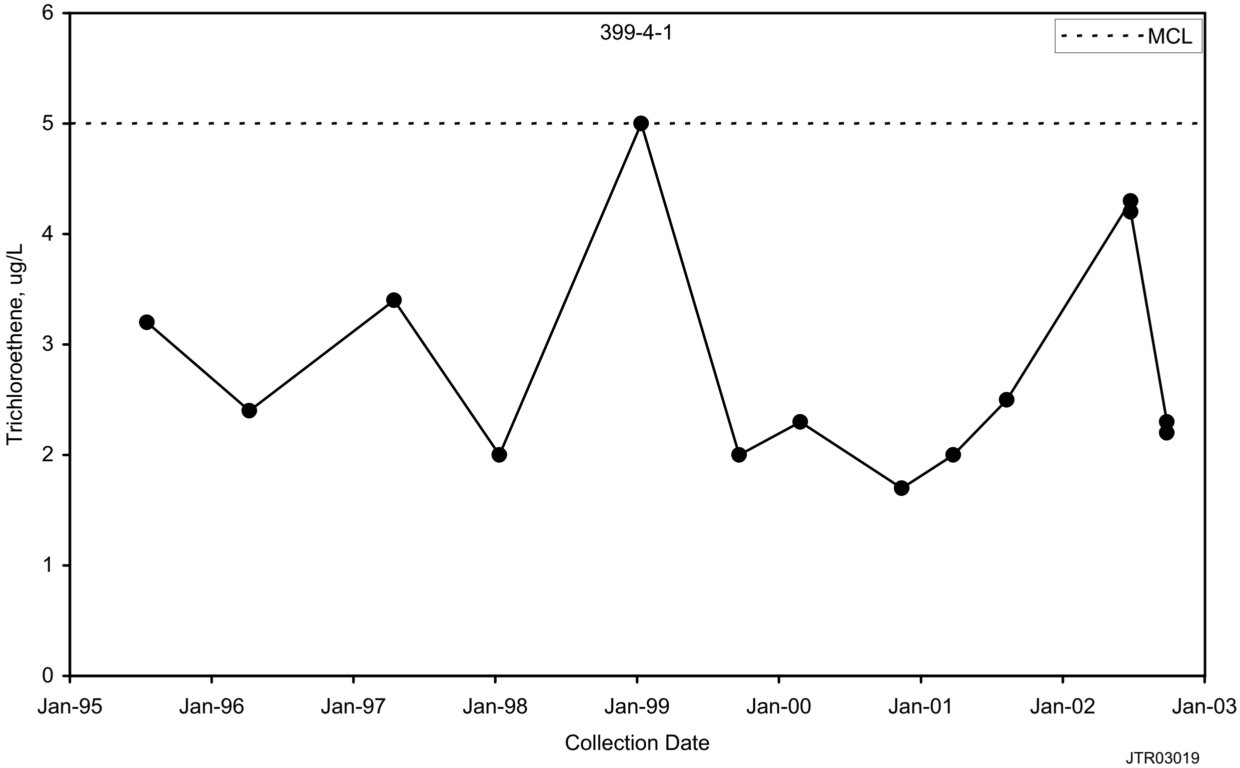

Figure 2.12-11. Trichloroethene Concentrations in the South 300 Area

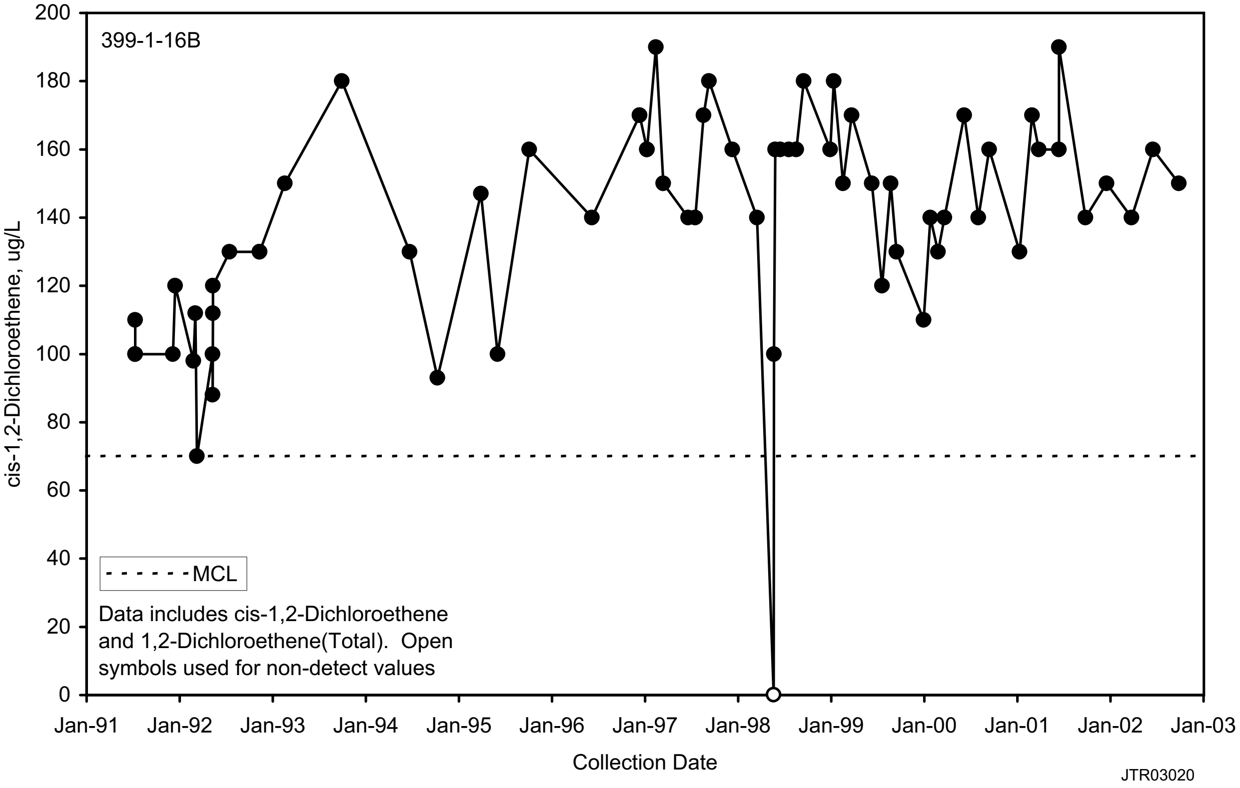

Figure 2.12-12. cis-1,2-Dichloroethene Concentrations Near the 316-5 Process Trenches

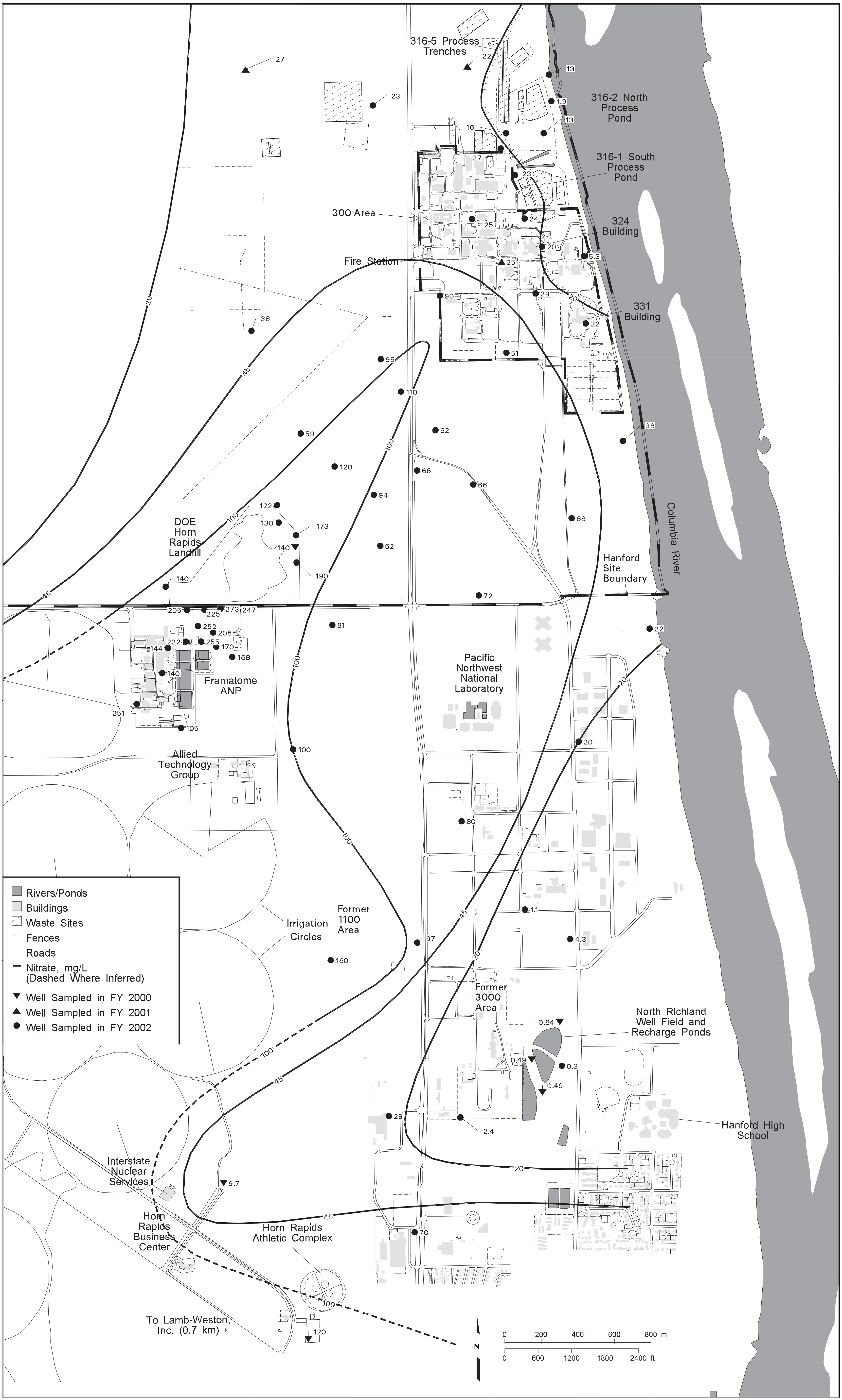

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Figure 2.12-13. Nitrate Concentrations in the 300 and Richland North Areas, Top of Unconfined Aquifer

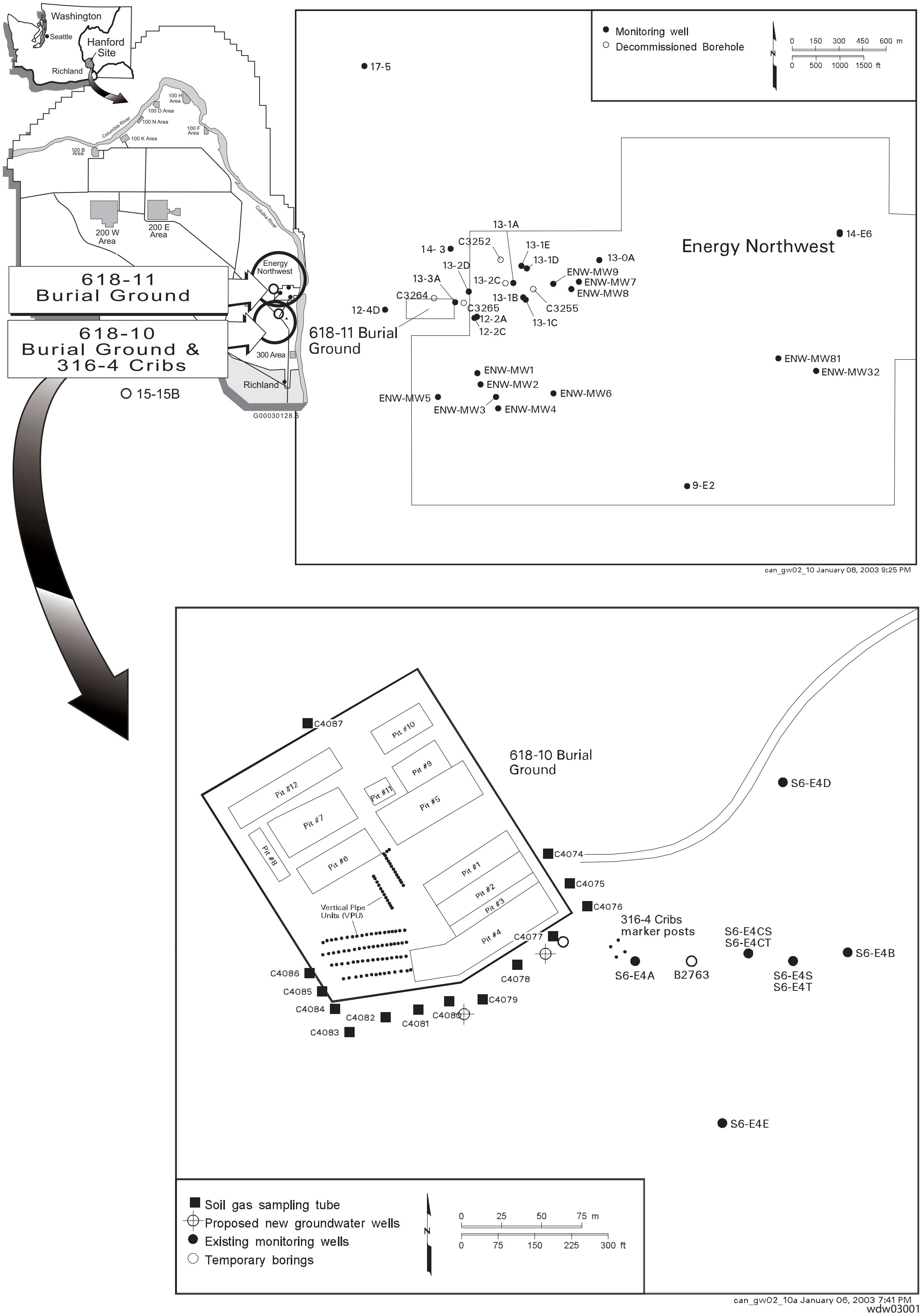

Figure 2.12-14. Groundwater Monitoring Wells Near the 618-10 and 618-11 Burial Grounds and the 316-4 Cribs

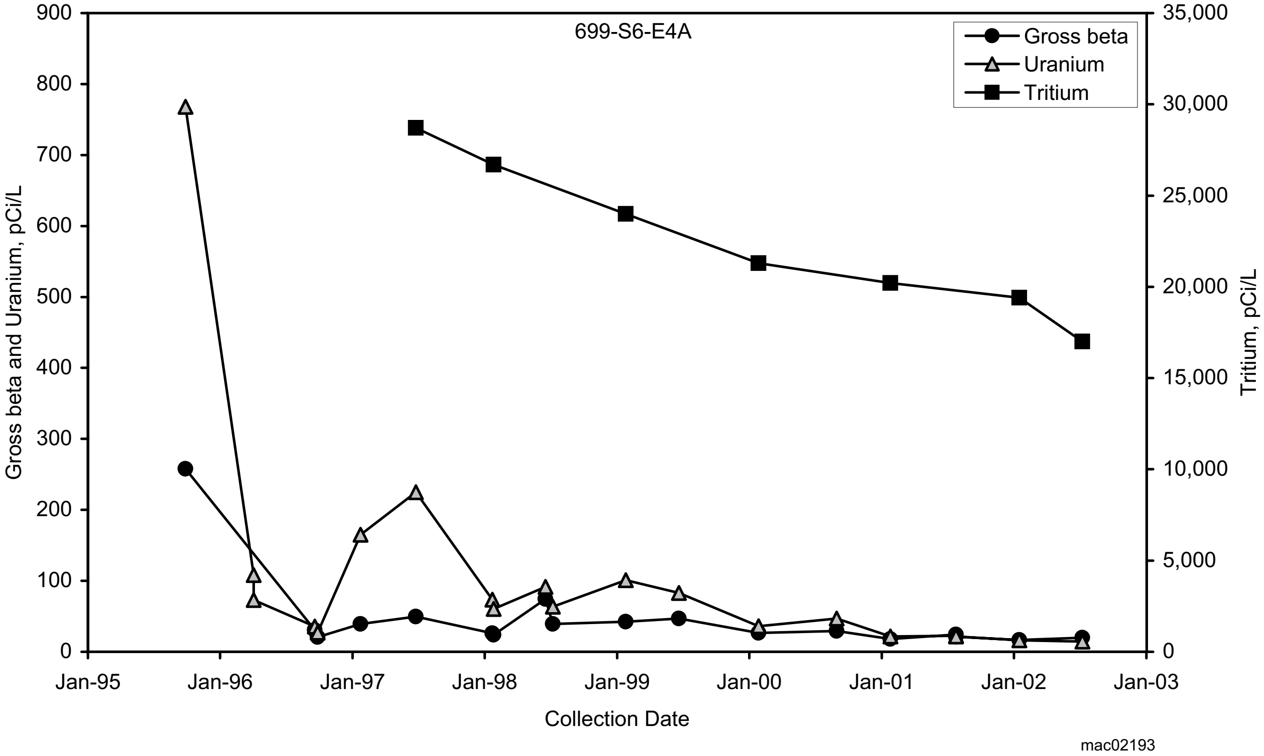

Figure 2.12-15. Uranium Concentrations Near the 316-4 Cribs and 618-10 Burial Ground

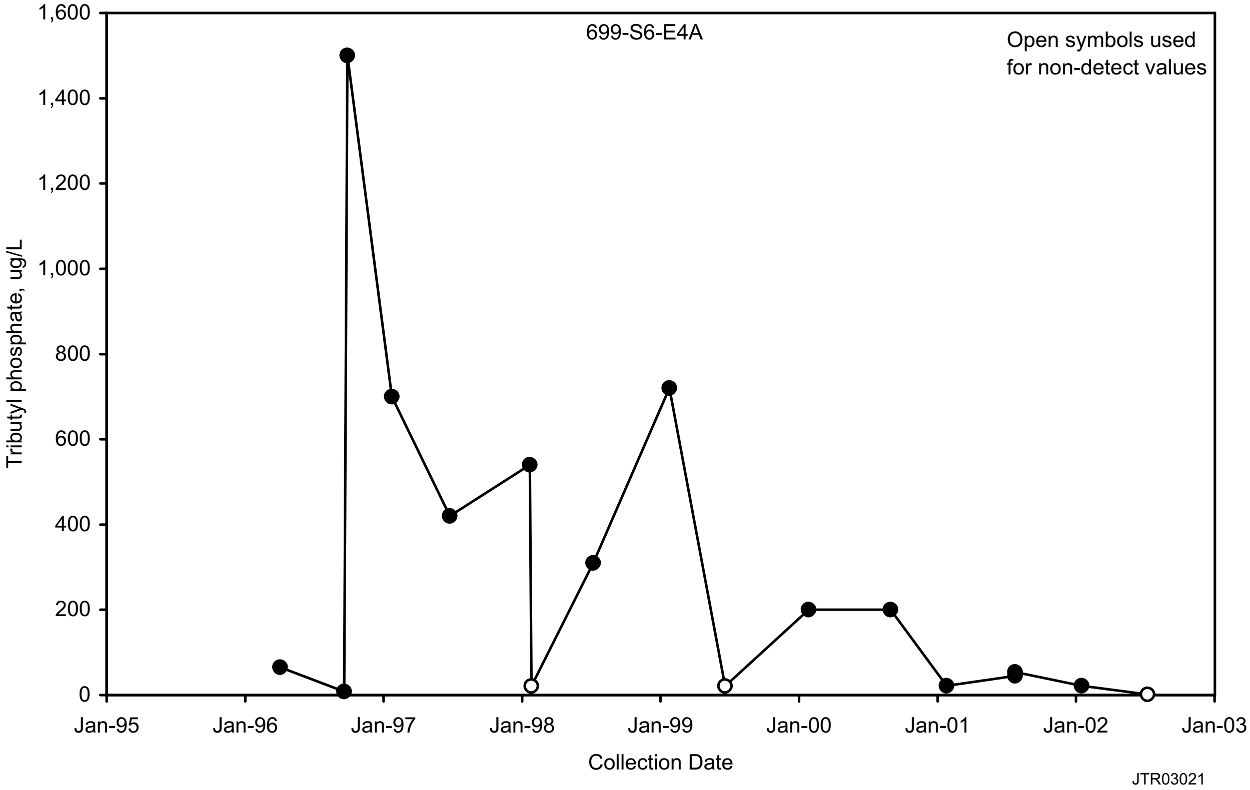

Figure 2.12-16. Tributyl Phosphate Concentrations Near the 316-4 Cribs and 618-10 Burial Ground

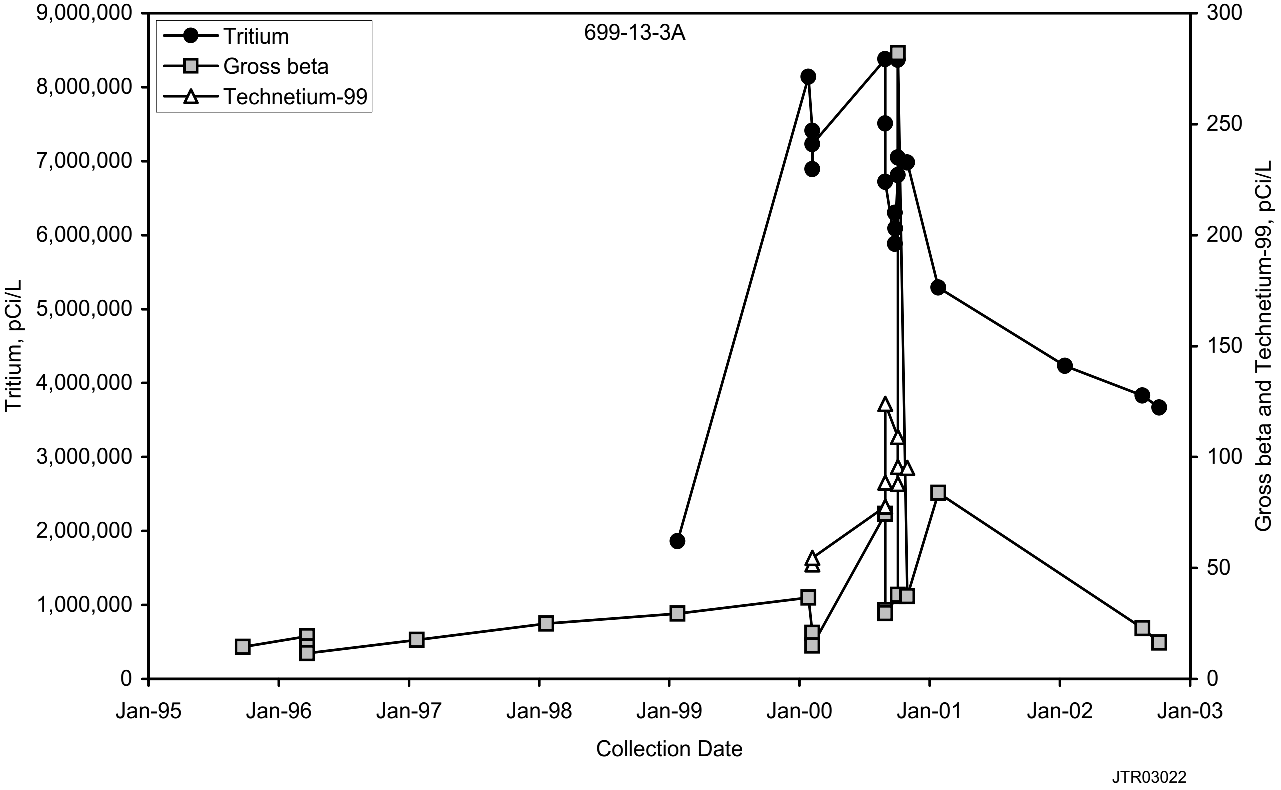

Figure 2.12-17. Tritium, Gross Beta, and Technetium-99 Concentrations Near the 618-11 Burial Ground

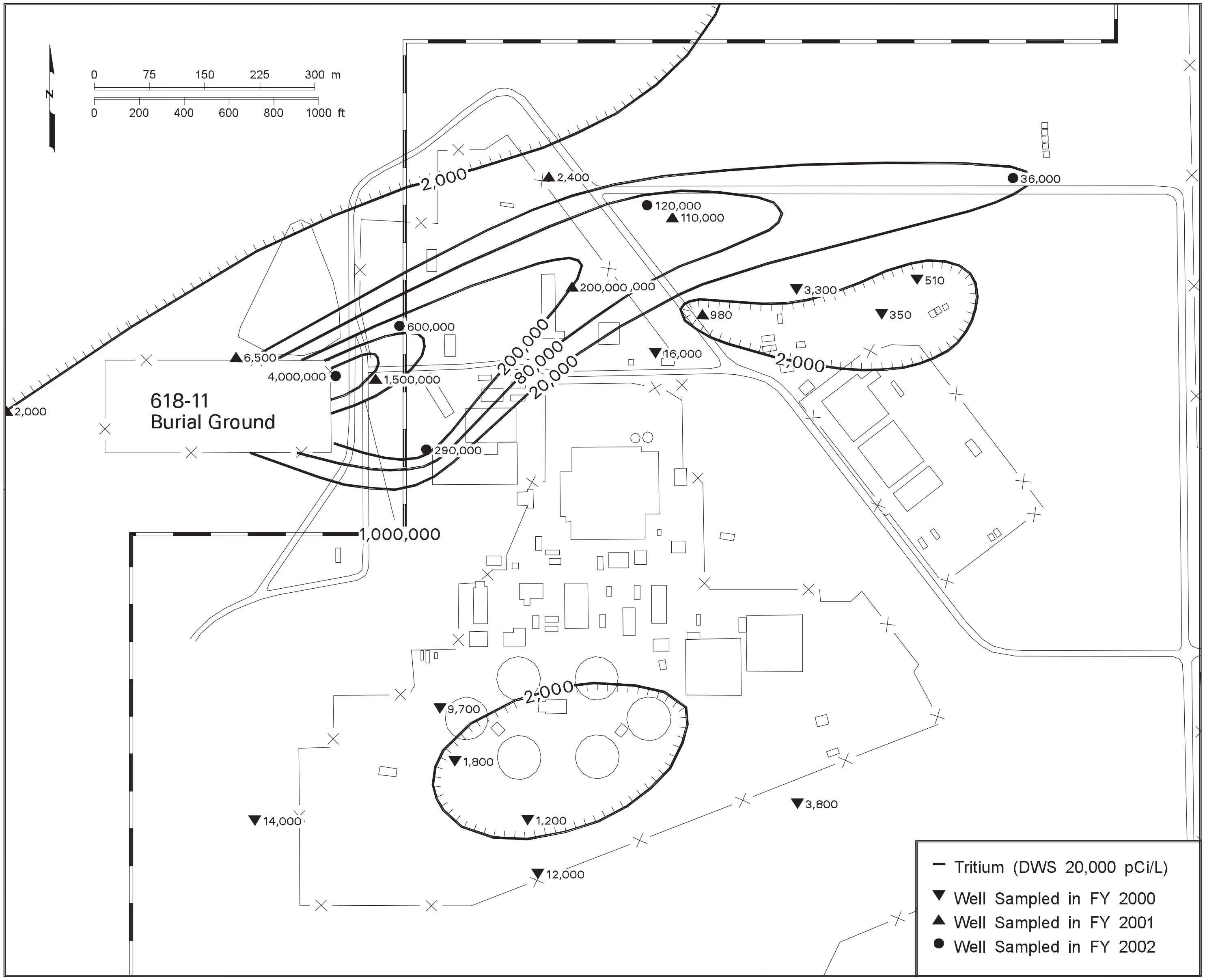

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Figure 2.12-18. Tritium Plume Downgradient of the 618-11 Burial Ground

2.13 Richland North Area

D. R. Newcomer

The Richland North Area is located in the south part of the Hanford Site (see Figure 2.12-2). For this report, the Richland North Area is defined as the former 1100 and 3000 Areas, that part of the 600 Area adjacent to the 300 Area, and parts of nearby Richland between the Yakima and Columbia Rivers. Ownership of the 1100 Area was transferred from the U.S. Department of Energy (DOE) to the Port of Benton in 1998. Ownership of the 3000 Area was transferred from DOE to the Port of Benton in 1996.

The area near the North Richland Well Field and Recharge Ponds is monitored closely to detect the possible impact of the tritium plume from the 200 Areas. Monitoring in fiscal year 2002 indicated that the tritium plume in the 300 Area receded to the northeast. Although tritium levels are far below the drinking water standard, frequent monitoring will continue.

2.13.1 Groundwater Flow

Figure 2.12-3 shows the March 2002 water-table elevations and corresponding groundwater flow directions for the Richland North Area. Groundwater in the Richland North Area generally flows eastward from the Yakima River (see Figure 2.1-1) and discharges to the Columbia River. In the north part of the Richland North Area, groundwater flows northeast and converges with groundwater entering the 300 Area before discharging to the Columbia River. In the south part of the Richland North Area, groundwater flow from the west is diverted to the northeast and southeast around a recharge mound before discharging to the Columbia River.

The Richland North Area is defined as the former 1100 and 3000 Areas, that part of the 600 Area adjacent to the 300 Area, and parts of nearby Richland between the Yakima and Columbia Rivers. Groundwater is monitored in this area to protect human health and the environment.

Monitoring Objectives in Richland North Area

Groundwater monitoring is conducted in the Richland North Area:

- triennially to annually to describe the nature and extent of contamination
- annually to detect the impact of contamination from off the Hanford Site
- annually or more frequently to ensure the safety of the North Richland Well Field and Recharge Ponds

The Yakima River has a regional effect on groundwater flow and is the primary source of groundwater recharge in the Richland North Area. A higher elevation in Yakima River stage (see Figure 2.1-1) than the water table implies that Yakima River water infiltrates and recharges the unconfined aquifer. Leakage from canals and ditches originating from the Yakima River during the summer months is also a source of groundwater recharge.

The North Richland Well Field and Recharge Ponds, in the south-central portion of the Richland North Area, is the most dominant local influence on changes in groundwater elevation in this area. This influence is important for determining groundwater flow directions and assessing the potential for movement of contaminants in the Richland North Area. The elevated groundwater level in this area continued to be maintained, with a 2.6:1 ratio of recharge to discharge at the well field during fiscal year 2002. This is compared to a recharge to discharge ratio of 2.7:1 in fiscal year 2001. Ratios of annual recharge to annual discharge in the last ~10 years, plotted in Figure 2.13-1, have averaged ~3:1.[a]

Groundwater levels in the area of the well field decreased ~0.5 to 1.0 meter between March/April 2001 and March 2002, as illustrated in Figure 2.13-2. This groundwater level change is a response to a change in the net volume of recharge at the well field. An approximate estimate of the net volume of recharge to groundwater is calculated as the difference between the total volume of recharge to the ponds and the total volume of discharge (i.e., pumpage from the well field wells). The annual net volume of recharge in the last ~10 years has varied from 2,425 to 9,200 million liters. However, the monthly net volume of recharge shows more variability and correlates with monthly groundwater levels. During this ~10-year period (1991 to 2002), the monthly net volume of recharge ranged from -410 million liters (i.e., discharge exceeds recharge) to +1,750 million liters (i.e., recharge exceeds discharge). Groundwater levels near the well field respond relatively quickly to changes in the net volume of recharge as illustrated in Figure 2.13-3. Figure 2.13-3 indicates that the height of the groundwater mound underlying the North Richland Well Field and Recharge Ponds can change by several meters in a matter of months.

Groundwater levels beneath the North Richland Well Field and Recharge Ponds decreased ~1 meter in response to less recharge to the ponds between fiscal years 2001 and 2002.

Irrigation of agricultural fields in the area between the Yakima River and the former 1100 Area, but south of the Hanford Site boundary, has a minimal effect on groundwater levels in the Richland North Area. Agricultural irrigation supplied primarily by the Columbia River recharges the unconfined aquifer between the Yakima and Columbia Rivers. Agricultural irrigation began in 1989, but irrigation was expanded in the early 1990s (PNL-10094). Seasonal effects associated with agricultural irrigation are illustrated from the hydrograph of well 699-S31-E8A adjacent to DOE's inactive Horn Rapids Landfill near the south boundary of the Hanford Site. Figure 2.13-4 shows that water levels affected by irrigation generally increase during the summer months and decrease during the winter months.

Columbia River stage fluctuations affect groundwater levels in the Richland North Area. In the north part of the Richland North Area, the influence by seasonal river stage fluctuations extends to at least the downgradient boundary of DOE's inactive Horn Rapids Landfill (DOE/RL-92-67). In the central to south part of the Richland North Area, the influence of river stage fluctuations is masked by recharge effects associated with the North Richland Well Field and Recharge Ponds.

(a) Recharge and discharge data provided by the city of Richland.

The potential for groundwater to move between the unconfined aquifer and underlying confined aquifers is controlled by the vertical hydraulic gradient. This is a controlling mechanism for the potential vertical movement of contaminants. The vertical hydraulic gradient between the unconfined aquifer and the confined aquifer underlying the clayey silt aquitard can be determined by evaluating hydraulic heads in well pairs monitoring each of these aquifers.

In Richland North Area, three well pairs monitor the unconfined aquifer and the Ringold confined aquifer underlying the clayey silt aquitard. Two of these well pairs are located near DOE's inactive Horn Rapids Landfill and one is near the North Richland Well Field and Recharge Ponds (Figure 2.13-5). Each of the well pairs indicates a different vertical hydraulic gradient condition. At the west edge of the landfill, the hydraulic head differences between these aquifers indicate a consistent, upward hydraulic gradient (Figure 2.13-5a). During fiscal year 2002, the vertical hydraulic gradient was ~2.2 meters over a vertical distance of 15 meters, or ~0.15 m/m at this location. Figure 2.13-5b shows that the vertical hydraulic gradient ranged from zero to a small downward gradient at the east edge of DOE's inactive Horn Rapids Landfill. During fiscal year 2002, the hydraulic heads showed a downward vertical hydraulic gradient of 0.004 m/m at this location. Near the North Richland Well Field and Recharge Ponds, there were essentially no hydraulic head differences between the unconfined and confined aquifers (Figure 2.13-5c), indicating no vertical groundwater flow between these aquifers in this area. Each of the vertical hydraulic head conditions represented in Figure 2.13-5 reflects the variety of hydraulic head conditions that exist in the Richland North Area.

2.13.2 Tritium

The south portion of the 200 Area tritium plume extends into the 300 Area and continues to be closely monitored because of its potential impact to the North Richland Well Field and Recharge Ponds (Figure 2.13-6). The tritium distribution in Figure 2.13-6 shows that concentrations decrease from >10,000 pCi/L to <100 pCi/L in a southwesterly direction across the 300 Area. Tritium concentrations continued to decrease in parts of the 300 Area in 2002 as shown graphically in Figure 2.13-7. As a result, tritium contours continued to shift slightly to the northeast, indicating that the tritium plume in these areas decreased slightly in size between fiscal years 2001 and 2002. Tritium levels continued to show stable levels just north of the 300 Area (well 699-S19-E13 in Figure 2.13-7).

The 200 Areas tritium plume has not reached the North Richland Well Field and Recharge Ponds or other offsite areas south of the Hanford Site. The tritium plume continued to shrink in size in fiscal year 2002.

South of the 300 Area, tritium levels were slightly elevated above background in wells near the North Richland Well Field and Recharge Ponds and in wells north of the well field during fiscal year 2002 (see Figure 2.13-6). The background geometric mean tritium concentration in the upper part of the unconfined aquifer was determined to be 63.9 pCi/L (DOE/RL-96-61). The average tritium concentration from monthly Columbia River samples collected at the Richland Pumphouse was 64.7 pCi/L during fiscal year 2002. However, the elevated levels are far below the 20,000-pCi/L drinking water standard. Trends in these tritium concentrations have consistently shown fluctuating levels in the last few years, as shown in Figure 2.13-8.

Tritium at elevated levels in the Richland North Area is likely residual tritium associated with recharge of Columbia River water discharged to the ponds during the 1960s (Figure 2.13-9). During the 1960s, tritium levels in Columbia River water were elevated because of fallout from thermonuclear weapons testing between 1952 and 1962. Since weapons testing, tritium for weapons has been attenuated by the oceans and radioactive decay (Clark and Fritz 1997). Clark and Fritz (1997) interpreted qualitative groundwater mean residence times for recharged aquifers in continental regions (Table 2.13-1). Thus, tritium concentrations >96 pCi/L near the North Richland Well Field and Recharge Ponds represent a considerable component of recharge from the 1960s and tritium concentrations >160 pCi/L represent predominantly 1960s recharge.

Tritium is not migrating in groundwater from the 200 Areas tritium plume to the well field. Several factors limit the migration of the tritium plume into the Richland North Area.

- Groundwater generally flows from west to east between the Yakima River and the Columbia River.
- Artificial recharge from agricultural irrigation west of the Richland North Area contributes to the eastward flow.
- Flow is directed outward from the elevated groundwater levels at the North Richland Well Field and Recharge Ponds.

These factors produce converging flow lines in the 300 Area and discharge to the Columbia River (see Figure 2.12-2). Figure 2.13-6 shows a region of low tritium concentrations between the 200 Areas tritium plume and the slightly elevated tritium concentrations near the North Richland Well Field and Recharge Ponds. Thus, there is no indication that the tritium plume is migrating southward and affecting the well field.

Tritium in the top of the unconfined aquifer potentially can migrate to deep parts of the unconfined aquifer or to underlying confined Ringold aquifers. To determine if tritium has reached these depths, tritium is monitored in deep parts of the unconfined aquifer and in underlying confined Ringold aquifers in the Richland North and 300 Areas. This monitoring information is important to evaluate the movement of the unconfined aquifer tritium plume in the 300 Area because of its proximity to offsite areas.

Tritium is monitored in deep parts of the unconfined aquifer at a frequency of one to three years in the Richland North and 300 Areas. The distribution of tritium in these areas is shown in Figure 2.13-7 of PNNL-13788. The wells that are completed in these deeper portions monitor near the middle or bottom of the unconfined aquifer. The bottom of the unconfined aquifer lies above either a clayey silt aquitard or the lower Ringold mud. The only known location where tritium is elevated above background levels in the deep portion of the unconfined aquifer is well 399-1-16B in the north part of the 300 Area. This well is located in the same area as the tritium plume that resides in the top of the unconfined aquifer. Tritium trends in this well have shown an increase of 1,240 pCi/L in recent years, but decreased to 690 pCi/L in fiscal year 2002.

Tritium also is monitored every 3 years in confined Ringold aquifers below the clayey silt aquitard and below the lower Ringold mud unit. The distribution of tritium in these aquifers in the Richland North and 300 Areas is shown in Figure 2.13-9 of PNNL-13788. The data indicate that tritium levels in the confined aquifers above the basalt are indicative of background concentrations. These concentrations suggest that tritium from the tritium plume in the top of the unconfined aquifer has not reached the confined aquifers in the Richland North and 300 Areas.

2.13.3 Nitrate

Nitrate contamination migrates to the Richland North Area from industrial and agricultural activities off the Hanford Site. Concentrations generally continued to increase in fiscal year 2002.

The nitrate distribution in groundwater is shown in Figure 2.12-13. Nitrate contamination that is found in the Richland North Area is likely the result of industrial and agricultural uses off the Hanford Site. Industrial uses occur at

Framatome ANP Richland, Inc. and Lamb-Weston, Inc. Agricultural uses include application of fertilizers onto irrigation circles in the southwest part of the Richland North Area (see Figure 2.12-2).

Concentrations above the 45-mg/L maximum contaminant level are found over much of the Richland North Area and continued to increase in a number of wells. Some of the highest nitrate levels occur near Framatome ANP Richland, Inc. and DOE's inactive Horn Rapids Landfill. Elevated nitrate near these areas is likely the result of agricultural activities to the west and southwest. An example of elevated nitrate concentrations showing a recent increasing trend occurred along the west edge of DOE's inactive Horn Rapids Landfill immediately north of the Framatome facility (Figure 2.13-10). The highest nitrate concentration in this area was 273 mg/L northeast (downgradient) of Framatome ANP Richland, Inc. Nitrate data for Framatome wells are reported in EMF-1865, Addenda 27 and 30. Nitrate concentrations continued to be elevated in wells downgradient of DOE's inactive Horn Rapids Landfill in fiscal year 2002. The highest average nitrate concentration in this area was 188 mg/L. The shape of the plume (as defined by the 100-mg/L contour) near Framatome ANP Richland, Inc. and DOE's inactive Horn Rapids Landfill indicates that nitrate in these areas continues to migrate in a northeast direction toward the 300 Area.

Nitrate levels continued to be elevated in an area northwest of the North Richland Well Field and Recharge Ponds during fiscal year 2002. These elevated levels are illustrated by the trend plots in Figure 2.13-11. The most likely source of these elevated nitrate levels is the agricultural irrigation to the west. The shape of the plume indicates that the eastward migration of nitrate is being diverted around the groundwater mound that is in the vicinity of the North Richland Well Field and Recharge Ponds (see Figure 2.12-3). Nitrate levels in wells at the well field continued to be lower than ambient groundwater, a result of recharge from infiltration of river water at the North Richland Well Field and Recharge Ponds.

2.13.4 Chlorinated Hydrocarbons

Trichloroethene contamination occurs in the Richland North Area beneath DOE's inactive Horn Rapids Landfill and offsite in Framatome ANP Richland, Inc. wells (see Figure 2.12-9). The distribution of trichloroethene in the upper part of the unconfined aquifer shows that the plume has an elongated configuration. This configuration, which is slightly narrower in fiscal year 2002 than it was in fiscal year 2001, indicates a northeast flow direction around the North Richland Well Field and Recharge Ponds and toward the 300 Area.

Trichloroethene contamination in Richland North Area has sources off the Hanford Site. Concentrations are naturally declining.

Average trichloroethene concentrations continued to be <5 µg/L in all Framatome ANP Richland, Inc. wells during fiscal year 2002 (EMF-1865, Addenda 27 and 30). The maximum average trichloroethene concentration was 4.1 µg/L. The past use of solvent to install and maintain process lagoon liners at Framatome ANP Richland, Inc. is the only potential source of trichloroethene identified in the Richland North Area (DOE/RL-92-67).

Trichloroethene concentrations have decreased in essentially all the plume areas near DOE's inactive Horn Rapids Landfill. Trichloroethene concentrations decreased by more than an order of magnitude in this area since monitoring began in 1990 (Figure 2.13-12). In fiscal year 2002, average trichloroethene concentrations were all <5 µg/L, ranging from less than detection to 3.5 µg/L downgradient of the landfill. The decreased concentrations in the majority of wells downgradient of DOE's inactive Horn Rapids Landfill suggest that some elements of natural attenuation (e.g., volatilization, passive pumping) may have reduced the plume mass. For a discussion of trichloroethene in the 300 Area, see Section 2.12.4.

Trichloroethene is monitored in a deep portion of the unconfined aquifer immediately downgradient of DOE's inactive Horn Rapids Landfill. The monitored portion of the deep aquifer lies above a clayey silt aquitard at a depth of ~5 to 8 meters below the water table. Figure 2.13-13 indicates that trichloroethene concentrations in the deep portion of the unconfined aquifer have decreased by more than an order of magnitude since monitoring began in 1990. These concentrations, which show a similar pattern of natural attenuation as the trend shown for the upper part of the unconfined aquifer in Figure 2.13-12, indicate that trichloroethene in the deep portion of the unconfined aquifer downgradient of the source area is in a dissolved state.

A confined aquifer in the Ringold Formation is also monitored for trichloroethene downgradient of the landfill. This confined aquifer lies below the clayey silt aquitard, but above the basalt surface, at a depth of ~18 to 21 meters below the water table. Trichloroethene has not been detected in this confined aquifer since monitoring began in 1991, which suggests that the trichloroethene plume in the unconfined aquifer did not migrate downward into the underlying confined aquifer.

The city of Richland monitors upper unconfined groundwater quarterly for chemical constituents at their Horn Rapids Sanitary Landfill (formerly Richland Landfill). The landfill is located west of the Richland North Area adjacent to the south boundary of the Hanford Site (see Figure 2.2-2). Chlorinated hydrocarbons were detected in city landfill monitoring wells between ~1 and 1.5 kilometers south of the Hanford Site boundary at levels above their respective maximum contaminant levels during fiscal year 2002 (City of Richland 2002a, 2002b, 2002c, 2002d). The highest average concentrations were 56 μg/L 1,1-dichloroethane, 81 μg/L cis-1,2-dichloroethene, 74 μg/L tetrachloroethene, and 24 μg/L trichloroethene. During fiscal year 2002, these constituents were found to be below their respective minimum detection limits at an onsite well (699-S31-1) just northeast of the city's sanitary landfill.

2.13.5 Gross Alpha and Uranium

Relatively low levels of ammonia, fluoride, and uranium detected near DOE's inactive Horn Rapids Landfill are from industrial sources off the Hanford Site.

Elevated levels of gross alpha and uranium occur downgradient of Framatome ANP Richland, Inc. near DOE's inactive Horn Rapids Landfill. The highest gross alpha level was an average of 98 pCi/L in well SPC-GM-8 during fiscal year 2002 (EMF-1865, Addenda 27 and 30). This maximum level is an increase from 87 pCi/L in fiscal year 2001. Most of the downgradient Framatome ANP Richland, Inc. wells showed average gross alpha levels that were above the 15-pCi/L maximum contaminant level, which excludes uranium. However, it is probable that the gross alpha levels are largely attributed to uranium because Framatome ANP Richland, Inc., which manufactures nuclear fuel pellets and assemblies for commercial nuclear power plants and processed uranium hexafluoride (UF_6) in the past. If gross alpha is attributed to uranium with natural isotopic abundances, then 98 pCi/L gross alpha is equivalent to ~142 μg/L uranium, which is above the 30-μg/L maximum contaminant level for uranium. Framatome ANP Richland, Inc. is not required to analyze samples collected from their wells for uranium.

The distribution of uranium near DOE's inactive Horn Rapids Landfill is shown in Figure 2.12-5. The map shows a small plume of uranium with levels less than the 30 μg/L maximum contaminant level near the landfill. Uranium concentrations in wells downgradient of the landfill decreased slightly or did not change between fiscal year 2001 and fiscal year 2002. Uranium concentrations ranged up to 15.2 μg/L, with the highest concentration immediately downgradient of DOE's inactive Horn Rapids Landfill in well 699-S31-E10B (Figure 2.13-14). At this time, the landfill is not considered a source of the uranium contamination in groundwater because no known uranium sources exist in the landfill. The shape of the uranium contours suggests a uranium source off the Hanford Site.

2.13.6 Other Constituents

Ammonia, fluoride, and gross beta are found at low levels in wells near Framatome ANP Richland, Inc.

Ammonia – Concentrations of ammonia in the Framatome ANP Richland, Inc. wells generally remained steady in fiscal year 2002 (EMF-1865, Addenda 27 and 30). The highest average concentration detected was 15.1 mg/L (as NH_3) in well SPC-GM-10. Ammonia is typically absorbed by plants and soil microorganisms or is taken up as an exchangeable ion on soil particles (Hausenbuiller 1972). However, ammonia is usually less stable than nitrate in a biological system like the soil medium and is rapidly converted to nitrate. Ammonia was detected in seven downgradient Framatome ANP Richland, Inc. wells in fiscal year 2002. The fact that ammonia is found in the groundwater suggests that relatively high concentrations reached the soil column.

Fluoride – Two wells downgradient of Framatome ANP Richland, Inc. continued to show fluoride concentrations above the 4 mg/L maximum contaminant level in fiscal year 2002 (EMF-1865, Addenda 27 and 30). The highest average concentration was 4.1 mg/L in well SPC-GM-8. Fluoride contamination is most likely the result of past processing of uranium hexafluoride (UF_6) at the Framatome facility. Average fluoride concentrations in onsite wells for this area continued to be <1 mg/L.

Gross Beta – Gross beta continued to be detected in wells downgradient of Framatome ANP Richland, Inc. during fiscal year 2002 (EMF-1865, Addenda 27 and 30). The highest average gross beta measurement in fiscal year 2002 was 40 pCi/L in well SPC-GM-8. Low levels of technetium-99, detected near DOE's inactive Horn Rapids Landfill, may be related to the gross beta measurements.

Table 2.13-1. Qualitative Interpretations of Groundwater Mean Residence Times in Continental Regions (adapted from Clark and Fritz 1997)

Range of Tritium (tritium units)	Range of Tritium (pCi/L)	Qualitative Interpretation
<0.8	<2.6	Submodern – recharged prior to 1952
0.8 to ~4	2.6 to ~13	Mixture between submodern and recent recharge
5 to 15	16 to 48	Modern (<5 to 10 years)
15 to 30	48 to 96	Some tritium present
>30	>96	Considerable component of recharge from the 1960s or 1970s
>50	>160	Dominantly the 1960s recharge

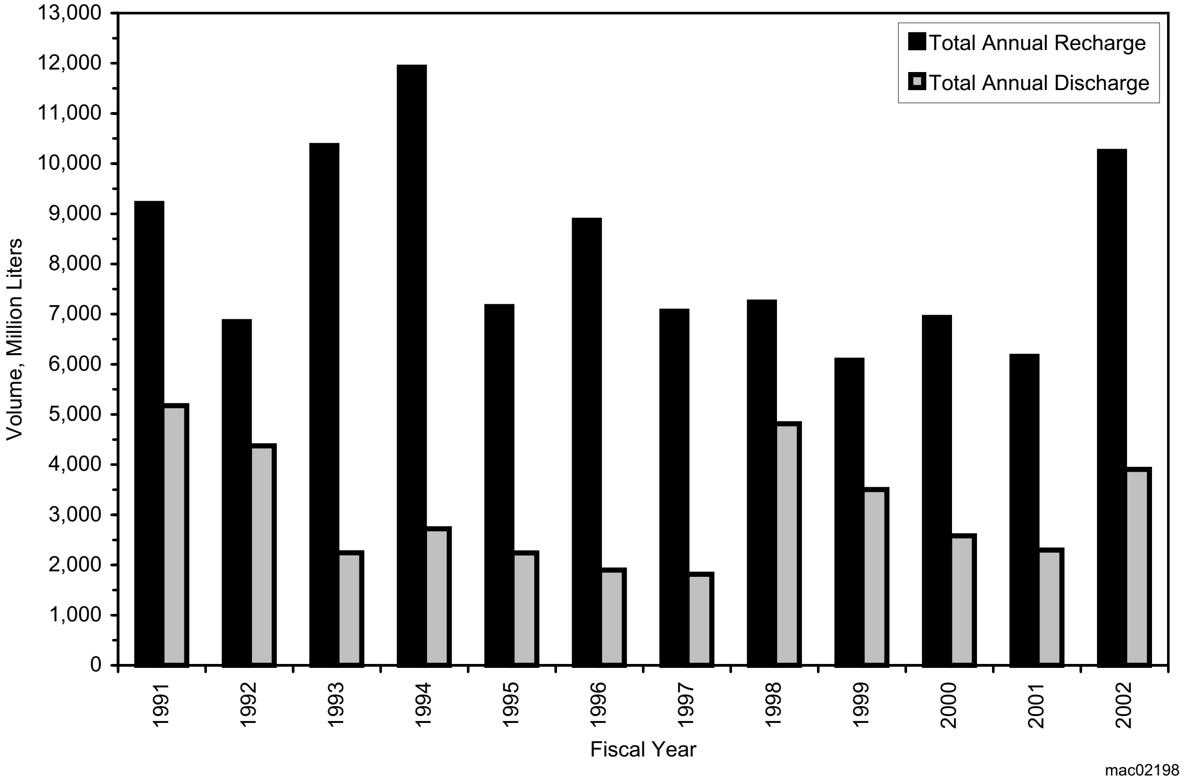

Figure 2.13-1. Total Annual Recharge and Discharge at the Richland North Well Field and Recharge Ponds

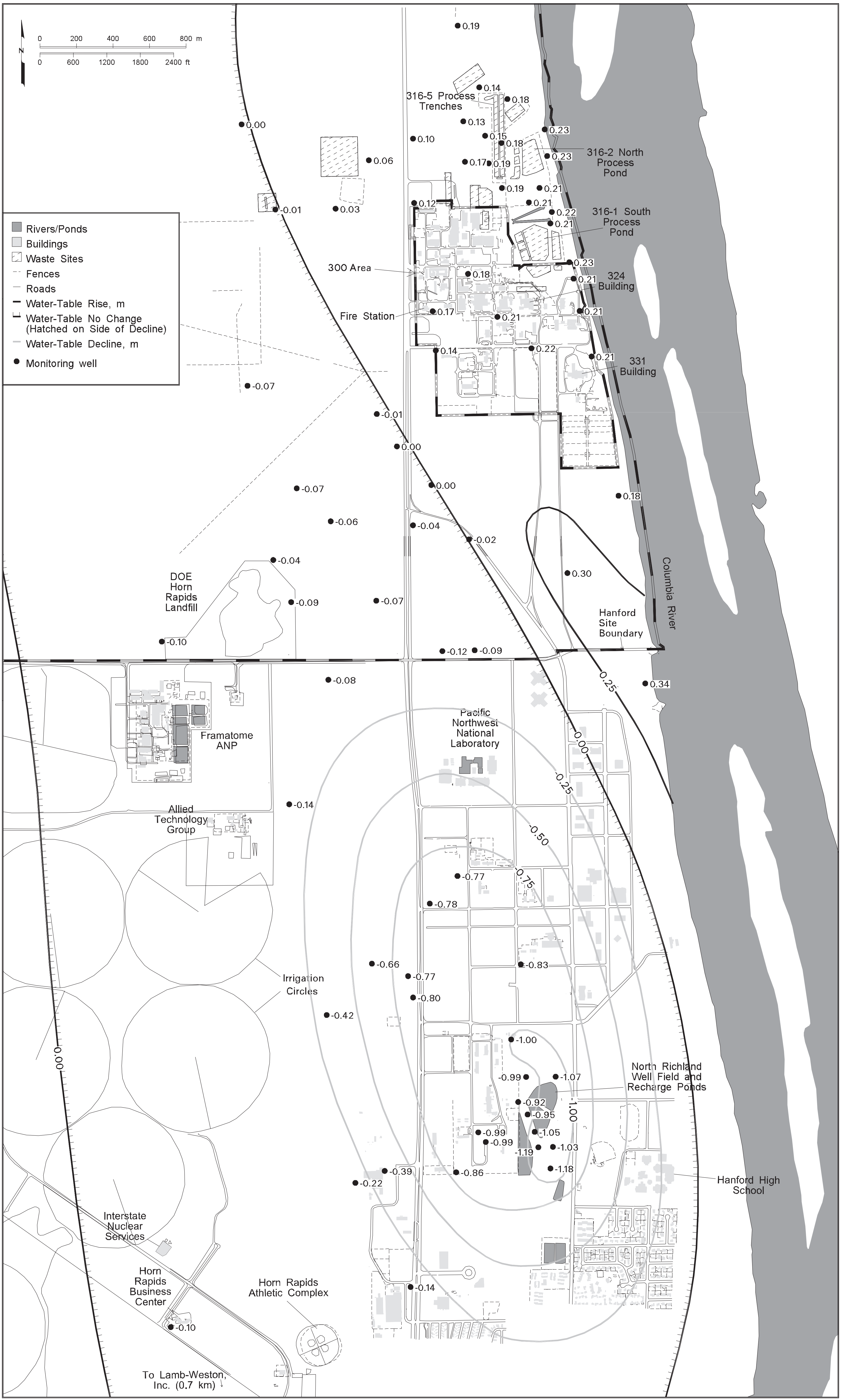

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Figure 2.13-2. Water-Table Changes in the Richland North Area Between March/April 2001 and March 2002

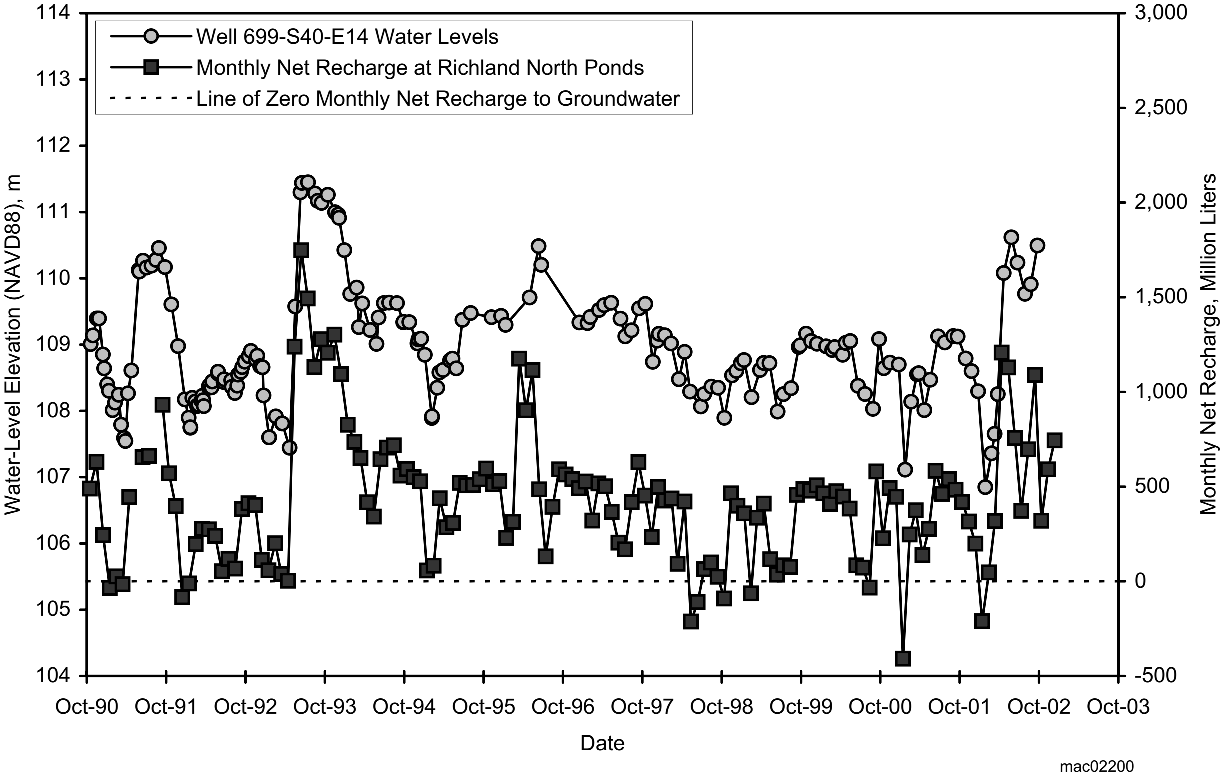

Figure 2.13-3. Comparison of Water Levels and Monthly Net Volume of Recharge at the Richland North Well Field and Recharge Ponds

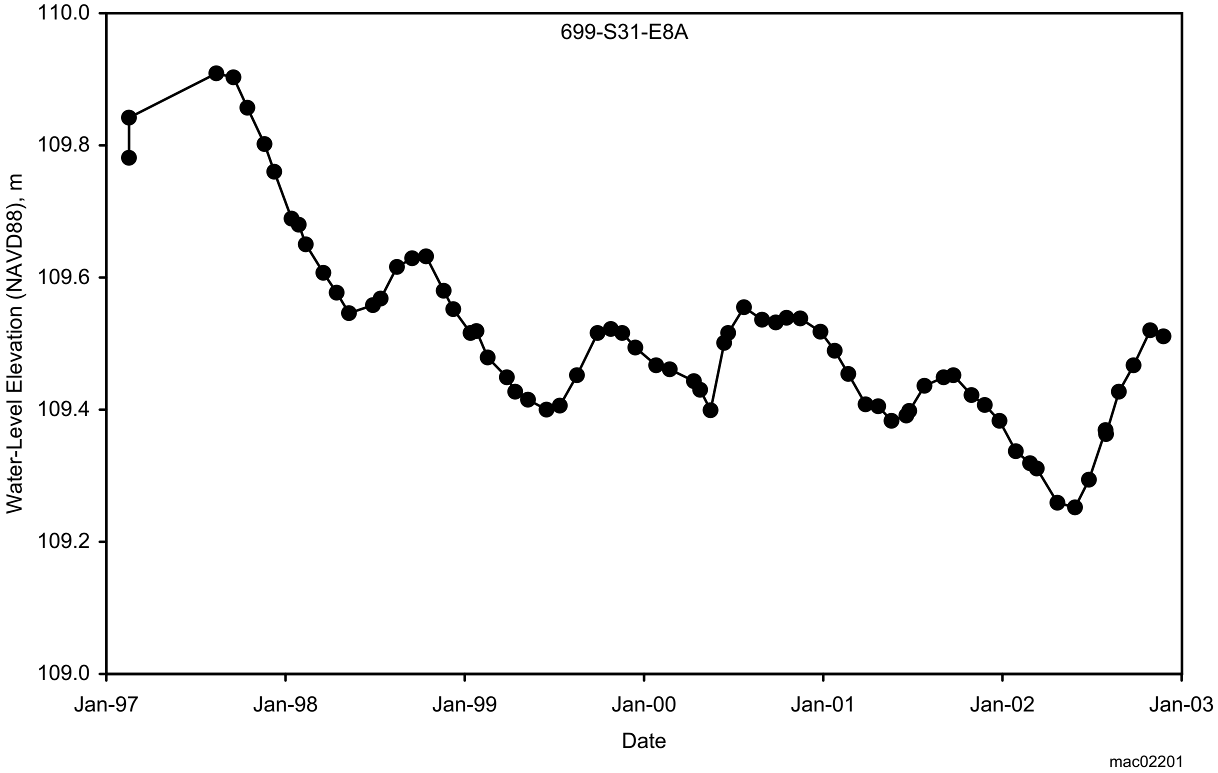

Figure 2.13-4. Water Levels Adjacent to the U.S. Department of Energy's Inactive Horn Rapids Landfill Near the South Boundary of the Hanford Site

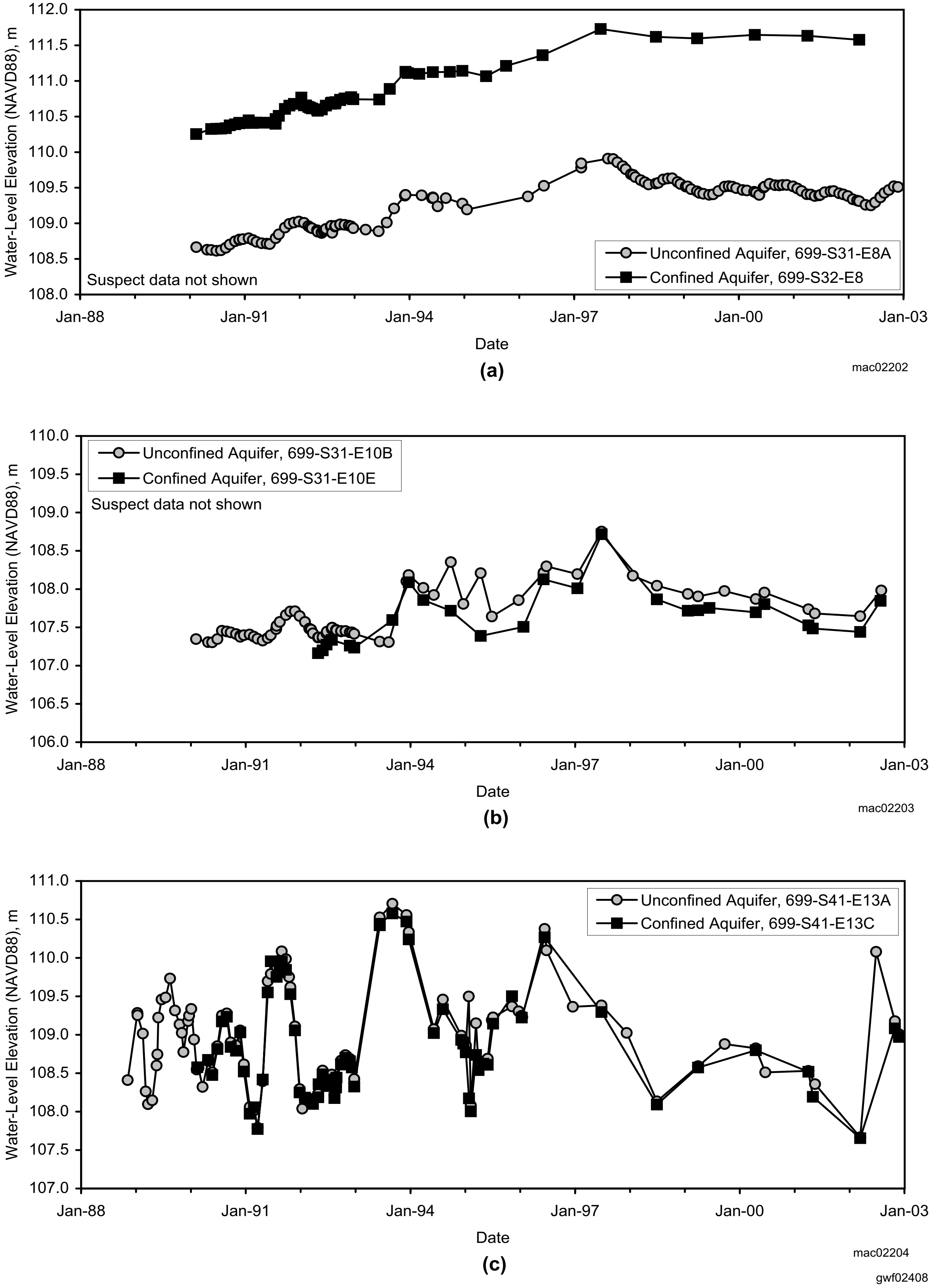

Figure 2.13-5. Well Pairs Monitoring the Unconfined and Confined Aquifers in the Richland North Area

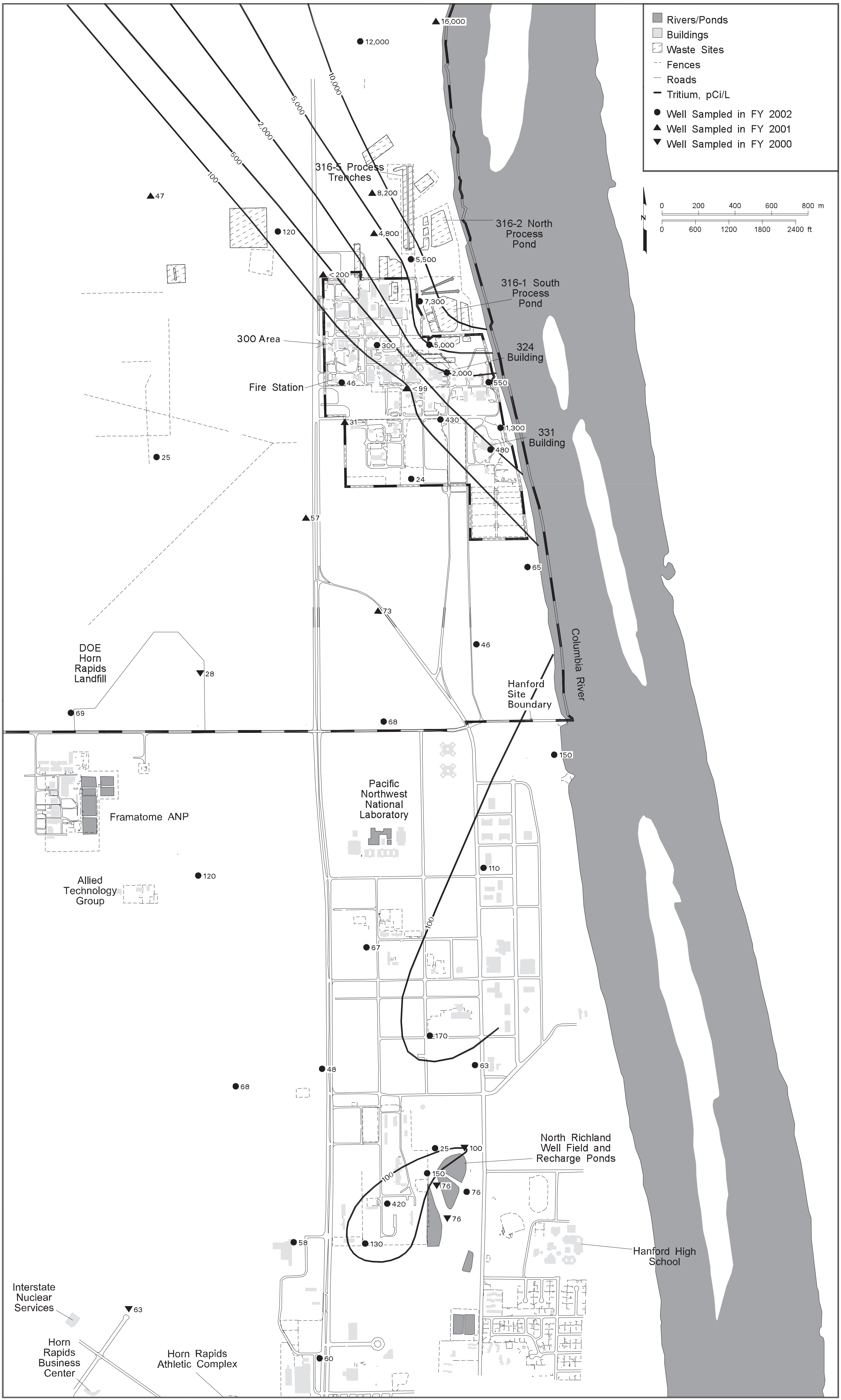

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Figure 2.13-6. Tritium Concentrations in Groundwater at 300 and Richland North Areas, Top of Unconfined Aquifer

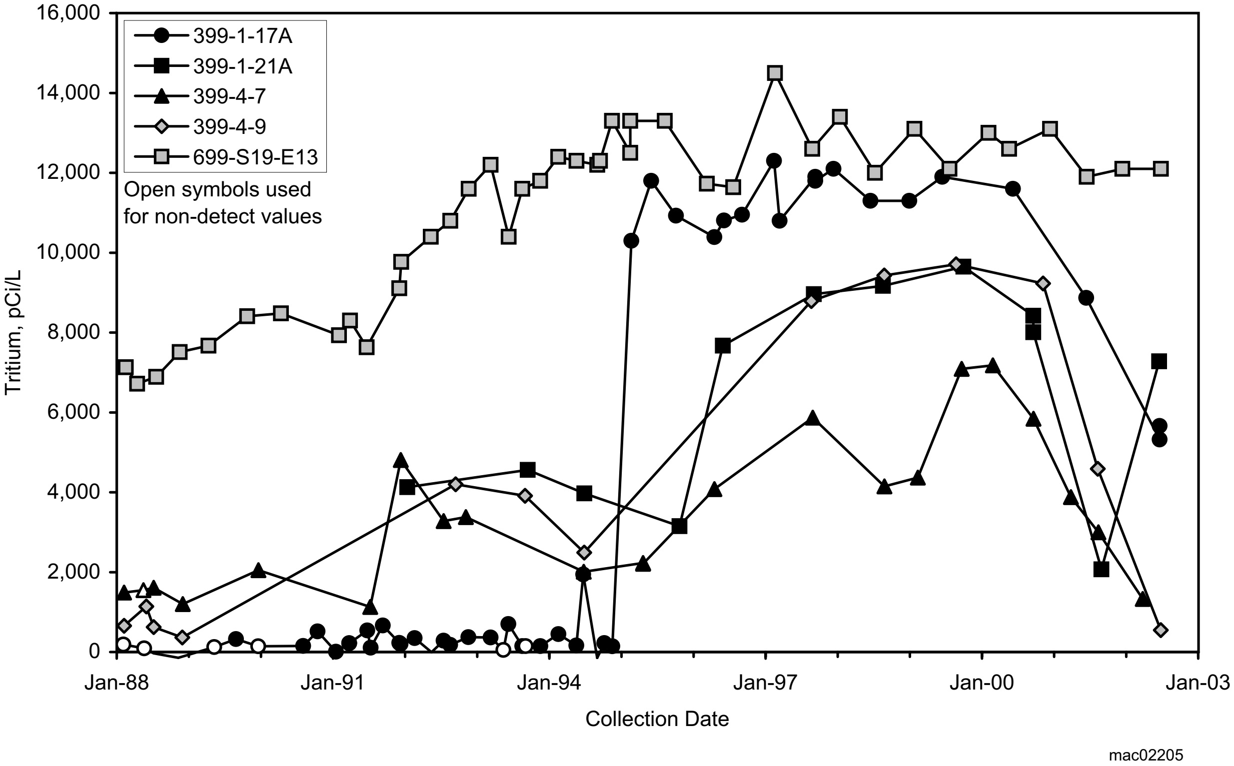

Figure 2.13-7. Tritium Concentrations in Wells Monitoring the 300 Area

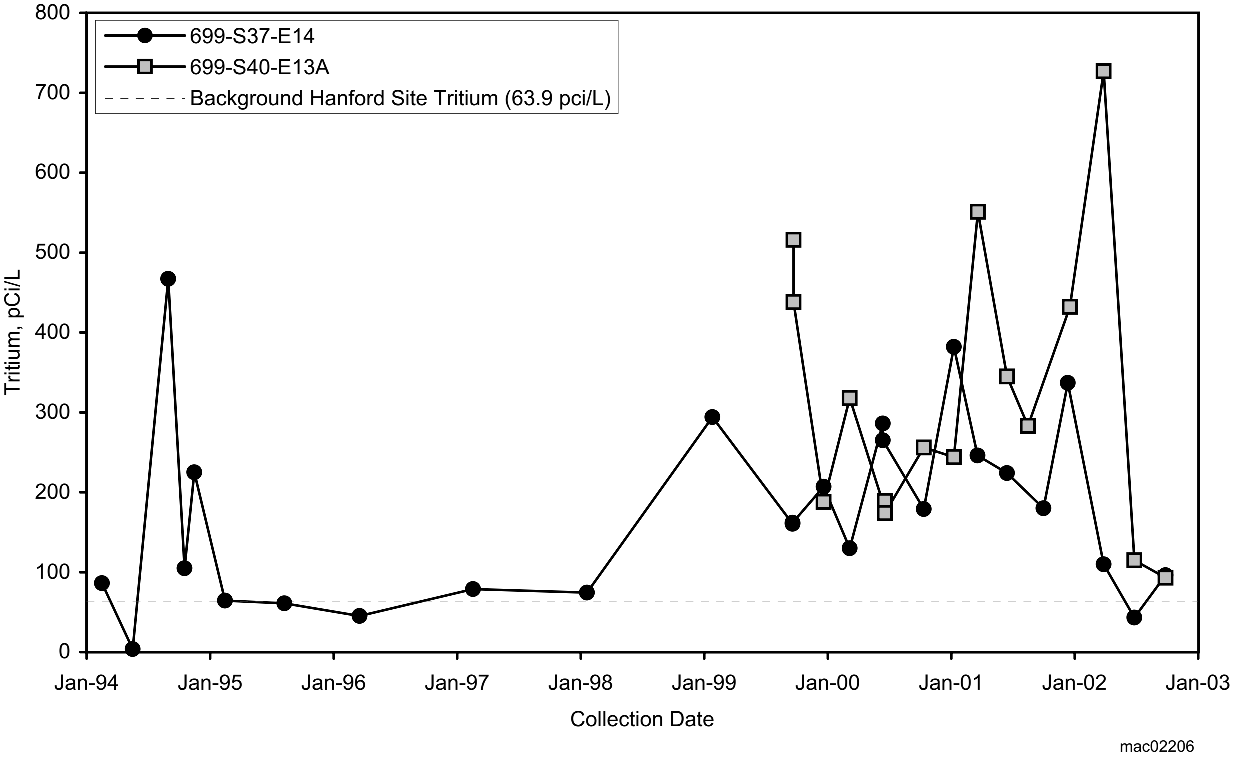

Figure 2.13-8. Tritium Concentrations in Wells Monitoring the Richland North Area

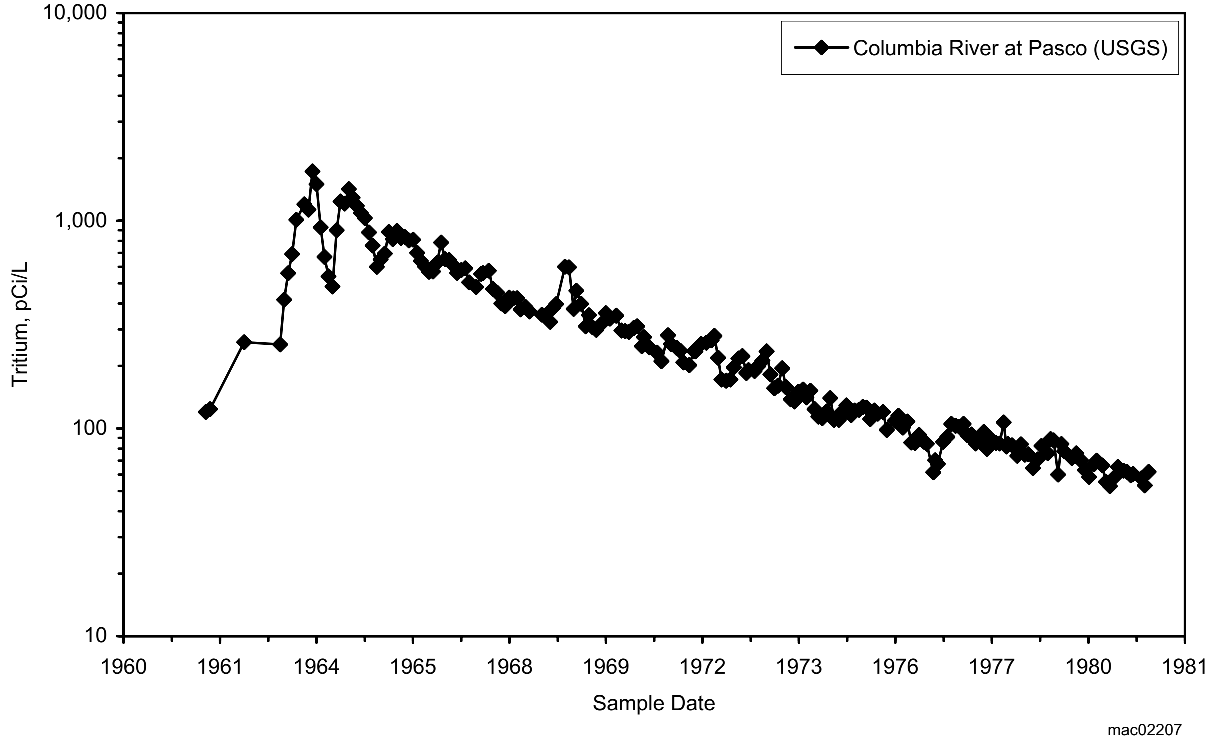

Figure 2.13-9. Tritium Concentrations in Columbia River Water

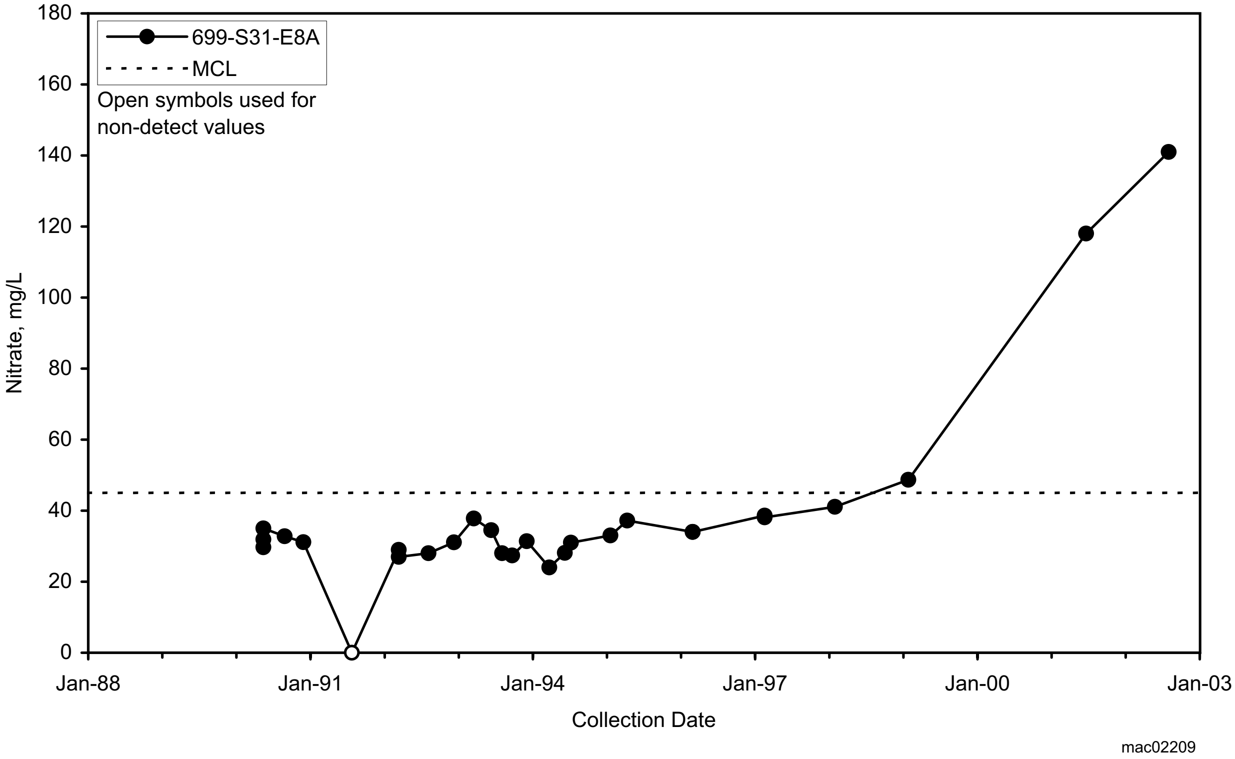

Figure 2.13-10. Nitrate Concentrations Near Framatome ANP Richland, Inc. and U.S. Department of Energy's Inactive Horn Rapids Landfill

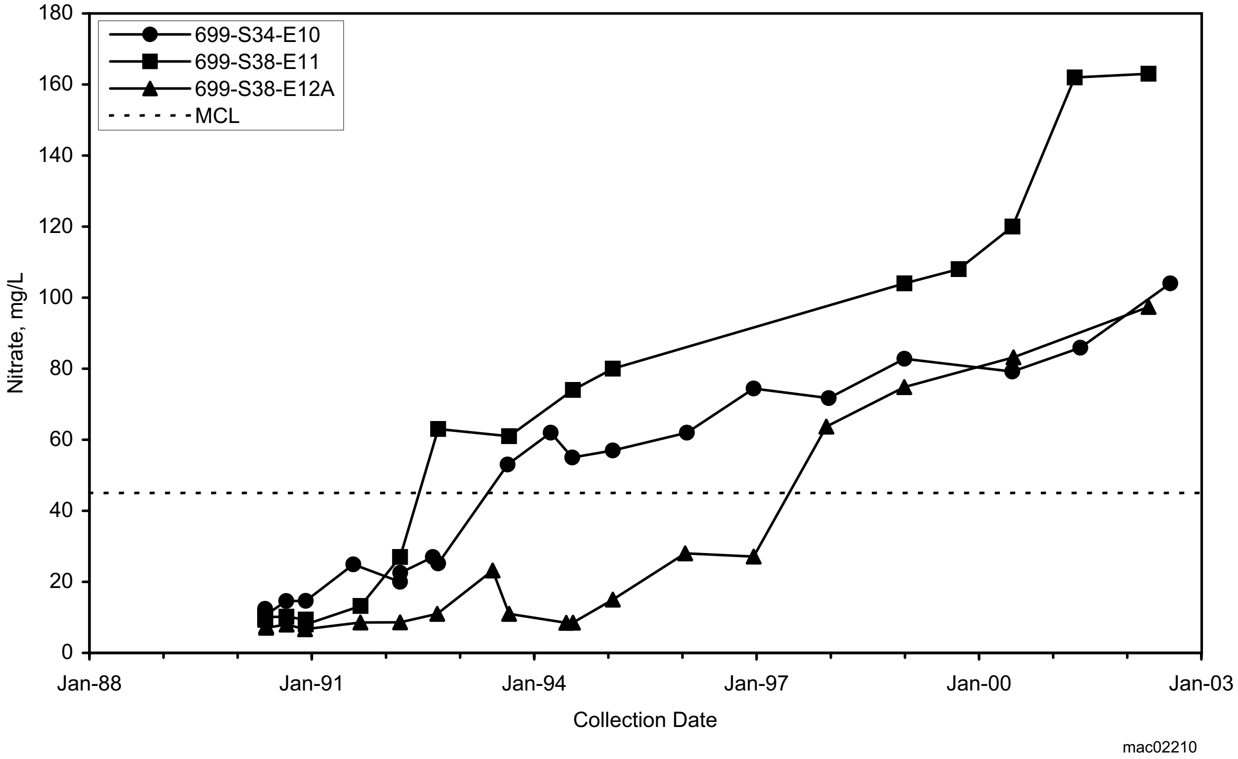

Figure 2.13-11. Nitrate Concentrations in Wells Northwest of the North Richland Well Field and Recharge Ponds

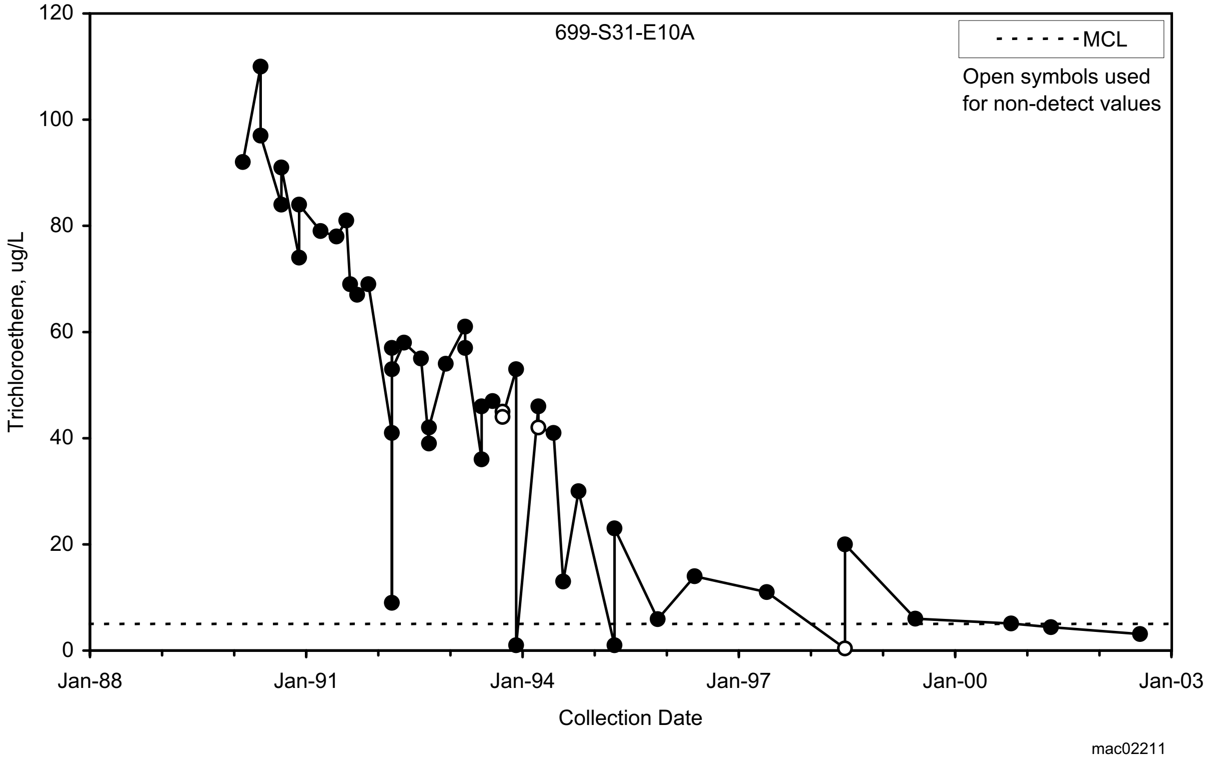

Figure 2.13-12. Trichloroethene Concentrations in the Upper Part of the Unconfined Aquifer Near the U.S. Department of Energy's Inactive Horn Rapids Landfill

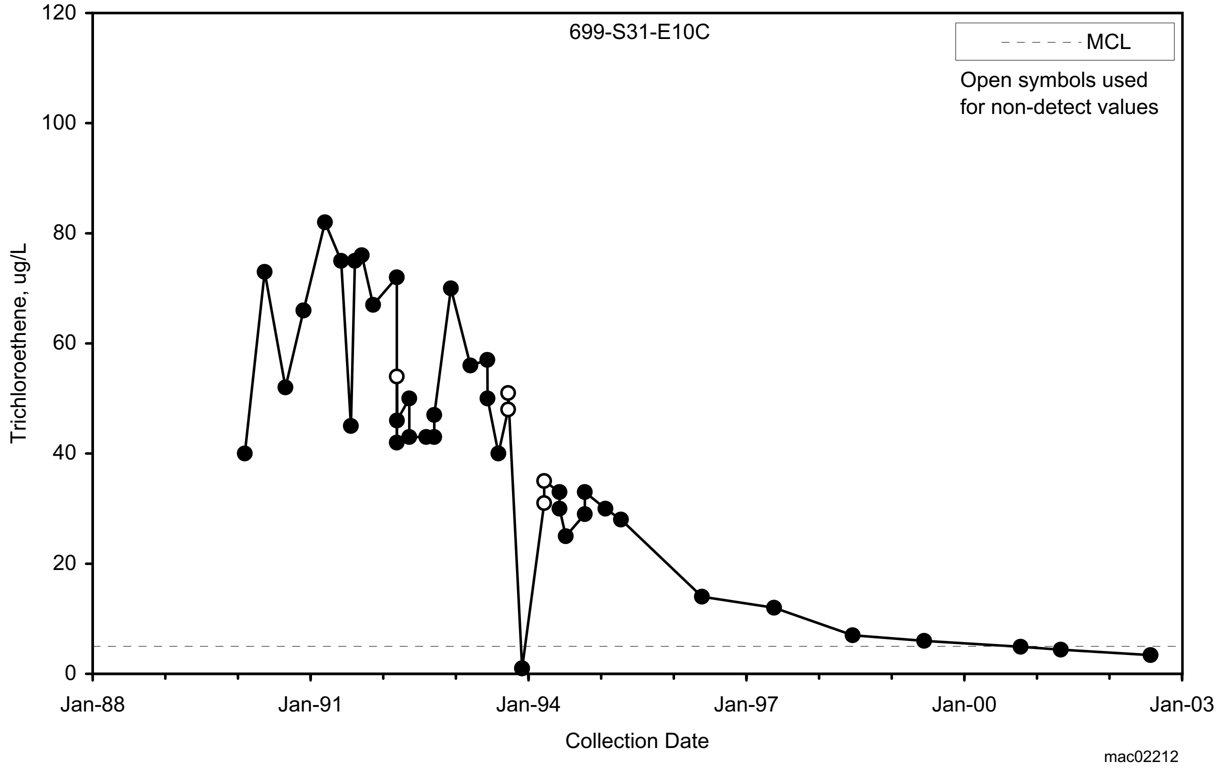

Figure 2.13-13. Trichloroethene Concentrations in the Deep Portion of the Unconfined Aquifer Near the U.S. Department of Energy's Inactive Horn Rapids Landfill

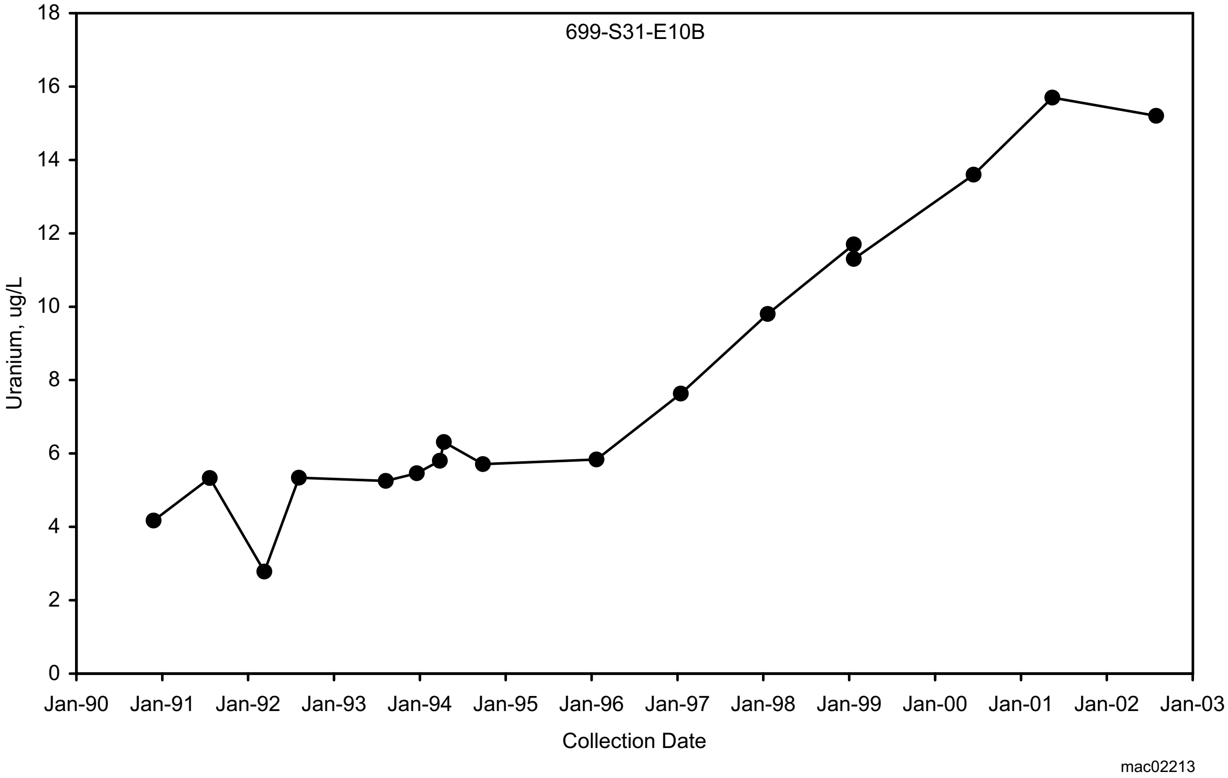

Figure 2.13-14. Uranium Concentrations Near the U.S. Department of Energy's Inactive Horn Rapids Landfill

2.14 Upper Basalt-Confined Aquifer

D. R. Newcomer and J. P. McDonald

Upper basalt-confined aquifer groundwater quality is monitored because of the potential for downward migration of contaminants from the overlying unconfined aquifer. Contaminants that reach the upper basalt-confined aquifer have the potential to migrate through this aquifer and deeper confined aquifers to areas off the Hanford Site. The upper basalt-confined aquifer is also monitored to assess the potential migration of contaminants onto the Hanford Site from offsite sources.

The quality of groundwater in the upper basalt-confined aquifer is monitored because of the potential for downward migration of contaminants from the overlying unconfined aquifer.

The upper basalt-confined aquifer is affected much less from contamination than the overlying unconfined aquifer system. Contamination found in the upper basalt-confined aquifer is most likely attributed to areas where confining units of basalt have been eroded away or were never deposited and where past disposal of large amounts of wastewater resulted in downward hydraulic gradients. In some areas, wells penetrating the upper basalt-confined aquifer system provided a downward pathway for contaminant migration. Because of these factors, intercommunication between the aquifers permitted groundwater flow from the unconfined aquifer to the underlying confined aquifer, thereby increasing the potential to spread contamination.

An area of intercommunication between the unconfined and upper basalt-confined aquifer systems was first identified in the north part of the 200 East Area (RHO-BWI-ST-5; RHO-RE-ST-12 P). Several confined aquifer wells north and east of the 200 East Area have shown evidence of intercommunication with the overlying unconfined aquifer (PNL-10817). Intercommunication between the

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In the area of Gable Mountain, shown above, erosion into the basalt or lack of deposition has resulted in isolated communication between the unconfined aquifer and the upper basalt-confined aquifer.

unconfined and confined aquifers in this region has been attributed to erosion of the upper Saddle Mountains Basalt and a downward hydraulic gradient that resulted from groundwater mounding associated with past wastewater disposal to the ground. However, the groundwater mound has diminished in recent years (see Section 2.14.1).

Contaminants have the potential to migrate to areas off the Hanford Site after reaching the upper basalt-confined aquifer system. Several potential offsite migration pathways for contaminants within the upper basalt-confined aquifer have been identified (PNL-10817). These pathways include

- migration across the south boundary of the Hanford Site
- migration across the east-southeast boundary of the Hanford Site
- migration to deeper confined aquifers in the Gable Mountain-Gable Butte structural area

The potential exists for contaminants to migrate off the Hanford Site. However, groundwater monitoring results indicate that contaminants have not migrated off the Hanford Site to the south and southeast, toward urban development.

The potential exists for contaminants to migrate through the upper basalt-confined aquifer across the south boundary of the Hanford Site to offsite areas. The potential for contaminants to migrate across this boundary is highly uncertain because of a lack of hydrogeologic and hydrochemical data for the upper basalt-confined aquifer in this area. However, urban development and agricultural activity continues to increase in this region. As a result, groundwater use from sources within the upper basalt-confined aquifer system continues to increase in response to the demand to meet agricultural, municipal, and domestic needs. A limited investigation on the hydrogeology and hydrochemistry of this region was reported in PNNL-14107 (see Section 2.14.3).

The potential for offsite migration of contaminants across the east-southeast boundary of the Hanford Site is low for several reasons. Lateral groundwater flow velocities along this flow path are low in the upper basalt-confined aquifer. The Columbia River forms a discharge area for the upper basalt-confined aquifer in this region, and high hydraulic head conditions east of the river inhibit eastward flow across this boundary.

Contaminants that reach the upper-basalt confined aquifer in the Gable Mountain-Gable Butte structural area have the potential to migrate downward to transmissive Wanapum Basalt aquifers underlying the Saddle Mountains Basalt. A potential for offsite migration through the deep Wanapum Basalt aquifers exists because of highly transmissive interflow aquifers within the Wanapum Basalt, their deep hydrogeologic setting, and offsite regional uses for agricultural and domestic water supply. However, the potential for offsite migration through this pathway is uncertain.

2.14.1 Groundwater Flow

Confined groundwater generally flows from west to east beneath the Hanford Site, eventually discharging to the Columbia River through the unconfined aquifer.

Within the upper basalt-confined aquifer system, groundwater occurs within basalt fractures and joints, interflow contacts, and sedimentary interbeds within the upper Saddle Mountains Basalt (see Section 3.1.1 of PNNL-13080). The thickest and most widespread sedimentary unit in this system is the Rattlesnake Ridge Interbed, which is present beneath much of the Hanford Site. Groundwater also occurs within the Levey Interbed, which is present only in the south portion of the site. An interflow zone occurs within the Elephant Mountain member of the upper Saddle Mountains Basalt, and also may be significant to the lateral transmission of water. This system is confined by the dense, low-permeability, interior portions of basalt flows and in some places by Ringold Formation silt and clay units overlying the basalt. Groundwater flow rates within the Rattlesnake Ridge Interbed have been estimated to be between 0.7 and 2.9 meters per year (PNL-10817). This flow rate is considerably slower than most estimates for the overlying unconfined aquifer system.

Recharge to the upper basalt-confined aquifer system is believed to occur along the margins of the Pasco Basin and results from the infiltration of precipitation and surface water where the basalt and interbeds are exposed at ground surface. Recharge also may occur through the Hanford/Ringold aquifer system in areas where the hydraulic gradient is downward. Recharge may also occur from deeper basalt aquifers where an upward gradient is present. The Columbia River represents a regional discharge area for this aquifer system, at least in the south portion of the site. Discharge also occurs to the overlying Hanford/Ringold aquifer system in areas where the hydraulic gradient is upward. Discharge to overlying or underlying aquifers in the vicinity of the Gable Butte-Gable Mountain structural area may occur through erosional windows in the basalt.

The groundwater project measures hydraulic heads annually in the upper basalt-confined aquifer system. Figure 2.14-1, constructed by manual contouring, presents an approximation of the March 2002 potentiometric surface for this aquifer system south of Gable Butte and Gable Mountain. Measurements in the Rattlesnake Ridge Interbed (17 wells), the Levey Interbed (2 wells), and the Elephant Mountain Interflow zone (1 well) were primarily used to construct this map. Additional measurements in the upper Saddle Mountains Basalt (10 wells) were used for general contouring. The monitoring well network used for hydraulic head monitoring is presented in PNNL-13021. The region to the north of Gable Butte and Gable Mountain was not contoured because of insufficient well control. See PNL-8869 for a generalized potentiometric surface map of this area.

South of the Umtanum Ridge/Gable Mountain area, groundwater in the upper basalt-confined aquifer system generally flows from west to east across the Hanford Site toward the Columbia River. The elevated regions to the west and southwest of the site are believed to be recharge areas for this aquifer system, and the Columbia River represents a discharge area. The Yakima River may also be a source of recharge.

In the vicinity of the 200 East Area, the potentiometric surface in Figure 2.14-1 is similar to the potentiometric surface for the Ringold Formation confined aquifer (compare with Figure 2.9-29). The basalt in this area was significantly eroded by late Pleistocene catastrophic flooding (RHO-BWI-LD-5), which facilitates aquifer intercommunication. A diagnostic water level-barometric response analysis conducted at wells 699-49-57A (unconfined aquifer) and 699-49-57B (Rattlesnake Ridge Interbed) indicate that the Rattlesnake Ridge Interbed behaves as an unconfined aquifer in this area. In the vicinity of the 200 East Area and to the immediate north, the vertical hydraulic gradient between the upper basalt-confined aquifer system and the overlying Hanford/Ringold aquifer system is upward. Therefore, it is likely the upper basalt-confined aquifer system currently discharges to the overlying Hanford/Ringold aquifer system in this region.

Water-table and potentiometric surface maps of the upper basalt-confined aquifer system (see Figure 2.14-1), the unconfined aquifer (see Figure 2.1-1), and the Ringold Formation confined aquifer (see Figure 2.9-29) indicate that a downward hydraulic gradient from the Hanford/Ringold aquifer system to the upper basalt-confined aquifer occurs in the west portion of the Hanford Site, in the vicinity of the B Pond recharge mound, as well as in the regions north and east of the Columbia River. In the vicinity of B Pond, the vertical head gradient between the unconfined aquifer system and the upper basalt-confined aquifer system has diminished in recent years, but remains downward. In other areas of the Hanford Site, the hydraulic gradient is upward from the upper basalt-confined aquifer to the Hanford/Ringold aquifer system.

A downward hydraulic gradient from the Hanford/Ringold aquifer system to the upper basalt-confined aquifer occurs in the west portion of the Hanford Site, near the B Pond recharge mound, and in the regions north and east of the Columbia River. In other areas of the Hanford Site, the hydraulic gradient is upward from the upper basalt-confined aquifer to the Hanford/Ringold aquifer system.

Water levels in the upper basalt-confined aquifer beneath the Hanford Site declined over the period from March 2001 to March 2002. The decline in the 200 East Area and to the immediate north and east (near B Pond) ranged from -0.14 to -0.29 meter over the 12-month period (well 699-51-36B had an increase of 0.18 meter). Water level declines near the 200 West Area ranged from -0.07 to -0.35 meter. These declines are in response to curtailed effluent disposal activities in the 200 Areas and are consistent with water-level declines in the overlying Hanford/Ringold aquifer system.

The maximum hydraulic head associated with the B Pond groundwater mound has shifted to the northeast since periodic monitoring of the upper basalt-confined aquifer system began in 1991. Figure 2.14-2 shows a trend plot of hydraulic head at well 699-42-40C (located at B Pond and formerly the approximate center of the groundwater mound) and well 699-51-36B (the current approximate center of the groundwater mound). This figure shows that water levels beneath B Pond peaked higher and earlier and are now declining more rapidly than the water level at well 699-51-36B. This more rapid decline beneath B Pond causes the apparent shift in the groundwater mound. The May Junction Fault, located east of B Pond and trending north-south, acts as a barrier to groundwater flow in Hanford/Ringold aquifer system (PNNL-12261). It may also impede the movement of water in the upper basalt-confined aquifer system, which would explain the shifting of the groundwater mound toward the east.

2.14.2 Groundwater Quality

Figure 2.14-3 shows the locations of the upper basalt-confined aquifer monitoring wells on the Hanford Site. Most of the wells are completed in the Rattlesnake Ridge Interbed near the 200 East Area in the central part of the Hanford Site. A few wells are completed in the Elephant Mountain interflow zone, the Levey Interbed, or a composite of one or more interbeds and /or interflow zones within the upper Saddle Mountains Basalt.

Approximately 20 wells completed in the upper basalt-confined aquifer system are routinely sampled on the Hanford Site, according to the current sampling schedule (PNNL-14111). Sixteen of these wells are sampled every three years, and three are sampled annually.(a) During fiscal years 2000 through 2002, 23 samples were collected from these wells and analyzed for chemical and radiological constituents. Many of the samples were analyzed for tritium, iodine-129, and nitrate because these constituents (1) are the most widespread in the overlying unconfined aquifer, (2) are some of the most mobile constituents in groundwater, and (3) provide an early warning for potential contamination in the upper basalt-confined aquifer system. Groundwater samples from the upper basalt-confined aquifer were also analyzed for anions (besides nitrate), cations, cyanide, gross alpha, gross beta, gamma-emitters, strontium-90, technetium-99, and uranium isotopes. Data for the primary constituents of interest are listed in Table 2.14-1. A full data set is included in the data files that accompany this report.

Distribution of sample results for selected constituents and wells across the Hanford Site for fiscal years 2000 through 2002 is shown in Figure 2.14-4. Elevated tritium in the upper basalt-confined aquifer is limited to one well near the Gable Mountain/200 East Area. This well (699-42-40C) contained 5,770 pCi/L tritium in 2000, but concentrations have been decreasing since 1996 (Figure 2.14-5). Nearby wells completed in the overlying Ringold Formation contain tritium at levels exceeding the 20,000-pCi/L drinking water standard (see Section 2.9.3).

(a) One well was dropped from the sampling schedule after fiscal year 2000.

However, tritium trends in these wells have been declining, as represented by well 699-43-41E in Figure 2.14-5. Tritium over most of the Hanford Site (excluding the Gable Mountain/200 East Area) ranged from less than the detection limits near the discharge area in the east-southeast portion of the Hanford Site to 43.3 pCi/L at a recharge area near the Yakima River. Near the 618-11 burial ground, where a source of tritium has contaminated the unconfined aquifer at high levels, tritium was detected at a concentration of 25.3 pCi/L in the upper basalt-confined aquifer in fiscal year 2001.

In the north part of the 200 East Area, technetium-99 is elevated in the upper basalt-confined aquifer in one well (see Figure 2.14-4). The technetium-99 concentration was 1,120 pCi/L in this well (299-E33-12) in 2001. However this level, which exceeds the 900-pCi/L drinking water standard, is slightly lower than concentrations in the last ~10 years (Figure 2.14-6). Contamination in this well is attributed to migration of high-salt waste down the borehole during construction when it was open to both the unconfined and confined aquifers (RHO-RE-ST-12 P). This well is located in the vicinity of a technetium-99 plume in the overlying unconfined aquifer (see Section 2.9.1.4). Technetium-99 levels have generally been higher and more variable in the unconfined aquifer, as represented by the trend plot for well 299-E33-13 (see Figure 2.14-6).

Most of the samples collected from upper basalt-confined aquifer wells near the Gable Mountain/200 East Area were analyzed for iodine-129. These wells are located beneath or near the iodine-129 plume contained within the overlying unconfined aquifer. Iodine-129 was not detected in the upper basalt-confined aquifer during fiscal years 2000 through 2002 (see Table 2.14-1).

Cyanide and nitrate are elevated in an upper basalt-confined aquifer well (299-E33-12) in the north part of the 200 East Area (see Figure 2.14-4). However, these co-contaminants are at levels that do not exceed their respective drinking water standards. Concentrations of cyanide and nitrate have not changed significantly at this well in the last ~10 years (Figure 2.14-7). Like technetium-99, this contamination is associated with migration of high-salt waste down the borehole during well construction when it was open to both the unconfined and confined aquifers (RHO-RE-ST-12 P). Cyanide and nitrate are co-contaminants with much higher concentrations in the unconfined aquifer in the north part of the 200 East Area.

Elevated concentrations of cyanide, nitrate, and technetium-99 present in the overlying unconfined aquifer, were detected in one basalt-confined well in the northwest 200 East Area. Another basalt-confined well near the former B Pond has slightly elevated tritium. Other basalt-confined wells are uncontaminated.

Table 2.14-1 indicates that the majority of wells showing elevated nitrate in the upper basalt-confined aquifer occur near Gable Mountain and the 200 East Area. Elevated nitrate in the upper basalt-confined aquifer is a hydrochemical indicator of intercommunication with the overlying contaminated unconfined aquifer (RHO-BWI-ST-5; RHO-RE-ST-12 P; PNL-10817). Across the rest of the Hanford Site, nitrate levels in the upper basalt-confined aquifer ranged from less than detectable to ~1 mg/L in fiscal years 2000 through 2002.

Strontium-90 from four upper basalt-confined aquifer wells showed concentrations below the minimum detection limits during fiscal years 2000 and 2001 (see Table 2.14-1). Two of these wells are located near the former Gable Mountain Pond in the central part of the Hanford Site (see Figure 2.14-4), where strontium-90 contamination occurs in the overlying unconfined aquifer. Moderately mobile in groundwater, strontium-90 contamination in the unconfined aquifer is not expected to migrate to and reach detectable levels in the upper basalt-confined aquifer.

A few samples collected from upper basalt-confined aquifer wells were analyzed for gamma-emitting and uranium isotopes. Gamma-emitting isotopes were not detected in the upper basalt-confined aquifer on the Hanford Site, including the Gable Mountain/200 East Area. Uranium isotopes were not detected in this aquifer in the east part of the Hanford Site during fiscal years 2000 through 2002 (see Figure 2.14-4).

In summary, elevated tritium in the upper basalt-confined is limited to one location near the former B Pond in the Gable Mountain/200 East Area, but concentrations have been decreasing. Cyanide, nitrate, and technetium-99 are elevated in an upper basalt-confined aquifer well in the north part of the 200 East Area. Migration of high-salt waste via the well during its construction caused this contamination. Contaminants on the Hanford Site have not migrated through the upper basalt-confined aquifer system to several offsite sample locations south and southeast of the Hanford Site (PNNL-14107).

Table 2.14.1. Potential Contaminants in Upper Basalt-Confined Aquifer, Fiscal Years 2000 Through 2002

Well	Sample Date	Cesium-137 (pCi/L)	Cobalt-60 (µg/L)	Cyanide (mg/L)	Gross alpha (pCi/L)	Gross beta (pCi/L)	Iodine-129 (pCi/L)	Nitrate (µg/L)	Specific Conductance (µS/cm)	Strontium-90 (pCi/L)	Technetium-99 (pCi/L)	Tritium (pCi/L)
199-H4-2	07/20/00	NA	NA	NA	-0.2 U	10.50	NA	0.080 B	239	-0.08 U	NA	-1.2 U
299-E26-8	05/03/00	NA	NA	NA	NA	NA	0.09 U	3.9	309	NA	NA	20.80 G
299-E33-12	06/12/01	1.07 U	4.37 U	29	2.10	330	0.21 U	37.6	341	NA	1,120	194
399-5-2	06/14/01	NA	NA	NA	0.25 U	9.84	NA	0.009 U	351	NA	NA	7.55(a)
699-13-1C	02/08/00	-1.26 U	2.19 U	NA	0.56 U	7.32	0.12 U	0.102	330	0.28 U	-5.7 UP	110 U
699-13-1C	06/28/01	NA	NA	NA	0.83 U	6.82	NA	0.009 U	336	NA	NA	25.20
699-22-70	05/15/00	NA	NA	NA	NA	NA	NA	9.3 D	377	NA	NA	3.32 U
699-24-1P	11/01/01	NA	NA	NA	4.18	12.3	NA	0.0089 U	378	NA	NA	11.5
699-32-22B	05/15/00	NA	NA	NA	NA	NA	0.05 U	0.328	366	NA	NA	7.13 J
699-42-40C	05/18/00	NA	NA	NA	NA	NA	0.32 U	4.87	329	NA	NA	5,770
699-42-E9B	05/16/00	4.55 U	-1.28 U	NA	0.23 U	8.53	-0.051 U	0.062 B	424	NA	NA	9 J
699-42-E9B	05/15/01	-1.05 U	1.45 U	NA	0.87 U	9.88	0.24 U	0.009 U	420	NA	NA	4.61 U
699-42-E9B	08/09/02	1.64 U	-3.26 U	NA	0.42 U	5.84	-0.075 U	0.0195 U	425	NA	NA	1.2 U
699-49-57B	06/13/01	NA	NA	NA	2.18	5.29	0.14 U	1.11	301	NA	-5.49 U	21.80
699-50-53B	04/26/00	NA	NA	1.60 U	NA	8.31	0.038 U	11.1	359	NA	-6.5 UP	84 U
699-52-46A	06/13/01	NA	NA	NA	3.52	8.28	NA	1.64	340	0.18 U	NA	20.60
699-54-34	06/13/01	NA	NA	NA	0.75 U	7.05	NA	16.4 DH	315	NA	NA	15.80
699-56-43	06/14/01	NA	NA	NA	2.94	4.35	NA	4.87 D	321	NA	NA	8.96
699-56-53	05/01/00	3.97 U	1.07 U	1.60 U	NA	8.26	0.06 U	0.93	362	0.15 U	16.50 P	-34.6 U
699-S2-34B	08/30/01	NA	NA	NA	NA	NA	0.041 U	0.0089 UH	593	NA	NA	37.5 U
699-S11-E12AP	05/16/00	NA	NA	NA	-0.28 U	6.18	NA	0.062 B	365	NA	NA	7.98 J
699-S11-E12AP	05/29/02	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	18.6
699-S24-19P	07/24/01	NA	NA	NA	NA	NA	NA	1.15	230	NA	NA	43.3 Q
Wells Located South and Southeast of the Hanford Site												
699-ORV-1	11/06/00	NA	NA	NA	0.42 U	5.15	NA	102	245	NA	NA	42.70
09N28E04G01	11/06/00	NA	NA	NA	0.07 U	8.87	NA	49 U	377	NA	NA	46.50
09N28E06C02	11/06/00	NA	NA	NA	0.82 U	10.20	NA	2,570	534	NA	NA	55.60
10N27E14F03	11/06/00	NA	NA	NA	0.90 U	7.07	NA	49 U	282	NA	NA	56.20
10N27E14F03	11/06/00	NA	NA	NA	-0.06 U	8.07	NA	49 U	282	NA	NA	56.40
10N28E24R03	10/27/00	NA	NA	NA	0.57 U	12.20	NA	49 U	382	NA	NA	34.60
10N29E02Q01	10/27/00	NA	NA	NA	-0.18 U	10.70	NA	49 U	456	NA	NA	64.30
10N29E19E01	10/27/00	NA	NA	NA	-0.08 U	11.50	NA	49 U	384	NA	NA	56.10

(a) Sample was re-analyzed because batch blank result exceeded criteria.
B = Greater than minimum detection limit but below the analytical laboratory's required detection limit.
D = Analyzed at a secondary dilution factor.
G = Result is valid according to further review.
H = Analyzed after recommended holding time.
J = Estimated value.
NA = Not analyzed.
P = Potential problem; collection/analysis circumstances make value questionable.
Q = Associated quality control sample is out of limits.
U = Below detection limit.

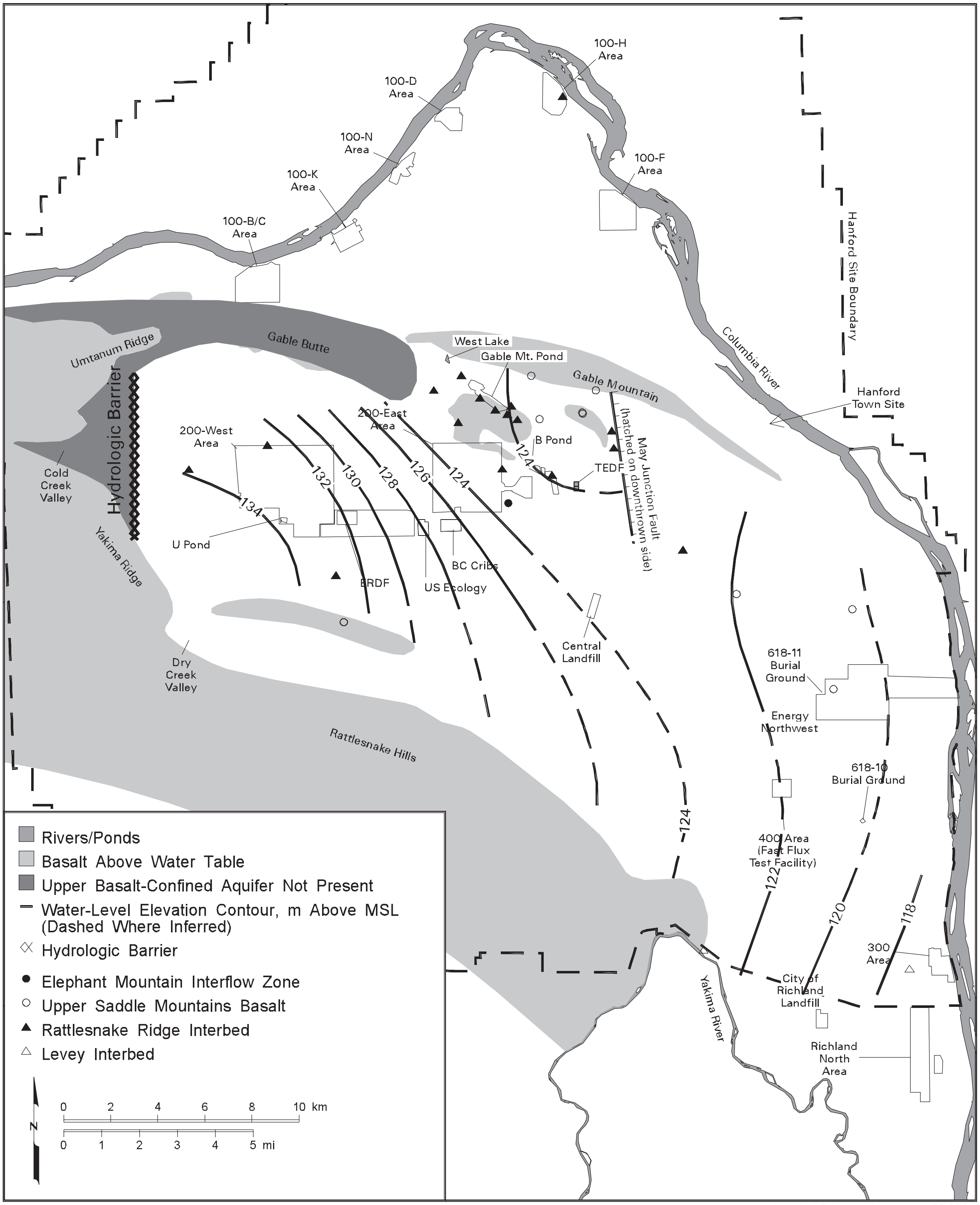

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Figure 2.14-1. Potentiometric Map of Upper Basalt-Confined Aquifer System, March 2002

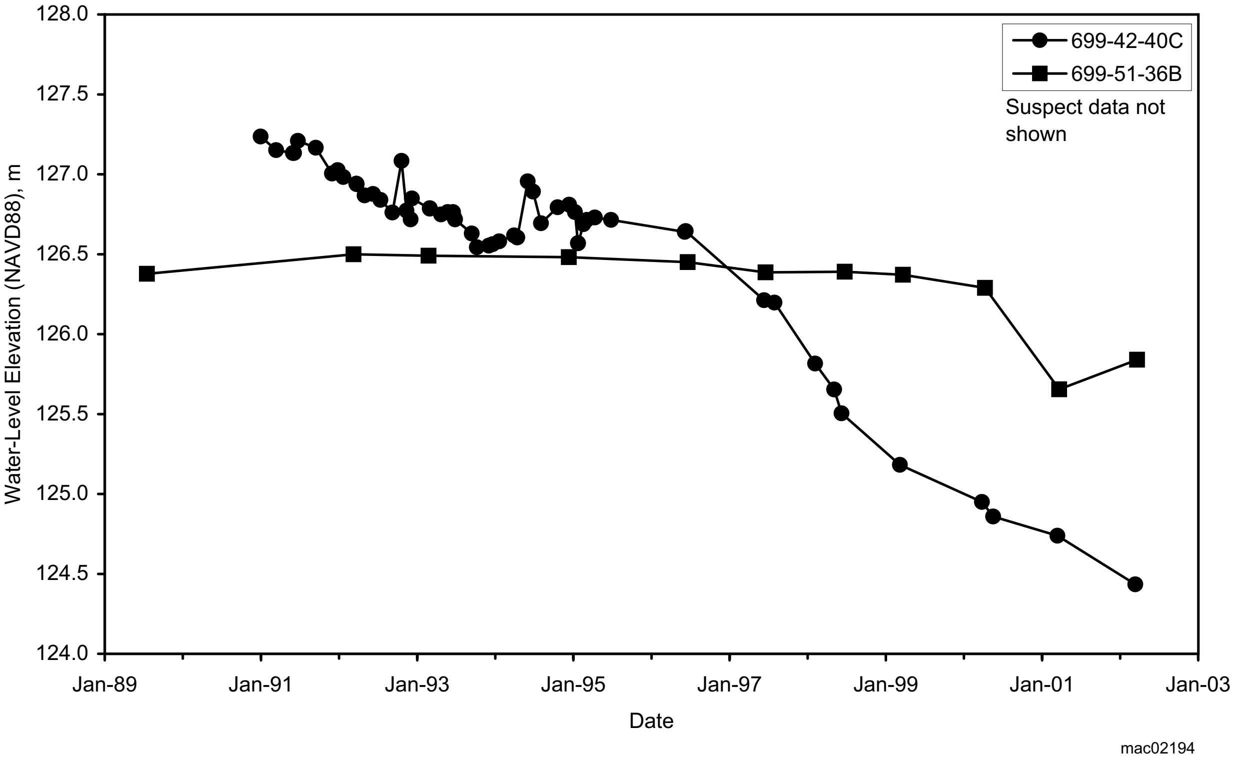

Figure 2.14-2. Water Levels in Upper Basalt-Confined Aquifer in Well 699-42-40C Near B Pond and Well 699-51-36B North of B Pond

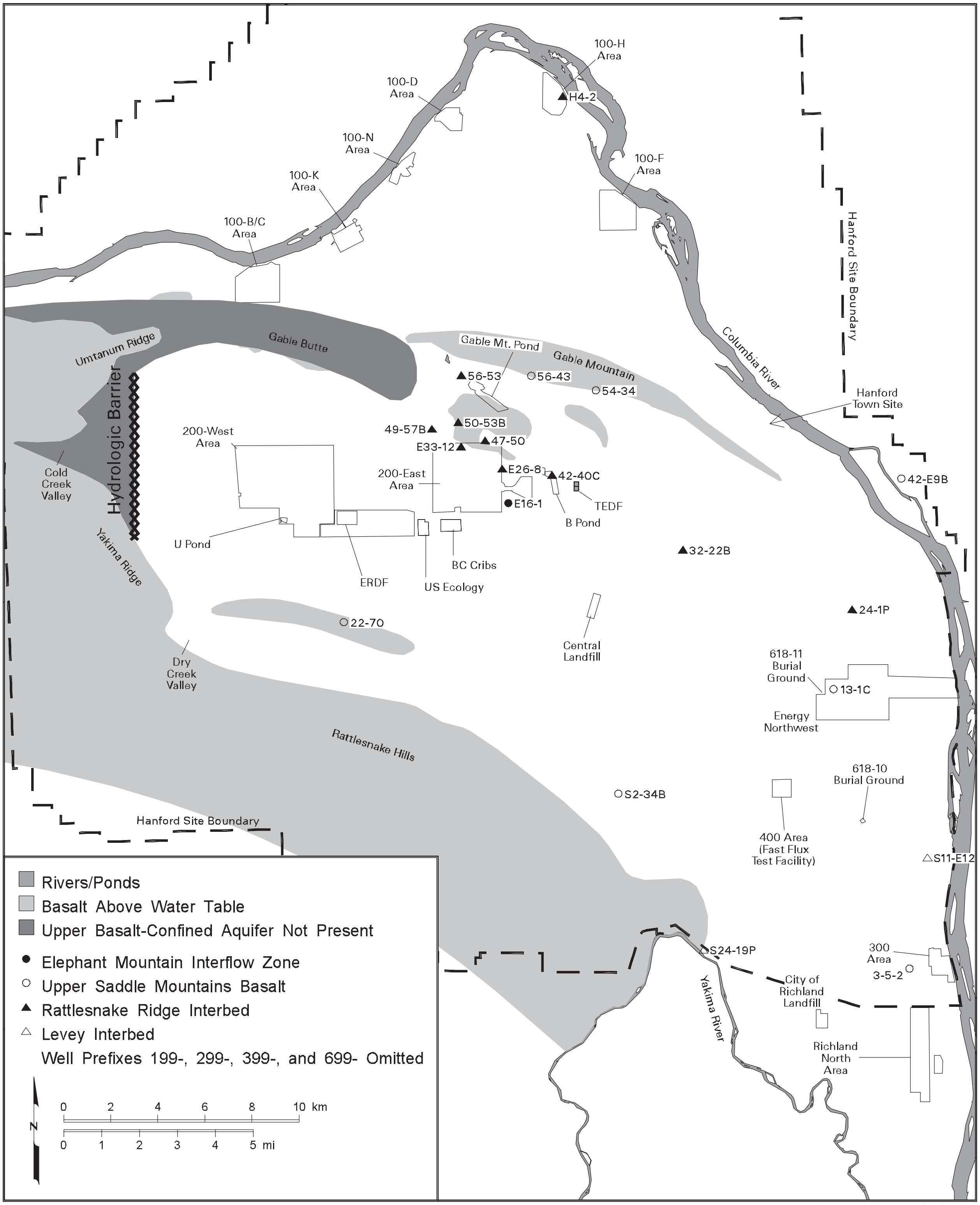

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Figure 2.14-3. Groundwater Monitoring Wells Sampled in the Upper Basalt-Confined Aquifer on the Hanford Site, Fiscal Years 2000 Through 2002

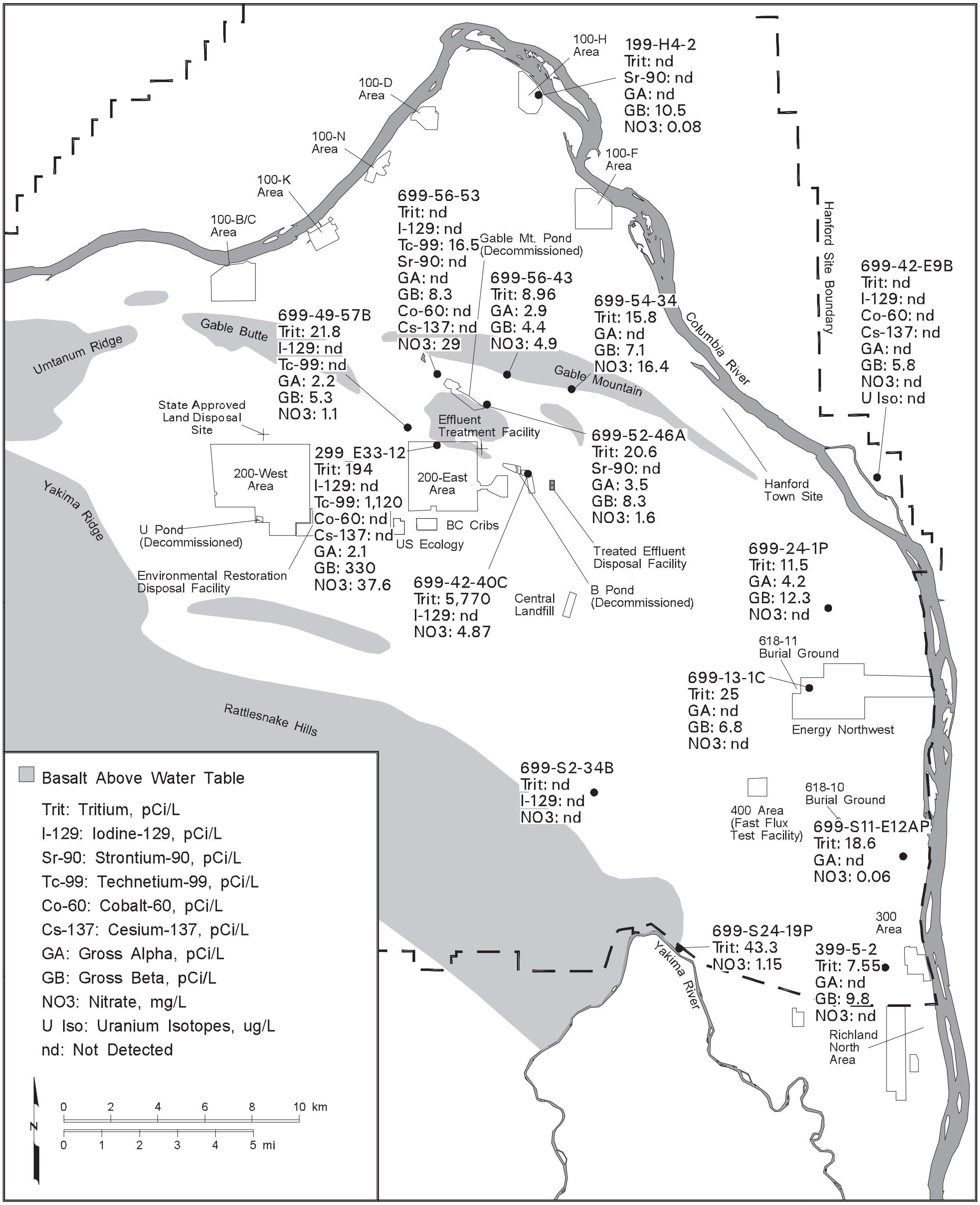

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Figure 2.14-4. Distribution of Chemical and Radiological Constituents in the Upper Basalt-Confined Aquifer, Fiscal Years 2000 Through 2002

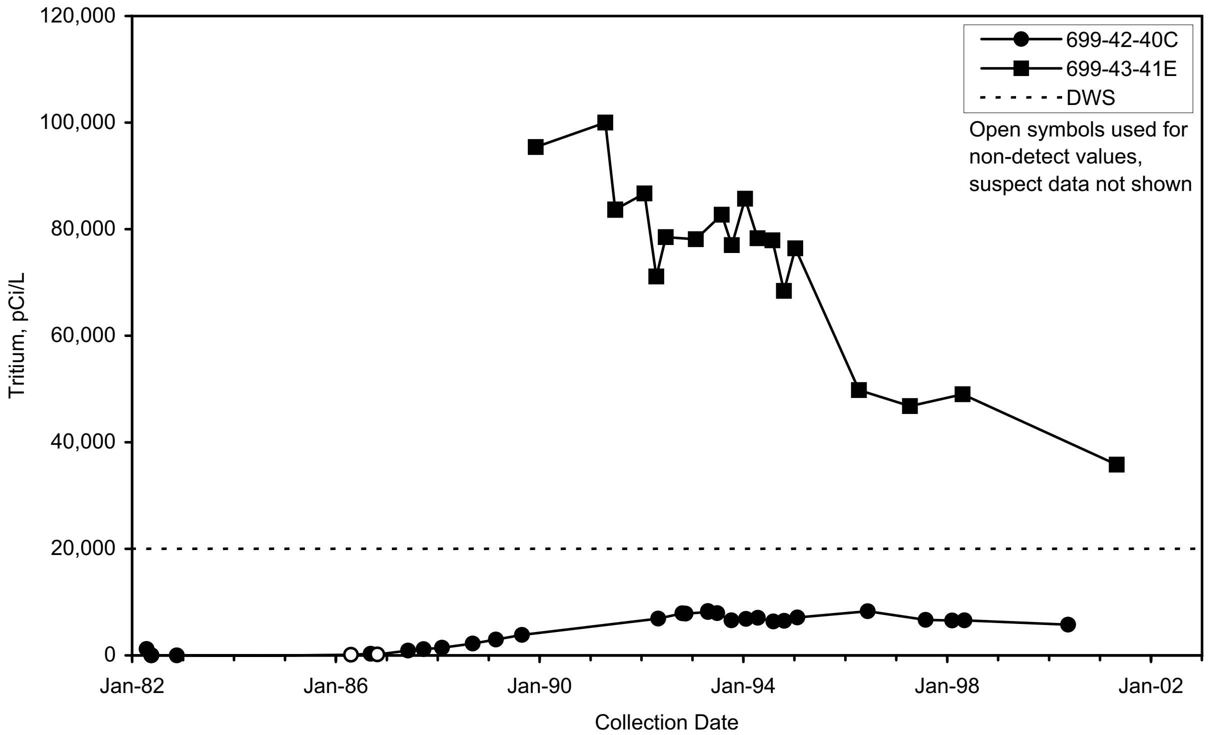


Figure 2.14-5. Tritium Concentrations in Wells 699-42-40C (Upper Basalt-Confined Aquifer) and 699-43-41E (Unconfined Aquifer)

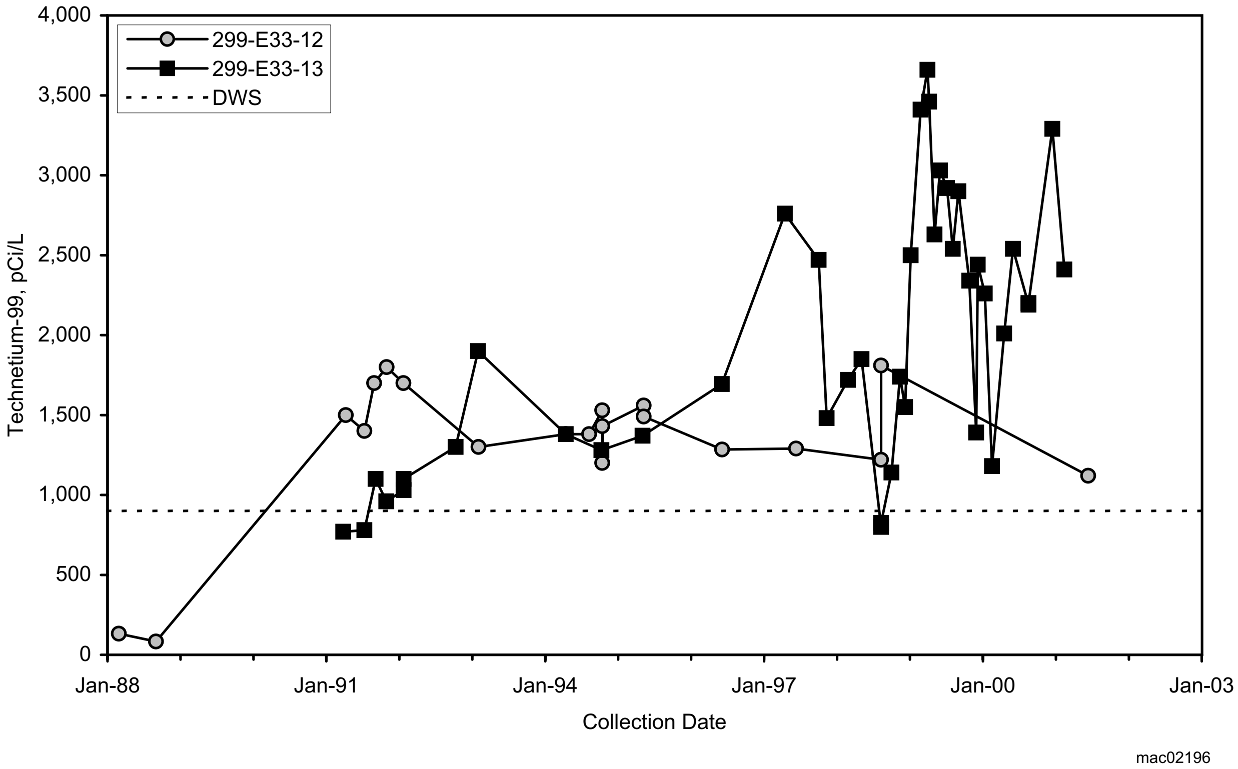


Figure 2.14-6. Technetium-99 Concentrations in Wells 299-E33-12 (Upper Basalt-Confined Aquifer) and 299-E33-13 (Unconfined Aquifer)

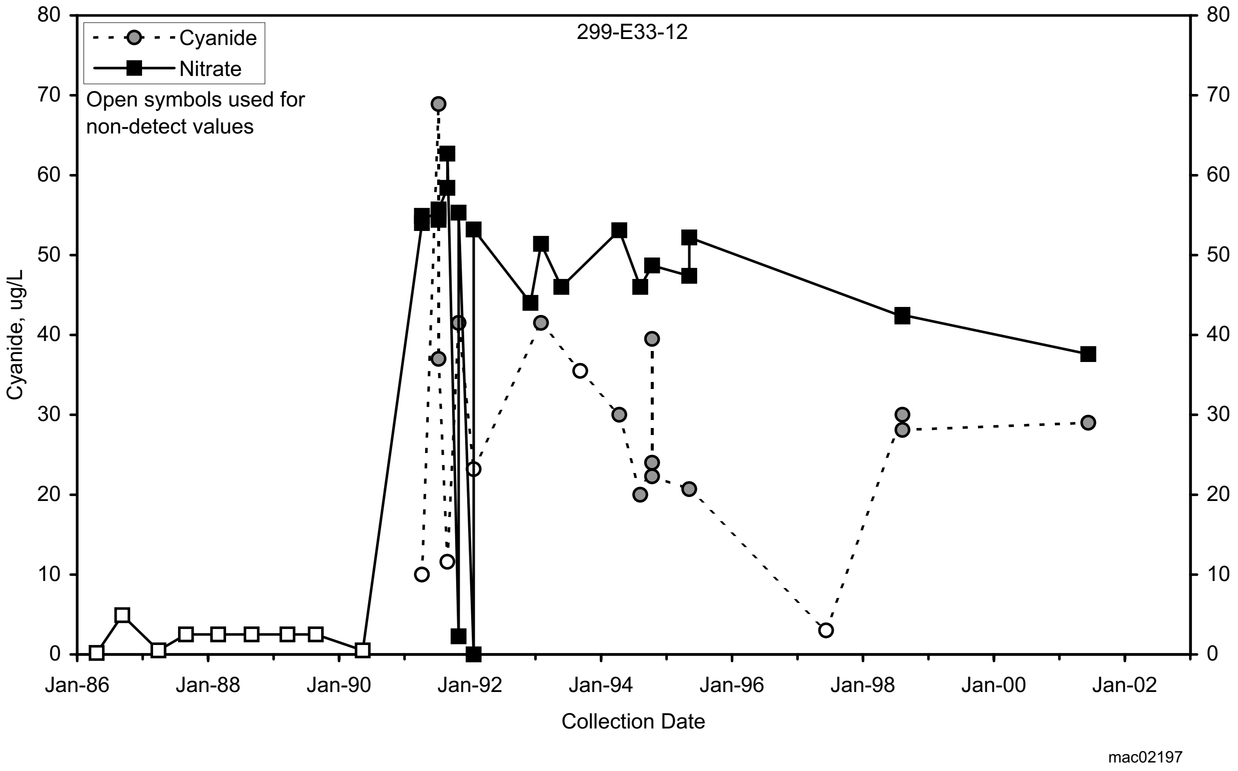


Figure 2.14-7. Cyanide and Nitrate Concentrations in the Upper Basalt-Confined Aquifer

3.0 Vadose Zone

D. G. Horton

Radioactive and hazardous waste in the soil column from past intentional liquid waste disposal, unplanned leaks, solid waste burial grounds, and underground tanks at the Hanford Site are potential sources of continuing and future vadose zone and groundwater contamination. Subsurface source characterization, vadose zone monitoring, and soil-vapor monitoring were conducted during fiscal year 2002 to better understand the distribution of subsurface contaminants and to track the movement of vadose zone contamination. Also, vadose zone remediation and associated characterization to assess post-remediation contamination were done in fiscal year 2002 as part of cleanup efforts at the Hanford Site.

This chapter summarizes major findings from those efforts, focused primarily on vadose zone soil contamination associated with reactor operations, past single-shell tank leaks, and liquid disposal to ground as a result of spent fuel processing. This chapter also summarizes several technical studies whose results could lead to new understandings of moisture and contaminant movement in the vadose zone, contaminant interactions with the soil column, and new and improved methods to characterize and monitor the vadose zone.

An overview of the major soil column sources of groundwater contamination is provided in PNNL-13080. This chapter discusses vadose zone contamination that could affect groundwater in the future. An overall evaluation depends, to a large degree, on integration of vadose zone and groundwater monitoring and characterization data to present a comprehensive picture of contaminant fate and transport. Significant fiscal year 2002 vadose zone results are summarized here. However, the bulk of the data interpretation on the effect to groundwater is present and discussed in Chapter 2.0.

3.1 Vadose Zone Characterization

This section describes significant vadose zone characterization activities that occurred during fiscal year 2002. These characterization activities were done to further the understanding of physical and chemical properties of the vadose zone and vadose zone contamination and to help delimit existing vadose zone contamination. During the year, vadose zone characterization activities were completed to evaluate the effectiveness of the *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA)-related remedial actions and to characterize existing vadose zone contaminant plumes to help plan future CERCLA remedial actions.

The vadose zone is the area between the ground surface and the water table.

Also during the year, several characterization efforts were accomplished at single-shell tank waste management areas. These include drilling and sampling at three new characterization boreholes at single-shell tank Waste Management Area TX-TY to learn more about contaminant distribution, particularly uranium, and contaminant transport mechanisms. The results of extensive geochemical characterization of core samples from Waste Management Area B-BX-BY became available in fiscal year 2002. These data allow comparison of contaminated vadose zone sediments with uncontaminated sediment and to try to determine the leading edge of contaminant plumes beneath single-shell tanks in the waste management area. The same drill cores were used for several laboratory studies to determine the geochemical characteristics of strontium and uranium in the vadose zone at Waste Management Area B-BX-BY.

Finally, characterization of the vadose zone at the location of the proposed Immobilized Low-Activity Waste Disposal Site continued in fiscal year 2002 to support the 2005 Performance Assessment.

P5020001

Borehole 299-E24-21 was drilled at the northeast corner of the immobilized low-activity waste disposal site. The purpose of the borehole was to obtain data about this site and to serve as a groundwater monitoring well for future RCRA monitoring.

3.1.1 Vadose Zone Characterization for Remediation at Past-Practice Disposal Facilities

Vadose zone characterization was completed at five sites in the 200 Areas to support remediation of sites that received waste from past-practice fuel processing. Characterization was completed at the 200-PW-1, 200-TW-1, 200-TW-2, 200-ZP-1, and 200-CS-1 Operable Units. The results of these activities provide needed information to plan remedial activities in those areas. Characterization also was completed at one site in the 100-F Area to assess the effectiveness of remediation in the reactor areas.

3.1.1.1 Characterization of Test Pit 116-F-14

S. W. Clark

Bechtel Hanford, Inc. excavated a test pit in the 116-F-14 retention basin at the 100-FR-1 Operable Unit in 2000 and 2001. The results of sampling the excavated sediment became available in fiscal year 2002. This section summarizes the field observations and analytical results of the excavation and sampling activities. The full description of the activities can be found in BHI-01613. Figure 2.7-1 shows the location of the 116-F-14 retention basin.

The 116-F-14 retention basin received essentially all cooling water effluent from F Reactor when the reactor was operating from 1945 to 1965. The volume of water has not been estimated, but the flow rate ranged from 156,000 to 296,000 liters per minute. The retention basin was made of reinforced concrete and measures 137 by 70 meters and is 7.3 meters deep; it was divided lengthwise into two chambers to hold the cooling water for a brief period of time, allowing radioactive decay and thermal cooling to occur before the water was discharged to the Columbia River. Numerous instances of retention basin leakage and overflows contaminated the soil in the immediate vicinity of the basin, including the soil beneath the basin.

Data from soil samples at the 116-F-14 test pit indicate that, except for arsenic, contaminant levels decrease with increasing depth. The relationship of decreasing concentrations with increasing depth has been observed in remedial action excavations throughout the 100 Areas.

The objective of the excavation and sampling activities was to determine the vertical extent and distribution of contaminants of concern within the vadose zone between the base of the basin and the water table. The test pit was excavated in an open trench with a bottom elevation at about 4.6 meters below the ground surface. The test pit was dug in a 1-meter depression that was the former location of a sump used to transfer process effluent and had formerly been a contamination "hot spot" within the trench.

The test pit was dug with a track hoe excavator. Samples were collected at the surface and at 1-meter intervals to groundwater at a total depth of 8.5 meters below the excavation floor. Nine samples of the vadose zone sediment were sampled.

The soil column underlying the waste site and extending to groundwater consisted of Hanford formation sediments. The sediments were predominantly medium-grained sand to dense sand and gravel, with varying amounts of silt and cobble. The contact between the Hanford formation and the underlying Ringold Formation is ~12 to 18 meters below the ground surface in the area and was not encountered in the excavation.

The soil data indicate that contaminant levels decrease with increasing depth with the exception of arsenic, which increases slightly with depth. This effect at the 116-F-14 site is most pronounced for europium-152, europium-154, and nickel-63, but is also apparent for total chromium, hexavalent chromium, cesium-137, cobalt-60, lead, and mercury. The highest concentrations were found within the first 2 meters below the top of the test pit. Figure 3.1-1 shows concentration trends with depth for several key constituents. The same general profile of decreasing concentrations with increasing depth has been observed for residual contamination in the bottom of remedial action excavations throughout the 100 Areas.

3.1.1.2 Characterization of the 200-TW-1 Scavenged Waste Group Operable Unit

M. E. Todd and C. A. Kahler-Rayer

Geophysical logging and laboratory analysis of sediment samples indicate that changes in sediment texture exert some control over the distribution of many, but not all, contaminants. Some contaminants that typically are not retarded by the sediments are chloride, hexavalent chromium, nitrate, nitrite, and sulfate.

Bechtel Hanford, Inc. drilled borehole C3102 through the 216-T-26 crib in the 200 West Area in 2001 to characterize the nature and vertical extent of contamination as part of the remedial investigation for the 200-TW-1 Scavenged Waste Group Operable Unit (BHI-01606). Field screening results from soil samples, geophysical logging results, and analytical results from 25 soil samples collected from borehole C3102 became available during fiscal year 2002. (See Figure 2.8-1 for the location of the crib.) The site received scavenged waste from uranium recovery and ferrocyanide processes. The 216-T-26 crib received ~12 million liters of liquid waste between August 1955 and November 1956 when the crib was deactivated. In 1975, the top 15 centimeters of soil were removed and replaced with clean fill to grade in order to stabilize the site. In May 1990, the surface of the crib was stabilized.

Waste disposed to the crib consisted of cesium-137; ferrocyanide complexes; fluoride; nitrate; nitrite; phosphate; plutonium; ruthenium-106; sodium compounds including sodium aluminate, sodium hydroxide, and sodium silicate; sulfate; strontium-90; and uranium.

Borehole C3102 was drilled to a total depth of 69.2 meters below ground surface. The upper 6.1 meters are backfill. The Hanford formation extends to a 27.4-meter depth where the Cold Creek unit was encountered between 27.4 to 35.1 meters. The upper Ringold Formation silts and sands are present from 35.1 to 36.6 meters. The Ringold Formation unit E extends from the base of the upper Ringold Formation at 36.6-meter depth to the total depth of the borehole at a 69.2-meter depth.

Soil samples were screened for alpha and beta activity in the field prior to sample collection for indications of contamination, to assist in selecting sample points, for worker safety, and for shipping documentation. The data showed elevated beta-gamma counts from 5.5 to 7.5 meters below ground surface.

Geophysical logging (Figure 3.1-2) detected cesium-137, europium-154, and cobalt-60. Cesium-137 was detected from the ground surface to 18.3 meters below ground surface. The highest cesium-137 concentration exceeded 3,000 pCi/g at about 5.8 and 11.3 meters below ground surface. Europium-154 was detected from a 10.7- to 16-meter depth and cobalt-60 was detected intermittently between 28 and 31 meters below ground surface.

In addition, a vapor sample was collected just above the water table for field analysis of carbon tetrachloride. The sample contained 4.12 parts per million by volume (ppmv) of carbon tetrachloride as well as detectable chloroform, methyl ethyl ketone, and methylene chloride.

Analytical results from soil samples agreed well with the geophysical logs. For example, cesium-137 was detected in soil samples to a depth of at least 10 meters and peaked at 5.5 meters and at 10.4 meters (Table 3.1-1). Peak concentrations for other contaminants typically were reached at 5.5, 10.4, and 28 meters.

Table 3.1-1 summarizes the concentrations of contaminants and depth intervals in which peak concentrations were reached.

Geophysical logging and analysis of sediment samples indicate that the stratigraphy exerts some control over contaminant distribution at the Hanford Site. The contact between the crib backfill and the Hanford formation, gravel-dominated sequence at ~5.5-meter depth is one horizon affecting contaminant distribution. Also, the contact between the Hanford formation upper gravel-dominated sequence and the sand-dominated sequence at ~10-meter depth also affects contaminant distribution. Finally, the Hanford formation-Cold Creek unit contact, at ~28-meter depth appears to influence contaminant distribution. These contacts are places across which significant changes in texture (i.e., grain size) occur. These texture changes result in retardation of many, but not all, contaminants. Contaminants that typically are not retarded by sediment, such as chloride, hexavalent chromium, nitrate, nitrite, and sulfate, were able to reach the total depth of the borehole and the water table at 69 meters below ground surface.

3.1.1.3 Characterization at the 200-PW-1 and 200-ZP-1 Operable Units

The relatively low concentrations of carbon tetrachloride detected in soil vapor from samples along pipelines in the Plutonium Finishing Plant area suggest that any pipeline leaks were small or were naturally remediated by diffusion or evaporation.

V. J. Rohay and D. G. Horton

Investigations were conducted in the 200 West Area at the Plutonium Finishing Plant and 216-Z-9 trench during fiscal year 2002 to support carbon tetrachloride remediation efforts (BHI-01631). Near the Plutonium Finishing Plant, a groundwater extraction/monitoring well (299-W15-42) was installed as part of the 200-ZP-1 Operable Unit investigations to evaluate the distribution of carbon tetrachloride and potentially to enhance groundwater remediation activities (see Figure 2.8-1 for location of well 299-W15-42). At the 216-Z-9 trench, two existing wells (299-W15-84 and 299-W15-95, see Figure 2.8-1) were deepened as part of 200-PW-1 Operable Unit investigations to characterize the distribution of carbon tetrachloride. The deepened wells were completed as soil-vapor extraction wells to enhance vadose zone remediation activities.

Also, soil sampling was conducted in the vicinity of the Plutonium Finishing Plant to characterize the carbon tetrachloride plume as part of the 200-PW-1 remedial investigation.

Carbon Tetrachloride Field Investigation Drilling at the Plutonium Finishing Plant and 216-Z-9 Trench

One well was completed at the Plutonium Finishing Plant site to characterize the distribution of carbon tetrachloride and co-contaminants. The first attempted well (299-W15-764) could not be completed and subsequently was decommissioned. The drill site was relocated farther south and completed as well 299-W15-42. The Hanford formation was found to be 35.7 meters thick in well 299-W15-42 (206.3- to 170.6-meters elevation above mean sea level) and the Cold Creek unit was found to be 4.2 meters thick (170.6- to 166.4-meters elevation above mean sea level). Carbon tetrachloride and co-contaminants chloroform and methylene chloride were detected in soil vapor both above and below the Cold Creek unit. No contaminants were detected in soil samples from either of the two boreholes with the exception of 4 µg/kg of carbon tetrachloride in well 299-W15-764 at an elevation of 169.4 meters above mean sea level. No artificially produced radionuclides were detected in soil samples. High calcium in the Cold Creek unit was reported in the sediment and is associated with paleosols in that formation. A carbon tetrachloride concentration of 1,800 µg/L was detected in groundwater and is consistent with previous investigations. Technetium-99, uranium-238, uranium-233/234, tritium, gross alpha, and gross beta also were detected in groundwater samples, which is consistent with previous investigations.

The results of characterization at the Plutonium Finishing Plant concluded that it is unlikely there is a source of contamination near the two wells (299-W15-42 and 299-W15-764) for carbon tetrachloride and co-contaminants because of the lack of carbon tetrachloride and co-contaminant detections in the soil samples and the relatively low concentrations of carbon tetrachloride and co-contaminant concentrations in the soil-vapor samples. Relatively low carbon tetrachloride concentrations in groundwater suggest that this area is not a vadose zone source of continuing contamination to the aquifer. The low concentrations of carbon tetrachloride in soil vapor detected between the Cold Creek unit and the water table (69.05 meters below ground surface; 137.25 meters above mean sea level) suggest that vapor is not currently acting as a source of contamination to the groundwater. Sampling results from these two boreholes suggest that the 216-Z-9 trench or 216-Z-1A tile field are the more likely vadose zone sources of contamination for the groundwater. Furthermore, data from the boreholes suggest that the two effluent pipelines that carried waste from the Plutonium Finishing Plant to the 216-Z-9 trench had not leaked near the boreholes.

Characterization of the vadose zone did not find contamination in the sediment, and only low concentrations of carbon tetrachloride and co-contaminant concentrations in the soil-vapor samples.

In the 216-Z-9 trench area, the Hanford formation was found to be 31.4 meters thick in well 299-W15-95 (202.9- to 171. 5-meters elevation above mean sea level) and the Cold Creek unit was 2.9 meters thick (171.5- to 168.6-meters elevation above mean sea level). Carbon tetrachloride was detected in both soil (9 µg/kg maximum in well 299-W15-84 and 5 µg/kg maximum in well 299-W15-95) and soil-vapor (539 ppmv in well 299-W15-81 and 95 ppmv in well 299-W15-95) samples from the Cold Creek unit. The investigation did not include soil from above the Cold Creek unit because these existing wells had previously been drilled through the Hanford formation. No artificially produced radionuclides were detected in soil samples. High calcium in the Cold Creek unit was reported for metals analyzed in the soil. Soil samples from the deepened parts of both wells indicate that the residual soil contamination is associated only with the Cold Creek unit. The relatively low concentrations of carbon tetrachloride in soil vapor detected between the Cold Creek unit and the water table suggest that the vapor phase is not acting as a source of groundwater contamination at this location. The 2002 distribution of carbon tetrachloride in these wells is consistent with the conceptual model that the Cold Creek unit would have retained more carbon tetrachloride than the overlying and underlying sands and gravels at the well locations.

Soil-Vapor Sampling at the 200-PW-1 Operable Unit

Characterization of the carbon tetrachloride vadose zone plume was conducted during fiscal year 2002 as part of the remedial investigation for the 200-PW-1 Operable Unit. The 200-PW-1 Operable Unit waste sites received plutonium-rich and organic-rich waste from several processes located within the Plutonium Finishing Plant complex. A primary component of the organic-rich waste was carbon tetrachloride. The objective of the vadose zone investigation was to locate and characterize the sources of carbon tetrachloride contamination that presently impact groundwater, as well as known and suspected release sites with the potential to impact groundwater in the future.

Soil-vapor sampling and analysis was used to explore the upper vadose zone in the vicinity of the Plutonium Finishing Plant as Step I of the remedial investigation into the dispersed carbon tetrachloride plume in the vadose zone at the 200-PW-1 Operable Unit. The sampling was conducted at engineered structures that had the potential to release carbon tetrachloride to the vadose zone. The engineered structures included liquid waste discharge pipelines, liquid waste discharge sites, and solid waste burial ground trenches. The vadose zone sampling was conducted using either the GeoProbe or cone penetrometer direct push technology. Sampling also was conducted through vent risers into the burial ground trenches. The analyses were conducted using a field-screening instrument.

The Step I soil-vapor sampling was conducted between May and October 2002. Characterization was performed in accordance with the *200-PW-1 Operable Unit Dispersed Carbon Tetrachloride Vadose Zone Plume Sampling and Analysis Plan – Step I* (DOE-RL-2001-67). The sampling methods and results are available in the *200-PW-1 Operable Unit Report on Step I Sampling and Analysis of the Dispersed Carbon Tetrachloride Vadose Zone Plume* (CP-13514).

Liquid waste discharge pipelines. Soil-vapor samples were collected along six liquid discharge pipelines to investigate potential leaks of carbon tetrachloride-bearing waste from the pipelines. The six pipelines connected the 234-5Z and 231-Z Buildings with various disposal facilities.

The relatively low concentrations of carbon tetrachloride found at eleven past-practice, liquid waste disposal sites near the Plutonium Finishing Plant suggest that these sites are no longer active sources of contamination in the upper vadose zone.

Seventy-nine locations were investigated along liquid waste discharge pipelines using a GeoProbe system. The GeoProbe system was used to collect soil-vapor samples from three intervals at each location. Soil probe rods were pushed to an approximate total depth of 7.6 meters below ground surface. This depth ensured that the probes would extend well below the waste pipelines, which are generally less than 3 meters deep and, thereby, capture any leakage. Soil-vapor samples were collected at 4.6 meters below ground surface and at the approximate elevation of the bottom of the pipeline. Samples were also collected at several dual purpose locations along pipelines (see next subsection for core pentometer sampling design.)

Relatively low concentrations of carbon tetrachloride (1 to 8 ppmv) were detected in some samples collected along the waste discharge pipelines leading to the 216-Z-18 and 216-Z-12 cribs and the 216-Z-1D, 216-Z-11, 216-Z-19, and 216-Z-20 ditch system. These cribs and ditches are known to have received carbon tetrachloride liquid waste. The detections were typically, but not exclusively, in the samples collected from a depth of 7.6 meters. However, the relatively low concentrations detected along the pipelines suggest that any pipeline leaks were small or were naturally remediated (e.g., by diffusion or evaporation) since the pipelines were last used. Carbon tetrachloride was not detected in samples collected along the pipeline to the 216-Z-9 trench, which is known to have received large volumes of carbon tetrachloride.

Liquid waste discharge sites. Soil-vapor samples were collected at eleven liquid waste discharge sites to investigate potential discharge of carbon tetrachloride-bearing wastes to the soil column at those sites. The eleven sites were: 216-T-19 crib, 216-Z-1A tile field, 216-Z-7 crib, 216-Z-8 French drain, 216-Z-9 trench, 216-Z-12 crib, 216-Z-16 crib, 216-Z-17 crib, 216-Z-18 crib, 216-Z ditch system (216-Z-1D, 216-Z-11, 216-Z-19, and 216-Z-20 ditches), and the 216-Z-21 pond.

Twenty-six locations were investigated at the liquid waste discharge sites. The maximum depth achieved using the cone penetrometer was 21.3 meters. Multiple samples were collected at each location. A sample also was collected at the depth that the liquid waste would infiltrate the vadose zone from the engineered structure. Other samples were collected at 4.6, 7.6, and then increments of 7.6 meters until refusal.

Relatively low concentrations of carbon tetrachloride (1 to 8 ppmv) were detected in some samples collected at liquid waste discharge sites 216-Z-12, 216-Z-1A, 216-Z-1D, 216-Z-11, 216-Z-19, and 216-Z-20 ditch system, 216-Z-7, and 216-T-19. Of these, only the 216-Z-7 crib was not known to have received carbon tetrachloride. The highest concentrations at each site were in samples collected from depths of 9.1 to 18.3 meters. The relatively low concentrations suggest that there is no longer an active source of contamination in the upper vadose zone at these locations. Carbon tetrachloride was not detected in samples collected at the 216-Z-9 trench or 216-Z-18 crib, which are both known to have received large volumes of carbon tetrachloride.

218-W-4C Burial Ground. Sampling in the 218-W-4C burial ground was conducted in three phases. During the first phase, vapor samples were collected from 27 vent risers generally aligned with the centers of the engineered trenches. During the second phase, the GeoProbe was used to collect samples at 12 locations in the vadose zone to a maximum depth of 7.6 meters below ground surface. The 12 locations were selected based on the results of the vent riser sampling. The GeoProbe was used initially to collect vapor samples at each of the 12 locations so that the results could be used to focus deeper sampling using the cone penetrometer. During the third phase, the cone penetrometer was used to collect samples at 5 of the 12 locations sampled using the GeoProbe.

During the first phase of the investigation in May 2002, vapor samples were collected from inside three engineered trenches through vent risers. Most of the samples were collected near the base of the trench, which is typically ~5 meters below the ground surface overlying the trench. Carbon tetrachloride was detected at all but one of the 27 vent risers sampled. Most of the detections were less than 10 ppmv, but a distinct "hot spot" of elevated carbon tetrachloride concentrations (maximum concentration of 1,760 ppmv) was detected at the east end of trench 4.

During the second phase of this investigation in August 2002, the GeoProbe was used to collect soil-vapor samples from the vadose zone at two depths, ~4.6 and 7.6 meters below ground surface, at 12 locations. At two locations, an additional sample was collected at depths where environmental monitoring detected elevated concentrations. Carbon tetrachloride was detected in soil-vapor samples collected at 5 of the 12 locations. Figure 3.1-3 shows a map of the analytical results.

During the third phase of this investigation in September 2002, the cone penetrometer was used to collect soil-vapor samples from the same five locations where carbon tetrachloride was detected during sampling using the GeoProbe. Samples were collected at the elevation corresponding to the base of the nearest trench and at other depths selected to provide a vertical concentration profile.

Carbon tetrachloride concentrations detected in samples collected from the vadose zone were much lower (maximum 62.1 ppmv) than in the samples collected inside the trench at the "hot spot." The highest vadose zone concentrations were in samples collected near the location of the elevated concentration within the trench. At this location, the highest concentrations were in samples collected at depths near the elevation of floor of the trench. Carbon tetrachloride was also detected in samples from two other locations near the trench 4 "hot spot" and at two locations east of trench 4.

3.1.1.4 Characterization of the 200-TW-2 Operable Unit

M. E. Todd and C. Trice

Bechtel Hanford, Inc. drilled boreholes C3104 through the 216-B-38 trench and C3103 through 216-B-7A crib in 2001 to characterize the nature and vertical extent of contamination as part of the remedial investigation for the 200-TW-2 Tank Waste Group Operable Unit (BHI-01607). The results of the investigation became available in fiscal year 2002. The 200-TW-2 waste sites received tank waste from first- and second-cycle decontamination processes associated with the bismuth-phosphate process at the B and T Plants. The locations of the 216-B-38 trench and the 216-B-7A crib in the 200 East Area are shown in Figure 2.9-1.

The 216-B-38 trench is located north of B Plant and west of the BX Tank Farm. The trench received 1,430,000 liters of high-salt, neutral/basic waste via tanks 241-B-110, 241-B-111, and 241-B-112. Waste constituents disposed to the trench include fluoride, nitrate, nitrite, phosphate, sodium compounds (including sodium aluminate, sodium hydroxide, and sodium silicate), and sulfate-based compounds. Radionuclides in the waste stream included 510 curies of cesium-137, 1,900 curies of strontium-90, 560 curies of ruthenium-106, 1.2 grams of plutonium, and 42 kilograms of uranium. The trench was deactivated and resurfaced in October 1982 with 0.6 meter of clean topsoil and then treated with herbicide.

Geophysical logging and laboratory analyses show that most radionuclides are concentrated in the backfill and the upper part of the Hanford formation at the 216-B-38 trench and the 216-B-7A crib.

The 216-B-7A and B cribs are located north of the B Tank Farm. The cribs operated from September 1946 to May 1967 and received a total volume of 43.6 million liters of waste. The waste included second cycle waste from the 221-B Building via tanks 241-B-202 through 241-B-204, lanthanum/fluoride process waste, cell drainage, and other liquid waste via cells 5 and 6 in the 221-B Building. Wastes disposed to the 216-B-7A and B cribs contained americium-241, cesium-137, plutonium, ruthenium-106, strontium-90, and uranium. The cribs became inactive in 1967, and the area was covered with ~0.45 to 0.61 meter of clean backfill.

Five test holes (C3340 through C3344) were drilled in the 216-B-38 trench to optimize the location for borehole C3104 by assuring that it penetrated the area of greatest contamination. The test holes were installed along the length of the trench and drilled to a depth of 18.3 meters. They were logged with both special gamma and neutron-moisture tools to identify the area of highest radiological contamination and moisture content. The test holes were then backfilled and decommissioned.

The geophysical logs showed that cesium-137 occurred between 4.6 and 9.8 meters below ground surface in test hole C3340 (the test hole closest to the head end of the trench). Cesium-137 also was detected at similar depths in test holes C3341 and C3342. Cesium-137 concentrations were minor in the other two drive casings. The maximum cesium-137 concentrations was 180,000 pCi/g at a 7.2-meter depth in test hole C3340. Based on the data from the five test holes, borehole C3104 was drilled near C3340, geophysically logged and sampled to a depth of 80.3 meters. The borehole was then decommissioned.

The stratigraphy encountered at borehole C3104 (Figure 3.1-4) in the 216-B-38 trench consists of backfill from the surface to a 4.5-meter depth, the Hanford formation gravel-dominated sequence from a 4.5- to 9.2-meter depth, the Hanford formation sand-dominated sequence from a 9.2- to 66.2-meter depth, and the Cold Creek unit from 66.2 meters to total depth at 80.3 meters. The water table was encountered at 80.3 meters below ground surface.

Borehole C3103 was drilled through the 216-B-7A crib to a total depth of 67.8 meters. The borehole was sampled, geophysically logged, and then decommissioned.

The stratigraphy encountered in borehole C3103 (Figure 3.1-5) in the 216-B-7A crib consists of backfill from the surface to 6.1 meters depth, the Hanford formation gravel-dominated sequence from a 6.1- to 10.6-meter depth, the Hanford sand-dominated unit from a 10.6- to 66.5-meter depth, and the Cold Creek unit from 66.5 meters to total depth at 70 meters. The water table was encountered at 68.8 meters.

Cesium-137 and cobalt-60 were the only manmade radionuclides detected by geophysical logging in borehole C3104 at the 216-B-38 crib (see Figure 3.1-4). Geophysical logging identified europium-154 and cesium-137 in borehole C3303 at the 216-B-7A crib (see Figure 3.1-5).

Soil samples were screened from both boreholes for alpha and beta activity prior to sample collection for indications of contamination, to assist in selecting sample points, for worker safety, and for shipping documentation. A total of 18 samples were collected from 216-B-38 borings and 22 samples from the 216-B-7A borehole at 3-meter intervals in support of the Tank Farm Vadose Zone Project. These samples were archived at Pacific Northwest National Laboratory. Five of the samples were collected in the zone of highest contamination to support the Science and Technology component of the Groundwater Protection Program.

Table 3.1-2 lists contaminants and maximum concentrations found in soil samples from borehole C3104 at the 216-B-38 crib. The analytical results and the geophysical logs show that most of the radionuclides occur in the backfill and the upper part of the Hanford formation. The radionuclide analyses agree well with the geophysical logs. Cesium-137, plutonium, and uranium appear to be concentrated in the silty sandy gravel of the Hanford formation gravel-dominated unit. Chemical constituents (e.g., ammonium, cadmium, chromium, copper, lead, nickel, and sulfate) have not penetrated deeper than the backfill.

Table 3.1-3 lists contaminants and maximum concentrations found in soil samples from borehole C3103 at the 216-B-7A trench. The distribution of radionuclides observed in analytical results and in geophysical logs are in close agreement. Americium-241, cesium-137, and plutonium are concentrated in the backfill and the upper part of the Hanford formation (the silty gravel-dominated unit and the upper part of the sand-dominated unit; see Figure 3.1-5). The anions and some metals (chromium, copper, and lead) show a bimodal distribution with depth occurring in the backfill and in the deeper Hanford formation sand-dominated unit and the Cold Creek unit. Metals and anions appear to have reached the water table.

3.1.1.5 Characterization of the 200-CS-1 Operable Unit Test Pits

C. S. Cearlock and D. L. Bowers

Bechtel Hanford, Inc. excavated four test pits during 2002 to characterize the vadose zone at three locations in the 216-A-29 ditch and one location in the 216-B-63 trench, 200 East Area (see Figure 2.9-1 for locations of the facilities). Both waste sites are *Resource Conservation and Recovery Act* (RCRA) treatment, storage, and disposal units and part of the 200-CS-1 Operable Unit. This section summarizes the field observations and analytical results from that work. A full description of the work can be found in BHI-01651.

The data from characterization activities were collected to support the decision-making process for future cleanup of the 200 East Area. Three test pits (AD-1, AD-2, and AD-3) were excavated at the 216-A-29 ditch. One test pit (BT-2) was excavated at the 216-B-63 trench. Figure 2.9-1 shows the locations of the 216-A-29 ditch and the 216-B-63 trench. Figure 3.1-6 shows the locations of the test pits. Data from test pit AD-3 also will be used to support the decision-making process for locating a proposed waste transfer line to the waste vitrification plant. Soil samples were collected from each test pit to assess the nature and vertical extent of contamination in the soil column.

A total of 27 samples were collected and analyzed for volatile organic compounds, semivolatile organic compounds, metals, total petroleum hydrocarbons, anions, and radionuclides.

Nine radionuclides exceeded the 90th percentile Hanford Site background concentrations (DOE/RL-96-12). The maximum concentrations were associated with the ditch/trench bottom samples. Concentrations decreased with depth and contamination extended to <3 meters below the ground surface.

The maximum concentrations of nine radionuclides that exceeded the Hanford Site background concentrations were found in sediment at the bottom of the 216-A-29 ditch and the 216-B-63 trench. Concentrations decreased with depth and contamination extended to less than 3 meters below the ground surface.

The primary manmade radionuclides detected were cesium-137, strontium-90, and plutonium-239/240. Cesium-137 was detected in test pits AD-1 and AD-2 at the 216-A-29 ditch with maximum concentrations of 98.4 and 4.94 pCi/g, respectively. Cesium-137 concentration was less than site background concentration of 1.05 pCi/g at the 216-B-63 trench. The maximum strontium-90 concentration was 29.5 pCi/g at the BT-2 test pit in the 216-B-63 trench at a 2.3- to 2.6-meter depth. Strontium-90 was <1 pCi/g at the 216-A-29 ditch (Site background = 0.178 pCi/g).

Plutonium-239/240 (background of 0.0248 pCi/g) and americium-241 (no established background) were detected in test pits AD-1 and AD-2, with maximum concentrations of 25.8 and 1.9 pCi/L, respectively. Background concentrations of uranium-233/234 (1.10 pCi/g) and uranium-238 (1.06 pCi/g) also were exceeded from a 2.3- to 2.6-meter depth in test pit AD-2. The maximum uranium-233/234 concentration was 2.31 pCi/g and the maximum uranium-238 concentration was 1.81 pCi/g.

Thirteen of 24 metals had concentrations greater than the 90th percentile Hanford Site background concentrations (DOE/RL-92-24). The metals exceeding background were arsenic, calcium, cadmium, total chromium, copper, iron, lead, potassium, silver, sodium, nickel, selenium, and vanadium. However, all concentrations that exceeded the Hanford Site background were below the *Model Toxics Control Act* (WAC 173-340) Method C direct exposure cleanup values.

Four anions had concentrations greater than the laboratory quantitation limit or above the 90th percentile Hanford Site background (DOE/RL-92-24). The four anions were ammonia, chloride, nitrate, and sulfate. All anions exceeding background concentrations were well below the *Model Toxics Control Act* (WAC 173-340) Method C direct exposure cleanup values.

The concentrations of polychlorinated biphenyls (PCBs), kerosene range organic compounds, semivolatile organic compounds, and volatile organic compounds in all samples were below the *Model Toxics Control Act* (WAC 173-340) Method C direct exposure cleanup values.

3.1.2 Vadose Zone Characterization and Technical Studies at Single-Shell Tank Farms

New characterization boreholes were drilled and sampled at Waste Management Area TX-TY and the results of geochemical characterization of core samples from boreholes at Waste Management Area B-BX-BY became available in fiscal year 2002. Results from the analysis of core samples allow comparison of contaminated and uncontaminated sediment in the area, which helps delineate the leading edge of vadose zone plumes beneath the B, BX, and BY Tank Farms. These results are summarized in this section.

3.1.2.1 Tank Farm Vadose Zone Project — Drilling and Sampling

D. A. Myers

Tank farm Vadose Zone Project characterization activities were conducted in the TX Tank Farm in fiscal year 2002. Three boreholes were advanced using the drive and sample method developed for the slant borehole in the SX Tank Farm. The boreholes were advanced to refusal, which was met at a depth of ~35 meters in each borehole. This depth corresponds to the caliche layer in the Cold Creek unit.

Each borehole was sampled at preselected intervals for chemical, radiological and geochemical property analysis. The boreholes were located as follows (Figure 3.1-7):

- C3832 at the southeast quadrant of tank TX-104
- C3831 southwest of tank TX-107 (northwest of tank TX-103)
- C3830 midway between tanks TX-101 and TX-105

The location of borehole C3830 was based on spectral gamma logs that showed a potentially large metal waste contamination zone. High uranium concentrations were noted in several dry wells in this area between tanks TX-105 and TX-101. The location of borehole C3831 was based on a review of spectral gamma log data from nearby boreholes that indicated an extensive and fairly well defined contaminant zone from a past leak. Relatively high concentrations of cobalt-60 and europium isotopes were noted in this area. A review of spectral gamma data indicated that the leading edge of the contaminant zone attributed to tank TX-107 extends to the southwest and is noted in dry well 51-04-05 (see Figure 3.1-7). Borehole C3832 was drilled at a location to define the leading edge of contamination released from tank TX-107 and/or metal waste released from tank TX-104 (RPP-7578).

Three boreholes were drilled at the TX Tank Farm to characterize existing uranium, cobalt, and europium vadose zone plumes. Analytical results will be available in fiscal year 2003.

Sample horizons were selected based on spectral gamma logging results (GJO-HAN-11) and neutron moisture logs obtained in nearby boreholes immediately prior to the start of the drilling campaign. Analyses of these samples are scheduled to be completed during fiscal year 2003 and will be reported in the field investigation report for the T and TX-TY Waste Management Areas and summarized in the annual groundwater report for fiscal year 2003.

All three boreholes were decommissioned after drilling and sampling. Borehole C3830 between tanks TX-101 and TX-105 was instrumented with vadose zone monitoring equipment during its decommissioning (PNNL-14115), thus providing an opportunity to further assess the behavior of infiltrating water in the tank farm environment.

3.1.2.2 Characterization at Waste Management Area B-BX-BY

R. J. Serne, B. N. Bjornstad, G. W. Gee, H. T. Schaef, D. C. Lanigan, C. W. Lindenmeier, R. D. Orr, V. L. Legore, R. E. Clayton, M. J. Lindberg, I. V. Kutnyakov, S. R. Baum, K. N. Geiszler, M. M. Valenta, T. S. Vickerman, and L. J. Royack

Geochemical examination of drill core from three boreholes was completed in fiscal year 2002 to characterize vadose zone contamination at Waste Management Area B-BX-BY. The results of those studies are summarized in this section.

The drill cores studied were obtained from RCRA well 299-E33-338, borehole 299-E33-45, and borehole 299-E33-46. Figure 3.1-8 shows the locations of the boreholes. Well 299-E33-338, located southeast of the B Tank Farm in an uncontaminated area, was drilled to a depth of 83.9 meters. Characterization data from this well are thought to represent natural background in the area of Waste Management Area B-BX-BY. Borehole 299-E33-45, located east of tanks BX-101 and BX-102, was drilled through a uranium plume to a depth of 77.42 meters. This borehole was drilled to evaluate concentrations of mobile contaminants, primarily technetium-99 and nitrate, assumed to co-exist with uranium. Borehole

299-E33-46 is located northeast of tank B-110. This borehole was drilled to a 78.03-meter depth to characterize contamination from a leak in a transfer line to tank B-110.

Elevated levels of chemical and radionuclide contaminants indicate that the maximum contamination is at depths of ~50 meters near single-shell tank BX-102 and at ~40 meters at single-shell tank B-110.

All three boreholes encountered essentially the same stratigraphy which is summarized in Figure 3.1-8. All three boreholes were sampled for analysis of moisture content and all three were logged with a neutron-moisture tool. The geophysical log and the laboratory analyses were in good general, qualitative agreement. High moisture zones tended to exist at finer grained beds in the Hanford formation sand-dominated sequence, the contact between the Hanford formation sand-dominated sequence and the underlying gravel-dominated sequence, and within the Cold Creek unit. A perched water zone was found in borehole 299-E33-45 at ~69-meter depth where moisture content reached 20 to 25 wt.%.

An extensive set of chemistry analyses of water extracts was completed on samples from borehole 299-E33-338. Pore-water composition was measured after addition of enough deionized water to the soil sample to obtain sufficient fluid for analysis. Analytical results were corrected for dilution. Chemical characteristics showed no strong trends as a function of depth, and there is very little indication of tank waste interaction with vadose zone soil. The results of analyses of borehole 299-E33-338 samples are very similar to samples from other uncontaminated boreholes (PNNL-13757-1). Borehole 299-E33-338 serves as a baseline against which to compare results of analyses of contaminated samples from boreholes 299-E33-45 and 299-E33-46.

A set of water-extract chemistry analyses identical to that performed on samples from borehole 299-E33-338 was completed on samples from boreholes 299-E33-45 and 299-E33-46. Also, for borehole 299-E33-45, pore water was directly separated from 14 samples and analyzed directly.

Elevated pH (8.9 to 9.5) was found in borehole 299-E33-45 between a 30- and 46-meter depth. The base of the elevated pH is interpreted to be the approximate location of initial tank fluid interaction with the soil column. Increases in electrical conductivity above background also indicate where tank fluid currently resides. In borehole 299-E33-45, elevated electrical conductivity occurs between a 24- and 48-meter depth, somewhat lower in the soil column relative to the maximum pH (Figure 3.1-9).

In borehole 299-E33-46, elevated pH was found between a 16- and 37-meter depth. Electrical conductivity also was elevated in this depth interval. The elevated pH and electrical conductivity suggest that the maximum depth of tank fluid interaction with the soil column is ~40 meters below ground surface at that location.

One of the primary indicators of tank waste is the occurrence of elevated nitrate. Elevated nitrate was found in borehole 299-E33-45 between a 21-meter depth and the bottom of the borehole at a 78-meter depth. The highest concentrations were between ~43- and 52-meter depth (Figure 3.1-10). A second enriched nitrate zone occurs in the Cold Creek unit silt facies. In borehole 299-E33-46, elevated nitrate was found between a 25- and 69-meter depth with maximum concentrations between 33- and 52-meter depths. Maximum nitrate concentrations in borehole 299-E33-46 are approximately an order of magnitude less than the maximum concentrations in borehole 299-E33-45. Unlike in borehole 299-E33-45, where nitrate is the dominant species at depths corresponding to maximum electrical conductivity, borehole 299-E33-46 has bicarbonate and fluoride corresponding to the depth of the highest electrical conductivity. These depths are similar to the depths in which maximum nitrate occurs in borehole 299-E33-45. Given their location in the soil column, in borehole 299-E33-46, both bicarbonate and fluoride appear to have reacted with the vadose zone soils at relatively shallow depths whereas nitrate was much less reactive and migrated deeper in the vadose zone.

Among the cations, elevated sodium concentrations are the primary indicators of tank fluid in the soil column. Sodium concentrations are elevated over the depth interval from 23.8 to 48.8 meters in borehole 299-E33-45 and display variations similar to nitrate. In borehole 299-E33-46, sodium concentrations are elevated throughout much of the soil column; however, the highest concentrations are between a 15- and 40-meter depth.

Calcium, magnesium, and potassium show distinct concentration patterns with depth in both boreholes. The alkali and alkaline earth metals (except sodium) are depleted in the zones with high sodium concentrations and are elevated in a zone beneath the maximum sodium concentration. This is especially evident in borehole 299-E33-46 (Figure 3.1-11). This combined distribution pattern of calcium, potassium, magnesium, and sodium in the soil column is a classic example of ion exchange of sodium for the other natural cations in the soil.

The zoning of alkali and alkaline earth elements results from the high sodium concentrations in tank fluids displacing the other cations in the exchange sites of minerals in the sediments. In this way, the high sodium fluids push the other cations deeper in the profile.

Analyses of selected radionuclides and trace metals were done on samples from boreholes 299-E33-45 and 299-E33-46. The dominant radionuclides in borehole 299-E33-45 were technetium-99 and uranium. The distribution of technetium-99 in the borehole was nearly identical to that of nitrate (see Figure 3.1-11). Elevated uranium concentrations in borehole 299-E33-45 were found primarily between 21 and 52 meters below ground surface (Figure 3.1-12). Within this interval, smaller zones, associated with silt-rich layers, showed local elevated uranium concentrations.

A perched water zone was detected in the Cold Creek unit silt-facies between a 69- and 70-meter depth in borehole 299-E33-45. The perched water contained ~78,000 pCi/L tritium and ~560 to 2,300 pCi/L technetium-99. Also, the perched water is dominantly alkaline (pH ~7.3) and contains elevated concentrations of nitrate, sulfate, calcium, magnesium, and sodium. The source of the tritium and other contaminants in the perched water may be from Waste Management Area B-BX-BY or may be from past-practice sources located northeast of the waste management area. Local dip is quite variable in the area of Waste Management Area B-BX-BY but there is evidence that the Cold Creek silt facies and the lower part of the Hanford formation dip slightly toward the southwest (HNF-5507). If this is the case, then effluent disposed to the past-practice facilities north of the 241-B tank farm could have infiltrated to the lower part of the Hanford formation and the Cold Creek unit and then migrated in the vadose zone down dip toward borehole 299-E33-45.

The radionuclides identified in borehole 299-E33-46 sediments were uranium, strontium-90, and technetium-99. Strontium-90 is the primary radionuclide released from tank B-110 transfer lines and is concentrated between ~14 and 26 meters below ground surface. The bottom of the strontium-90 plume is at ~27- to 34-meter depth.

Water extractable uranium concentrations suggest that there is process uranium from Hanford Site activities at low concentrations in the Hanford formation between a 15- and 36-meter depth. Technetium-99 was detected in the lower part of the Hanford formation sand-dominated sequence and in the Cold Creek unit (see Figure 3.1-12).

The depth distribution of strontium-90 in the soil column suggests that initially strontium-90 was relatively unreactive with soil. Because the strontium-90-bearing fluids were from the strontium recovery process, it is likely that an organic component in the waste stream formed an anionic species with strontium-90 that migrated with the fluid to some depth. No trace of organic components has been found and water-versus-acid extraction experiments indicate that now strontium-90 is relatively immobile. This suggests that the chelating species became unstable after some time in the soil column, and the period of high strontium-90 mobility ceased.

The primary reactions involving tank waste and the soil column appear to be a reduction of tank fluid pH as the tank fluid reacts with lower pH soil water, in situ displacement of ambient divalent cations with high sodium concentrations present in the tank fluids, and at well 299-E33-46, variable reactivity of strontium-90 with the soil column. Best estimates of the starting tank waste fluid suggest that a pH between 10 to 11 was likely. Observations of elevated zones of pH (elevated with respect to background values) with pH between 8.5 and 9 indicate partial buffering of the infiltrating tank fluid by reaction with soil phases and soil water whose ambient pH values are ~8.

Distinct fluid migration appears to have occurred in the Cold Creek unit in borehole 299-E33-45 where a perched water zone currently exists. Comparison of perched water chemistry with that of nearby water extract data suggests the perched water is a laterally migrating fluid slightly enriched in nitrate and tritium, and depleted in uranium. It is not clear whether the technetium-99 in the perched water came with the laterally migrating fluids or was present at lower moisture contents from the tank waste sources before the migration event. Mixing of the laterally migrating fluid with the pre-existing tank fluid has locally increased the moisture content, reduced technetium-99 concentrations, added tritium, and slightly increased nitrate concentrations.

3.1.2.3 Strontium Adsorption, Desorption, and Transport in Pristine and Contaminated Sediment

J. M. Zachara

The Hanford Science and Technology Project was initiated in 1998 as part of the Groundwater Protection Program (formerly the Groundwater/Vadose Zone Integration Project) with the goal of coordinating and performing scientific research to support decision making for environmental cleanup at the Hanford Site. This section summarizes the results of the Science and Technology Project's investigation of strontium-90 geochemistry and transport at single-shell tank B-110 in support of the Waste Management Area B-BX-BY Field Investigation Report (RPP-10098). The key results summarized here are from four separate but related studies by several principal investigators from Pacific Northwest National Laboratory, Los Alamos National Laboratory, and Lawrence Livermore National Laboratory. This summary is taken from RPP-10098 where the interested reader can find detailed descriptions of the work.

The primary mechanism to fix strontium-90 in the Hanford formation is isotopic exchange with stable isotopic strontium. Approximately 75% of the sorbed strontium-90 is present in an ion exchangeable state and 25% is precipitated in calcite.

The River Protection Project drilled borehole 299-E33-46 near tank B-110 in fiscal year 2001 to investigate a potential strontium-90 plume implied by spectral gamma monitoring of drywells near tanks B-107, B-108, B-110, and B-111. The plume was suspected to be the result of a 94,600-liter leak from tank B-110 in the early 1970s. Characterization of the sediment from the borehole confirmed the presence of strontium-90 between ~15- and 27-meter depth with a maximum concentration of 11,000 pCi/g of sediment. The strontium-90 plume was associated with a plume of sodium-bicarbonate-fluoride between a 17- and 50-meter depth. No other contaminants in appreciable concentration were observed in this plume. The noted contaminant distribution in borehole 299-E33-46 was not expected given the waste inventory records for tank B-110 (RPP-7389). The observed waste constituents are now thought to result from the leakage of Plutonium-Uranium Extraction Plant strontium-recovery waste from a transfer line. The strontium-recovery waste was believed to contain nitrilo-triacetic acid and other organic complexants, but chemical analysis of the borehole sediments did not detect their presence.

The Science and Technology task focused on the development of information to interpret the migration of strontium-90 in borehole 299-E33-46 and at other locations at the Hanford Site. Two primary research activities were initiated on strontium-90 geochemistry. First, uncontaminated sediments from various locations in the 200 East and 200 West Areas, including two composite sediments from different depth intervals in the B Tank Farm, were used in experiments to define a multicomponent ion exchange model for strontium in sodium-bicarbonate and sodium-nitrate solutions. Second, contaminated sediments from the B-110 strontium plume were studied to identify: (1) the mineral phases containing sorbed strontium-90 and (2) the desorption characteristics of strontium-90 as a measure of potential future migration. These studies were performed to provide insights on water and strontium-90 distributions in the vadose zone, the future migration of the B-110 vadose zone plumes, and additional contaminant fluxes to groundwater.

The vadose zone strontium-90 plume encountered in borehole 299-E33-46 at single-shell tank B-110 currently appears to be stable and immobile.

The following are key findings as described in the field investigation report (RPP-10098):

1. The primary attenuation mechanism for strontium-90 in Hanford formation sediment is isotopic exchange with stable isotopic strontium. Most of the exchangeable strontium-90 exists on cation exchange sites in the sediment. The cation exchange capacity exhibits a range of 20 to 60 μeq/g on B Tank Farm sediment. Natural, non-radioactive strontium typically occupies 5% to 10% of the exchange complex.
2. Distribution ratios measured for strontium on a variety of Hanford formation sediment (including two from the B Tank Farm) in sodium and calcium solutions varied from 1,000 to 0 ml/g in 0.001 to 5 mol/L sodium solutions and 58.9 to 0.68 ml/g in 0.0005 to 0.05 mol/L calcium solutions, attesting to the strong competing ion effect on Sr^{2+} adsorption.
3. The ion exchange adsorption of Sr^{2+} was enhanced in bicarbonate solutions (the dominant anion in the B-110 strontium plume), presumably by formation of adsorbing $SrHCO_3^+$ complexes. Nitrilo-triacetic acid, a possible complexant present in the B-110 strontium recovery waste stream, had no effect on Sr^{2+} ion exchange adsorption in bicarbonate solution when its concentration was 1.5 mmol/L, but reduced the Sr^{2+} distribution coefficient from ~56 to 3.16 ml/g. (The distribution coefficient is a ratio of the amount of strontium sorbed on the solid to that remaining in solution.)
4. A multicomponent (Na^+, K^+, Ca^{2+}, Mg^{2+}, Sr^{2+}) cation exchange model was developed to describe the distribution of both stable strontium and strontium-90 between pore water/wastewater and sediment. Calcium is the most important competitive ion, and accurate calculations with the model require specification of the total, exchangeable calcium concentration in the sediment; the distribution of calcium between water and the exchange complex; and the sediment exchange capacity. Sodium becomes an important competitive ion when its aqueous concentration exceeds ~0.1 mol/L.
5. Approximately 75% of the sorbed strontium-90 in sample 26A was present in an ion exchangeable state and 25% was precipitated in a high magnesium-calcite. The isotopic ratios of strontium in these two strontium-containing geochemical pools were different indicating that they were not in isotopic equilibrium.

6. The extent of strontium desorption and its dependence on solution composition was well described with the multicomponent exchange model. The ionic compositions and concentrations required to induce significant desorption (e.g., 1 to 5 mol/L sodium and 0.05 mol/L calcium) were much higher than those currently existing in the B-110 plume.
7. The best estimate of the strontium-90 distribution coefficient for exchangeable strontium under the existing in situ geochemical conditions is 5.62 ml/g. The effective in situ retardation factor would be quite high because the low volumetric moisture content. Additional measurements and calculations underway will further refine this value.
8. Approximately 25% of the sorbed strontium-90 appears to be incorporated into a precipitated carbonate phase. This precipitated strontium-90 is not desorbable in sodium or calcium solution, and is essentially fixed unless subsurface pH changes to more acidic values. The precipitated strontium-90 appears to exchange very slowly with other sources of stable strontium.
9. The vadose zone strontium-90 plume currently appears stable and immobile. Infiltration of dilute meteoric waters could further increase retardation by the dilution of pore-water Na^+. An increase in pore-water Ca^{2+} could mobilize a portion of the adsorbed strontium-90.

3.1.2.4 Uranium Speciation and Dissolution from BX-102 Sediment

J. M. Zachara

The Hanford Science and Technology Project investigated uranium speciation and dissolution in sediments from Waste Management Area B-BX-BY in 2002. This section summarizes the results of those investigations that were performed to provide insights on uranium distribution and future migration of the vadose zone plumes, and in support of decision making for environmental cleanup at Waste Management Area B-BX-BY. The key results summarized here are from five separate but related studies by several principal investigators from Pacific Northwest National Laboratory, Los Alamos National Laboratory, Argonne National Laboratory, and Stanford University. This summary is taken from RPP-10098 where the interested reader can find detailed descriptions of the work.

An estimated 347,000 liters of bismuth phosphate metal waste solution containing ~7 to 8 metric tons of uranium(VI) was discharged to the vadose zone in the BX Tank Farm as a result of the overfilling of single-shell tank BX-102 in 1951. This aqueous solution contained nominal concentrations of 0.5 mol/L uranium(VI), 2.5 to 5.0 mol/L sodium carbonate, 0.36 mol/L phosphate, and virtually all fission products except plutonium with pH of ~10 (RPP-7389). Characterization studies of the vadose zone near tank BX-102 have defined an extensive plume containing cesium, uranium, and other contaminants (ARH-2035; GJO-HAN-89) resulting from the leak event, whose character was apparently modified by the later leakage of waste solutions of different composition from tanks BX-102 and BX-101 (RPP-7389).

Borehole 299-E33-45 was drilled through the metal waste plume near tank BX-102 by the River Protection Program in 2001 to provide information on the depth distribution and inventory of uranium and technetium resulting from the 1951 waste overfill of tank BX-102 (see Section 3.1.2.2). Samples from this borehole were characterized, and the analyses have defined several zones of enriched uranium concentrations at depths between 21 and 52 meters. The Science and Technology Project selected three high uranium samples from borehole 299-E33-45 for study to provide information on the chemical speciation, mineral association, and leachability of uranium in and from the contaminated sediments. The scientific goals of this work were to identify: (1) post-release waste-sediment reactions that impacted uranium(VI) mobility, (2) retardation extent and mechanism, and (3) potential for future uranium(VI) migration and controlling factors.

The following are key findings from those studies as described in the field investigation report (RPP-10098):

1. Uranium exists as uranium(VI) in all three BX-102 samples studied. The uranium(VI) exists primarily as a precipitated phase. The uranium(VI) precipitates are found as discontinuous grain coatings, filamentous intergrain deposits, and as micron size crystallites within mineral microfractures.
2. Various independent lines of evidence suggest that the precipitated phase is a uranium silicate mineral falling in the uranophane – boltwoodite series. All lines of evidence also suggest that there is only one dominant precipitated uranium(VI) phase.
3. The precipitated uranium(VI) can dissolve from the sediments if water is added and the pH is above 8.5. The precipitated phase exhibits solubility behavior like that of uranophane/boltwoodite. In a system that is open to the atmosphere, the solubility of these phases increases from ~10^{-6} mol/L at pH = 8, to 10^{-4} mol/L and above at pH values in excess of 9.0. From 40 to 85% of the precipitated uranium(VI) will dissolve at pH 9.5 *in excess water*, given sufficient time.
4. The amount of precipitated uranium(VI) that will dissolve appears predictable (with additional analyses), and is most dependent on pH, bicarbonate/carbonate concentration ratio, and water content. Dissolved silicon is also an important factor, but its concentration is nominally fixed by equilibrium with poorly crystalline sediment silica. The dissolution of the precipitated uranium(VI) phase exhibits strong kinetic behavior, requiring 100 days or more to reach equilibrium in a well-mixed system. Much longer periods for equilibrium may be expected in the vadose zone with low moisture content.
5. Because of the psuedo-solubility behavior of the sediment uranium(VI) in the BX-102 samples, there is no uniform distribution coefficient. The distribution coefficient varies from 450 to 0.25 ml/g depending on the total uranium(VI) concentration, the pH, the carbonate concentration, and water content (or the rock-water ratio). The complex relationships among these factors are understood to a large degree. The distribution coefficient also varies with water contact or residence time, as the uranium(VI) silicate slowly dissolves to the equilibrium state.
6. At the present time, most of the uranium(VI) inventory in the studied BX-102 samples is associated with the solid phase and is effectively immobile. However, the precipitated uranium(VI) phases do maintain appreciable solubility and, for that reason, the pore-water concentrations of uranium(VI) are quite high. Spectroscopic measurements of the pore water indicate that the soluble uranium exists as uranium(VI)-carbonate complexes. This soluble uranium(VI) will continue to migrate, albeit slowly, because of the low water content.
7. The precipitated uranium(VI) phases in the BX-102 sediments are sufficiently soluble and reactive to function as long-term source terms to infiltrating waters if allowed. However, the slow dissolution kinetics of the precipitated phases indicates that non-equilibrium behavior is likely to prevail. Water management will be key to limiting further contamination because the total solubility of the precipitated uranium(VI) phases are a strong function of water content or water:rock ratio.
8. Direct spectroscopic measurements of uranium in pore water from borehole 299-E33-45 indicate that the mobile aqueous uranium species resulting from

At the present time, most of the uranium (VI) inventory in the BX-102 samples is associated with a solid phase and is effectively immobile. However, the precipitated uranium (VI) phases maintain appreciable solubility.

the metal waste spill are $UO_2(CO_3)_2^{2-}$ and $UO_2(CO_3)_3^{4-}$ complexes. Using thermodynamic models with the best available database, the $UO_2(CO_3)_3^{4-}$ complex was determined to be the dominant uranyl species in BX-102 metal waste supernate. This species has persisted in pore water since the time of the metal waste spillage in 1951.

3.1.3 Characterization for Immobilized Low-Activity Waste Disposal

Waste from plutonium production and separation processes is currently stored underground in 149 single-shell tanks and 28 double-shell tanks. The U.S. Department of Energy plans to retrieve tank waste, separate it into low- and high-activity fractions, and immobilize it using vitrification. The low-activity waste is planned to be disposed in near-surface burial facilities at the Hanford Site 200 East Area.

The results of geochemical and mineralogical characterization of borehole samples from the vadose zone at the location of the proposed disposal site for immobilized low-activity waste became available in fiscal year 2002. The information from that characterization effort will support the immobilized low-activity waste performance assessment in 2005.

A study of iodide sorption onto sediment from the immobilized low-activity waste disposal site was completed in fiscal year 2002. The results, for one of the most mobile radionuclides posing a health risk at the disposal site, also will support the immobilized low-activity waste performance assessment in 2005.

3.1.3.1 Immobilized Low-Activity Waste Borehole 299-E24-21 Geochemistry

D. G. Horton, H. T. Schaef, R. J. Serne, M. M. Valenta, T. S. Vickerman, I. V. Kutnyakou, S. R. Baum, K. N. Geiszler, and K. E. Parker

Borehole 299-E24-21 was drilled at the northeast corner of the immobilized low-activity waste disposal site in 2001. Near-continuous core was collected from the borehole between 13.7 meters below ground surface to a total depth at 102 meters below ground surface. The purpose of the borehole was to obtain characterization data in support of the immobilized low-activity waste 2005 performance assessment and to serve as a groundwater monitoring well for future RCRA monitoring. Details of the drilling and sampling can be found in BHI-01531 and in PNNL-13652.

Twelve samples were selected from the core for detailed analyses (Table 3.1-4). Two types of samples were collected: composite samples and discrete depth samples. Five composite samples were made by combining several 60-centimeter sections of core. Each composite was homogenized in buckets before subsampling for various analyses. Several kilograms of the characterized, composite samples remain for future studies.

Depth discrete samples were collected to characterize specific features identified by the geologists. A sample at a 24.5-meter depth was collected to characterize a paleosol identified by the geologist during description of the core. The paleosol was identified at 23.8 meters below ground surface, whereas the sample collected for this effort was taken at 24.5 meters below ground surface. Thus, the sample used for this study probably represents the bottom of the paleosol or the sediment immediately below the paleosol.

The sample collected at 34.5 meters below ground surface represents a discrete, thin (~1.3 centimeter thick) silt lens typical of silt lenses found in the Hanford formation sand-dominated sequence. The sample from 51.4 meters below ground surface is from the bottom of the R2 paleomagentic layer and represents a discrete sample of the Hanford formation sand-dominated, layer 2. The sample from 51.9 meters below ground surface is the paleosol identified at that depth during core logging. The two samples from 68.1 and 73.8 meters below ground surface are from above and below the N1/R1 paleomagnetic boundary and were collected to characterize any differences above and below that contact. (Paleomagnetic contacts are used to help establish stratigraphic continuity from one area to another.)

Extensive geochemical characterization of sediment from borehole 299-E24-21 confirmed the data used in the 2001 Performance Assessment for the Immoblized Low-Activity Waste disposal facility.

Particle size distributions were determined by the wet sieve/hydrometer method for composite samples only. All the samples are dominated by sand and moderately well sorted, but none are very well sorted, reflecting the fact that they are composites of several meters of core over relatively long intervals. None of the samples contained more than 8 wt.% fine-grained particles (silt plus clay) and only two samples contained greater than 5 wt.% gravel. The particle size distribution data indicate that all of the samples are typical of the Hanford formation sand-dominated sequence.

The moisture content of all composite samples ranged between 1.78 and 4.88 wt.% with only one sample having greater than 2.4 wt.% moisture. The moisture contents of the paleosols (5.05 and 5.26 wt.%) and the silt lens (5.19 wt.%) were somewhat higher. Although the moisture content of the composite samples is within the known range for the Hanford formation, the values are near the low end of the range. Probably, the samples partially dried in the laboratory during the homogenization process.

The bulk composition, as measured by x-ray fluorescence, total carbon content, inorganic carbon, and organic carbon (by difference) of the 12 samples from borehole 299-E24-21 are similar to those of other samples of the Hanford formation sand-dominated sequence (PNNL-13757-1). With the exception of the deepest sample from 76.5 meters below ground surface, the samples from the Hanford formation Layer 1 appear to have lower silicon dioxide and bound water content (from loss-on-ignition analyses) and greater iron oxide (FeO), calcium oxide, and magnesium oxide than do samples from the Hanford formation Layer 2 and Layer 3. However, the number of samples is small and the number of variables is large so that no general trends can be assumed without a larger database of analyses.

Somewhat surprising is the relatively low calcium carbonate content of the paleosols (1.42 to 1.83 wt.%). The amount of calcium carbonate in Hanford Site sediment is, in part, a function of the length of time available for soil development. Apparently, the paleosols present in borehole 299-E24-21 did not develop over extensive lengths of time. For comparison, the paleosols that are part of the Cold Creek unit commonly contain up to about 38 wt.% calcium carbonate and probably developed over several hundreds of thousands of years. Instead, the paleosols in the Hanford formation at borehole 299-W24-21 probably developed in only a few thousand years between flood deposits. The paleosols at 299-E24-21 were recognized by their mud content, bioturbated, and bleached nature (PNNL-13652) and not as a well-developed caliche.

X-ray diffraction analysis of the samples from borehole 299-E24-21 shows that all the sediments are mineralogically similar and are dominated by quartz and feldspar (both plagioclase and alkali-feldspar), with lesser amounts of mica, chlorite, and an amphibole. Trace amounts of the zeolite, laumontite, were identified in most of the samples. Samples from Layer 1 have higher plagioclase and lower quartz concentrations than do samples from Layer 2 or Layer 3, reflecting a higher basalt content. Also, the paleosols and the silt lens have greater potassium feldspar concentrations than do the other samples.

The clay-size fractions are dominated by smectite and illite with lesser amounts of chlorite and kaolinite. Quartz and feldspar minerals were present at trace amounts in the clay fraction. Overall, the mineralogy of the clay fractions from borehole 299-E24-21 are similar to clay fractions analyzed from clean boreholes and other composite samples of the Hanford formation sand-dominated sequence (PNNL-13757-1).

The surface area of the clay-size fraction (<1.4 µm) was measured for each of the twelve samples. The results ranged from 21.1 m^2/g to 53.0 m^2/g. There are no available previously measured values of surface area for the Hanford formation sand-dominated sequence for comparison. However, the values appear to be reasonable if they are compared to the mineralogy of the samples and to published values for monomineralic samples (Grim 1968).

The alkalinity, pH, and electrical conductivity of the samples from borehole 299-E24-21 are within the range of these parameters measured on other uncontaminated samples of the Hanford formation sediment (PNNL-13757-1). The most notable sample is the one associated with the upper paleosol at ~24.5-meter depth. This sample has a very high 1:1 water extract electrical conductivity of 375 µS/cm. This electrical conductivity is associated with high calcium, chloride, nitrate, and sulfate in the sample.

Also of note are the samples from 68.12 and 73.8 meters below ground surface, taken above and below the N1/R1 paleomagnetic boundary. These two samples have the highest pH values measured from the twelve samples with the 68.12-meter-deep sample (above the boundary) having the highest pH. There is also a distinct electrical conductivity difference between these two samples. The sample above the N1/R1 contact has higher electrical conductivity, associated with higher calcium, nitrate, chloride, and sulfate, than does the sample below the contact.

Analyses of major cations and anions in 1:1 water extracts show that calcium and sodium are the major cations and bicarbonate (from alkalinity) is the major anion. This was also the case for water extract analyses of samples from the Hanford formation sand-dominated sequence in two clean boreholes (PNNL-13757-1). In general, the water extracts from the composite samples from Layer 2 have lower magnesium, potassium, sodium, and sulfur than do the extracts from Layer 1 and Layer 3 samples. Also, nitrate and sulfate concentrations are relatively low and chloride concentration is relatively high in Layer 2 as compared with Layers 1 and 3. There does not appear to be any unusual features in the cation or anion concentrations of samples from borehole 299-E24-21.

No information was found by this characterization effort that would invalidate any of the data used in the 2001 performance assessment of the overall performance of the proposed immobilized low-activity waste repository.

3.1.3.2 Sorption Linearity and Reversibility of Iodide at the Proposed Immobilized Low-Activity Waste Repository at the Hanford Site

W. Um and R. J. Serne

A performance assessment of immobilized low-activity waste investigated the effects of the planned disposal on long-term environmental conditions and human health. The investigation showed that iodine-129, neptunium-237, technetium-99 and uranium-233, -235, and -238 pose the most potential health risks at the proposed disposal site. Because of its long half-life and high mobility in the subsurface environment, the sorption/desorption characteristics of radioactive iodine were investigated. Sorption/desorption experiments were conducted to validate sorption linearity and sorption reversibility both of which are assumed for transport modeling using the distribution coefficients (K_d). This section summarizes those experiments and their results.

Previous studies have shown that iodine sorption is expected to be affected by the organic carbon content, iron-oxide content, and the pH of the soil. For this reason, site-specific sorption/desorption experiments for iodine were needed to measure K_d values used to predict the fate and transport of iodine at the Hanford 200 East Area. (The K_d value is a numerical measure of the amount of a contaminant in a sediment divided by the amount dissolved in groundwater. The lower the K_d value, the more mobile the contaminant.)

Recent experiments suggest that, although iodide sorption is not strong on Hanford Site sediment, the sorption is not fully reversible. This means that some retardation of iodide should occur in the vadose zone.

The sediment used was a slightly gravelly, slightly silty sand from a composite of drill cores between a 33.5- and 41.8-meter depth in borehole 299-E24-21 at the immobilized low-activity waste site in 200 East Area (see Figure 2.9-1). The organic carbon content was 0.01 wt.% and the pH was 7.5. The moisture content, bulk chemical composition, mineralogy, surface area, and the electrical conductivity, alkalinity, metals, and anion concentrations in 1:1 sediment to water extract were previously characterized (see Section 3.1.3.1).[a] The samples used in the adsorption-desorption tests were sieved to remove particles greater than 2 millimeters.

Groundwater collected from a well in an uncontaminated portion of the Hanford Site was used as a background solution in all experiments. Batch experiments were conducted by mixing 1:10 ratio of sediment and groundwater spiked with known concentration of iodine-125 and stable iodide. Iodine-125 was used in place of iodine-129 because of its shorter half-life, and sodium iodide was used for stable iodide. The beta emission from iodine-125 was counted by liquid scintillation. Iodide from sodium iodide was measured by ion chromatography. The iodine-125 concentration in all sorption tests was 10 µCi/L.

Pre-equilibrated iodine containing groundwater was added to the sediment and the containers were shaken for 7 days. Previous kinetic experiments had shown 7 days were adequate for reaching equilibrium. After 7 days of contact, the suspensions were centrifuged and the supernatants were passed through 0.45-µm filters. The radioactivity in the filtrates was measured and the distribution coefficients, K_d values (mL/g) were calculated using the method described by PNNL-11966. Sorption linearity was tested by using solutions over a wide range of initial concentrations from 1 µg/L to 100 mg/L iodide.

Desorption experiments were conducted following the sorption experiments using the same samples. After the concentration of iodine-125 in the solid was determined, fresh iodide-free groundwater was introduced into each sample as the desorption solution. Each sample was mixed again. After passing through 0.45-µm filters, the concentration of desorbed iodine-125 in the supernatant was measured at different time intervals. The desorption data were corrected for the relatively short half-life of iodine-125.

The kinetic experiments were conducted as a function of contact time. The percentage of iodine-125 sorption tended to increase with time up to ~7 days (Figure 3.1-13). Only about 2.5% of the tracer was adsorbed between 7 and 309 days. Based on these results, all the batch sorption equilibrium experiments were performed for 7 days.

(a) Letter report from D. G. Horton, H. T. Schaef, R. J. Serne, M. M. Valenta, T. S. Vickerman, I. V. Kutnyakov, S. R. Baum, K. N. Geiszler, and K. E. Parker (Pacific Northwest National Laboratory, Richland, Washington) to CH2M HILL Hanford, Group, Inc. (Richland, Washington), *Geochemistry of Borehole 299-E24-21 (ILAW Borehole #2)*, dated September 2002.

A sorption isotherm for iodine-125 was made using initial iodide concentrations from 1 μg/L to 500 mg/L. The sorption isotherm, the equilibrium ratio of sorbed concentration on the soils to the concentration in the solution, is shown in Figure 3.1-14. Within the concentration range up to 100 mg/L, iodide sorption showed the ideal linear trend. The data suggest that the maximum iodide sorption capacity of the Hanford Site soil was not exceeded even at the 100-mg/L iodide concentration (~95 mg/L equilibrium iodide concentration).

The K_d value is equal to the slope of the line on Figure 3.1-14 and is 0.2 mL/g, similar to that measured on several Hanford Site sediments (PNNL-11966.) A K_d value for each initial concentration was also calculated after counting the iodine-125 activity. The calculated K_d values are given in Figure 3.1-15. The K_d values vary between 0.1 and 0.3 mL/g indicating 0.2 mL/g is a reasonable mean value below 100 mg/L initial concentration. The constant K_d values and the linear isotherm within the range of iodide concentrations <100 mg/L indicate that iodide sorption on Hanford Site sediment from 200 East Area is well described by the linear distribution coefficient.

Desorption experiments were conducted following the adsorption experiments. Iodine-125 desorption release versus reaction time is shown in Figure 3.1-16. The amount of desorbed iodine-125 increased with time and iodine-125 desorption was considered to reach a steady state after 14 days, about twice the time period needed to reach steady state adsorption conditions. Because ~60% of the iodide desorbed into iodide-free groundwater, iodine-125 sorption is partially reversible. The desorption release indicates that sorbed iodine-125 is not strongly bound to the Hanford Site sediment.

A desorption isotherm was determined using the 14-day desorption data. A desorption distribution coefficient, $K_{d(desorption)}$ was determined by the ratio of the remaining sorbed iodide in the sediment to the equilibrium iodide in the desorbing solution. Both sorption and desorption isotherms are shown in Figure 3.1-17. The calculated desorption K_d was 1.4 mL/g. The desorption K_d value is larger than the sorption K_d value, indicating iodide sorption is not fully reversible. Even though initial iodide sorption on the Hanford Site sediment was minor, some of sorbed iodide was retained on the sediment slightly longer than would be predicted by simple transport theory, with a linear isotherm. The partial reversibility of sorbed iodide on the Hanford Site sediment indicates there may be some retardation in the trailing edge of an iodide plume in the vadose zone if the pore-water composition does not differ significantly from natural conditions.

In summary, sorption linearity and partial reversibility were determined for iodine-125 on a typical Hanford formation sand from the second immobilized low-activity waste borehole in 200 East Area. Because iodine-129 is one of the key risk drivers at the Hanford Site, predictions for the fate of iodine-129 using simple transport models are technically defensible. However, since iodide desorption is slower than adsorption and only partially reversible, the concentration of iodide will not drop as fast as predicted and the time for iodide to leave the system may be longer than the time predicted by simple transport theory.

The results of these experiments support the results of the 2001 performance assessment of the overall performance of the proposed immobilized low-activity waste repository.

Table 3.1-1. Depth of Maximum Concentrations for Selected Contaminants in Samples from Borehole C3102 at the 216-T-26 Crib

Contaminant	Maximum Concentrations at Specific Depths			
	5.5 to 6.7 m	10.4 m	28 m	69 m
Aluminum (µg/kg)	75,800,000	9,540,000		
Amercium-241 (pCi/g)		227		
Bismuth (µg/kg)		198,000		
Cadmium (µg/kg)	670			
Calcium (µg/kg)	9,590,000	8,130,000		
Cesium-137 (pCi/g)	47,900	21,200		
Chloride (µg/kg)	6,500		46,000	
Chromium (µg/kg)	16,500	27,300	24,200	
Cobalt-60 (pCi/g)			0.074	
Copper (µg/kg)			18,100	
Cyanide (µg/kg)			7,900	
Europium-154 (pCi/kg)		61.9		
Europium-155 (pCi/g)		85.1		
Fluoride (µg/kg)	28,900	168,000	85,500	
Hexavalent chromium (µg/kg)		4,200	1,600	640
Iron (µg/kg)	24,900,000	19,200,000		
Lead (µg/kg)	5,600	11,600	13,700	
Mercury (µg/kg)		180		
Nitrate (µg/kg)	255,000		30,700,000	
Nitrite (µg/kg)			47,700	
Phosphate (µg/kg)			213,000	
Plutonium-238 (pCi/g)		35.2		
Plutonium-239/240 (pCi/g)		6,320		
Radium-226 (pCi/g)			0.887	
Radium-228 (pCi/g)			1.48	
Sodium (µg/kg)		1,510,000		
Sulfate (µg/kg)	106,000		250,000	
Total beta radiostrontium (pCi/g)	1,500	49,100		
Total organic carbon (µg/kg)	281,000			
Uranium (µg/kg)	10,500	61,100	9,470	
Uranium-233/234 (pCi/g)	3.11	18.1	3.27	
Uranium-235 (pCi/g)			0.224	
Uranium-238 (pCi/g)	4.58	21.1	6.84	
Vanadium (µg/kg)	65,700			
Zinc (µg/kg)	45,000			

Table 3.1-2. Depth of Maximum Concentrations for Selected Contaminants in Soil Samples from Borehole C3104 Near the 216-B-38 Trench

Contaminant	Maximum Concentrations at Specific Depth				
	1 m	3 m	4.4 m	5.5 m	6.9 m
Americium-241 (pCi/g)			43.9	24.1	
Ammonia (µg/kg)	3,890				
Cadmium (µg/kg)	60	100			
Cesium-137(pCi/g)	1.82		226,000	226,000	17,900
Chromium (µg/kg)	11,600	11,500			
Copper (µg/kg)	12,900	15,100			
Lead (µg/kg)	6,800	8,000			
Nickel (µg/kg)	12,100	10,700			
Nitrate (µg/kg)	94,400	208,000			
Plutonium-238 (pCi/g)			7.85	3.36	
Plutonium-239/240 (pCi/g)			4.64	159	64.6
Sulfate (µg/kg)	51,100	248,000			
Total beta radiostrontium (pCi/g)				2050	288
Total organic carbon (µg/kg)	274,000	1,060,000			
Uranium (µg/kg)	1,600	1,690	14,800	32,500	19,100
Uranium-233/234 (pCi/g)			5.16	9	8.52
Uranium-238 (pCi/g)			6.35		

Table 3.1-3. Depth of Maximum Concentrations of Selected Contaminants in Soil Samples from Borehole C3103 at the 216-B-24 Trench

	Maximum Concentrations at Specific Depths													
	Backfill						Gravel-Dominated			Sand-Dominated				CC Unit
Contaminant	1 m	1.7 m	3.3 m	3.8 m	5.5 m	6.9 m	7.6 m	10 m	10.7 m	14.6 m	22.1 m	29.7 m	44.8 m	66.8 m
Amercium-241 (pCi/g)					5,690	2,620	770	21.8	0.133	0.076				
Ammonia (µg/kg)	3,080	25,900								6,440			3,770	
Cadmium (µg/kg)			60	70	70									
Cesium-137 (pCi/g)	6.67	42.5	1.52	4.54	102,000	153,000	67,300	6,190	5,910	5.06				
Chloride (µg/kg)	6,500	9,040	11,100	12,800						5,400	3,000	8,500	12,200	24,800
Chromium (µg/kg)	12,900	13,500	14,000	12,400						12,100	9,400	16,900	22,200	44,200
Copper (µg/kg)	12,800	13,500	13,700	15,000						13,500	12,100	9,800	9,800	19,500
Europium-154 (pCi/g)					200									
Fluoride										28,800	11,800	5,100	5,100	101,000
Hexavalent Chromium (µg/kg)					15,100	17,800	80				970	1,100	1,300	3,800
Lead (µg/kg)	5,900	6,900	23,300	10,000						3000	6,100			11,300
Mercury (µg/kg)											50	20		40
Nitrate (µg/kg)	110,000	193,000	77,300	65,300	65,300					23,900	8,510	133,000	493,000	263,000
Phosphate (µg/kg)	7,330	3,100	3,300	3,000						12,700	2,500			17,800
Plutonium-238 (pCi/g)							140							
Plutonium-239/240 (pCi/g)					153,000	77,300	25,800	1,360	1.56	0.451				
Sulfate (µg/kg)	45,900	185,000	67,500	38,300						20,400	6100	14,200	14,600	121,000
Technetium-99 (pCi/g)					32.9									
Total beta radiostrontium (pCi/g)		2.66	9.44	13.5	940,000	2.34×10^{6}	5.7×10^{6}	128,000	98.3	39.5				
Total organic carbon (µg/kg)	1.05×10^{6}	3.85×10^{6}	1.37×10^{6}	9×10^{5}						2.68×10^{6}	2.25×10^{5}	1.57×10^{5}	1.43×10^{5}	2.73×10^{5}
Uranium-235 (pCi/g)										0.698				
Uranium-238 (pCi/g)								108	7.5	0.789				

CC = Cold Creek.

Table 3.1-4. Samples Collected from Borehole 299-E24-21 at the Immobilized Low-Activity Waste Disposal Facility

Sample Depth (m bgs)[a]	Description
13.7 to 15.8	Composite sample; Hanford formation Layer 3[b]
24.5	Sediment associated with a paleosol at the Hanford formation Layer 3/Layer 2 boundary; bedded, medium-grained sand; beds are distinguished by color and hardness
33.5 to 41.8	Composite sample; Hanford formation Layer 2
34.5	Silt lens in the Hanford formation Layer 2
45.7 to 46.9	Composite sample; Hanford formation Layer 2
51.4	Hanford formation Layer 2; bedded, medium-grained sand with a trace of silt; sample is from the base of the R2 (paleomagnetic) layer
51.9	Paleosol at the Hanford formation Layer 2/Layer 1 boundary; fine-grained sand to silt; bioturbated and bleached with calcite cement
61 to 62.2	Composite sample; Hanford formation Layer 1
65.5 to 71.3	Composite sample; Hanford formation Layer 1
68.1	Hanford formation Layer 1; coarse-grained sand; slight reaction to HCl; bottom of the N1 (paleomagnetic) layer
73.8	Hanford formation Layer 1; sandy gravel; near the top of the R1 (paleomagnetic) layer
76.5 to 80.3	Composite sample; Hanford formation Layer 1

(a) bgs = Below ground surface.
(b) See PNNL-13652 for definitions of layers 1,2, and 3 and paleomagnetic layers N1, R1, N3, and R2.

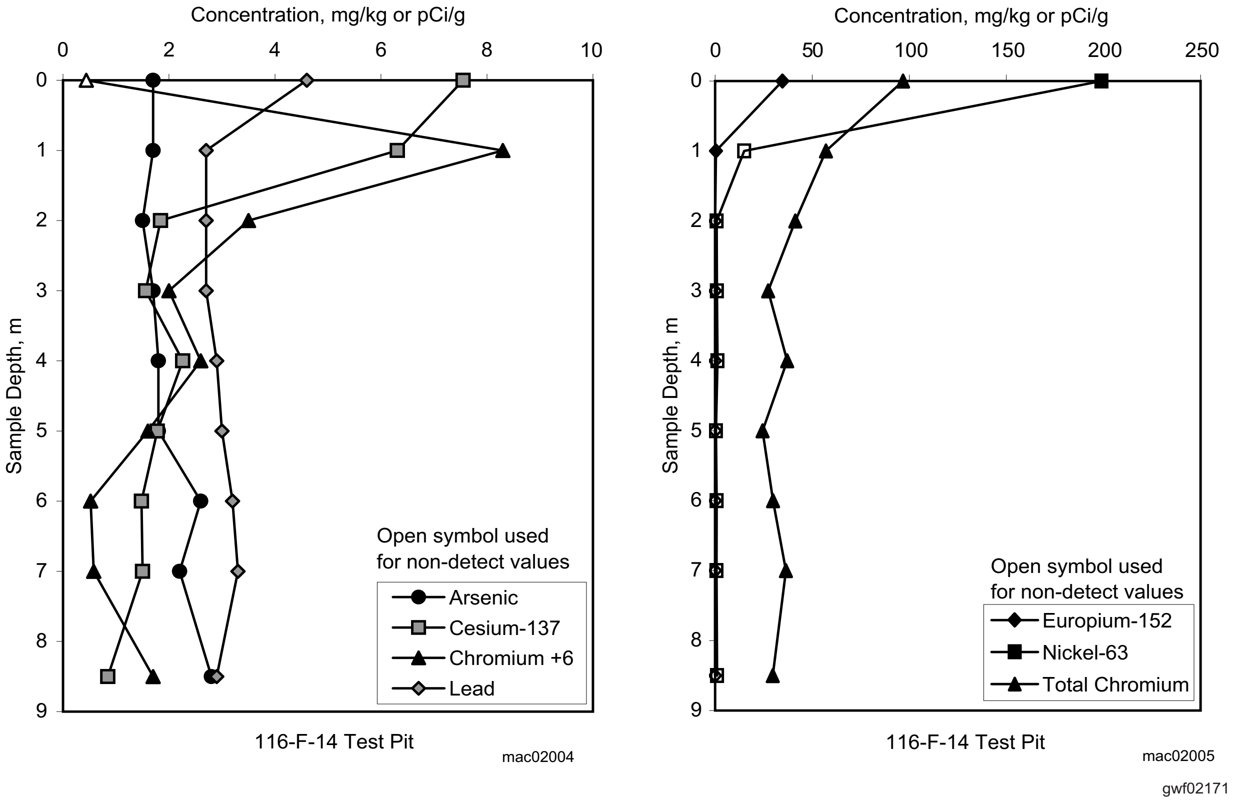


Figure 3.1-1. Concentration Versus Depth for Several Key Constituents in the 116-F-4 Test Pit

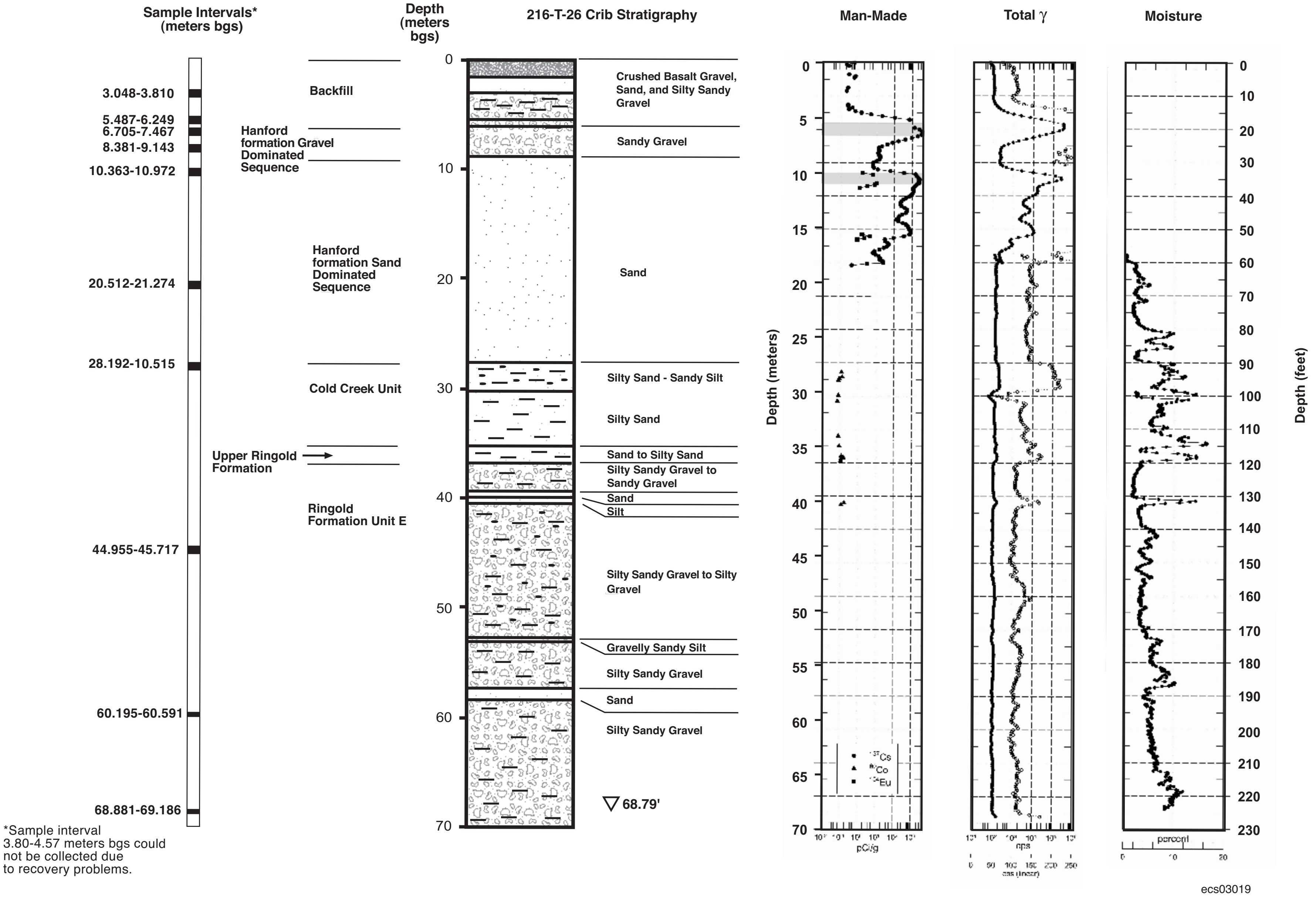
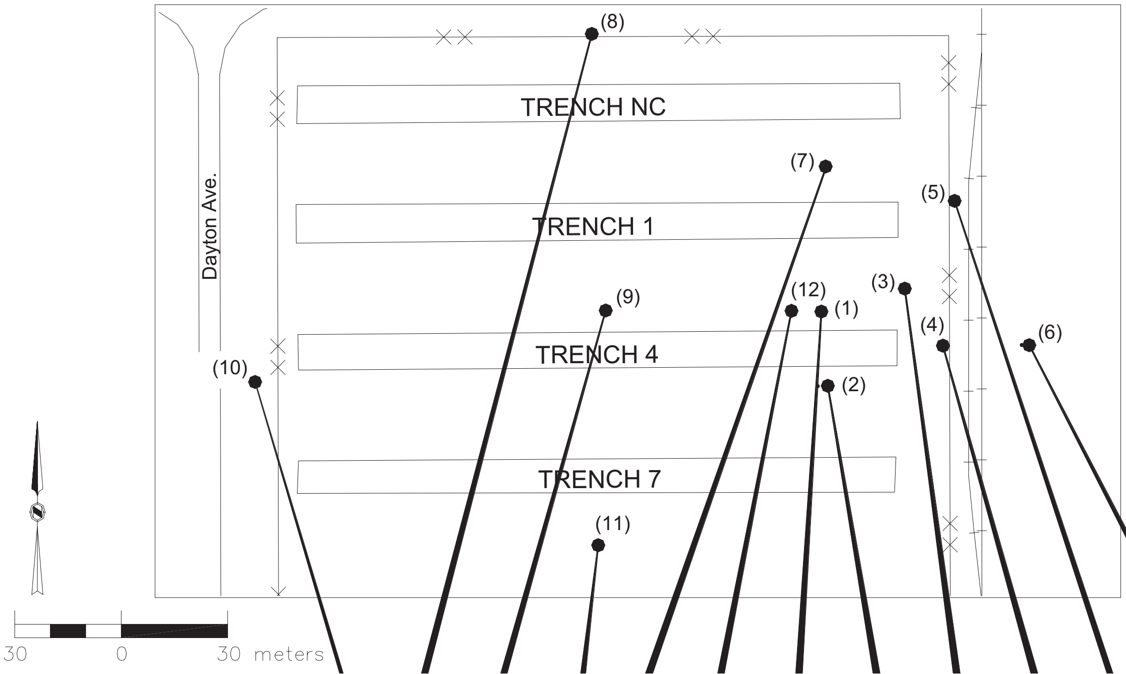


Figure 3.1-2. 216-T-26 Crib Stratigraphy, Sample Locations, and Geophysical Logging Results (from BHI-01606)

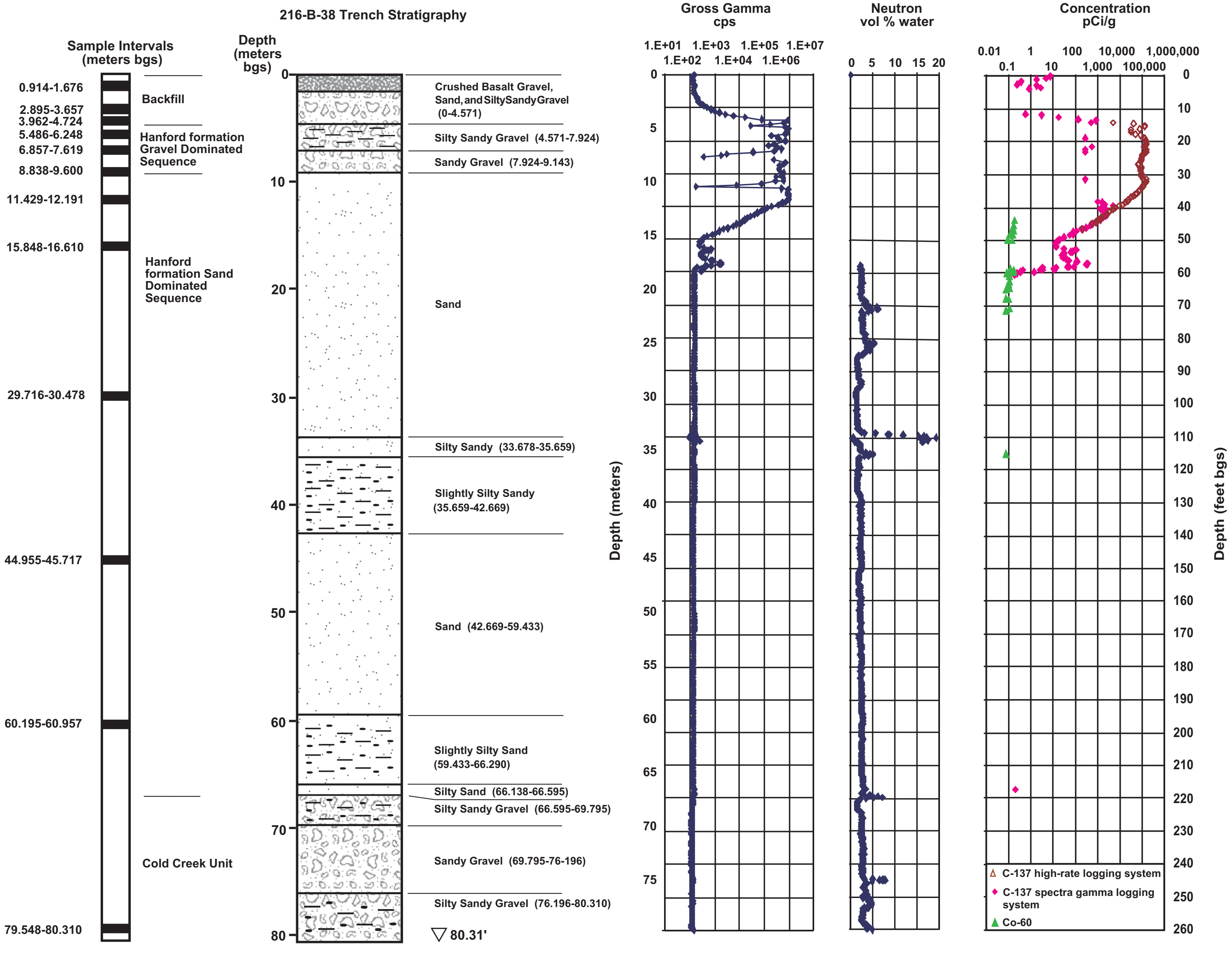


	Sample Location	10	8	9	11	7	12	1	2	3	4	5	6
Aug 2002	Maximum CCL4 (ppmv)	<1.0	<1.0	<1.0	<1.0	<1.0	14.8	10.5	62.1	<1.0	1.4	<1.0	2.4
	Depth (meters bgs)						6.1-7.0	4.6-4.9	3.7-4.0		7.0-7.3		7.3-7.6
Sep 2002	Maximum CCL4 (ppmv)						6.4	16	45.8		8.7		6.2
	Depth (meters bgs)						7.6	4.6	3		9.8		11.0-11.3

CCL4 = Carbon Tetrachloride
bgs = Below Ground Surface

wdw03003

Figure 3.1-3. Carbon Tetrachloride Concentrations in Vapor Samples from Vent Risers at the 216-W-4C Burial Ground



ecs03020

Figure 3.1-4. 216-B-38 Trench Stratigraphy, Sample Locations, Radiological Field Screening Data, and Geophysical Logging Results

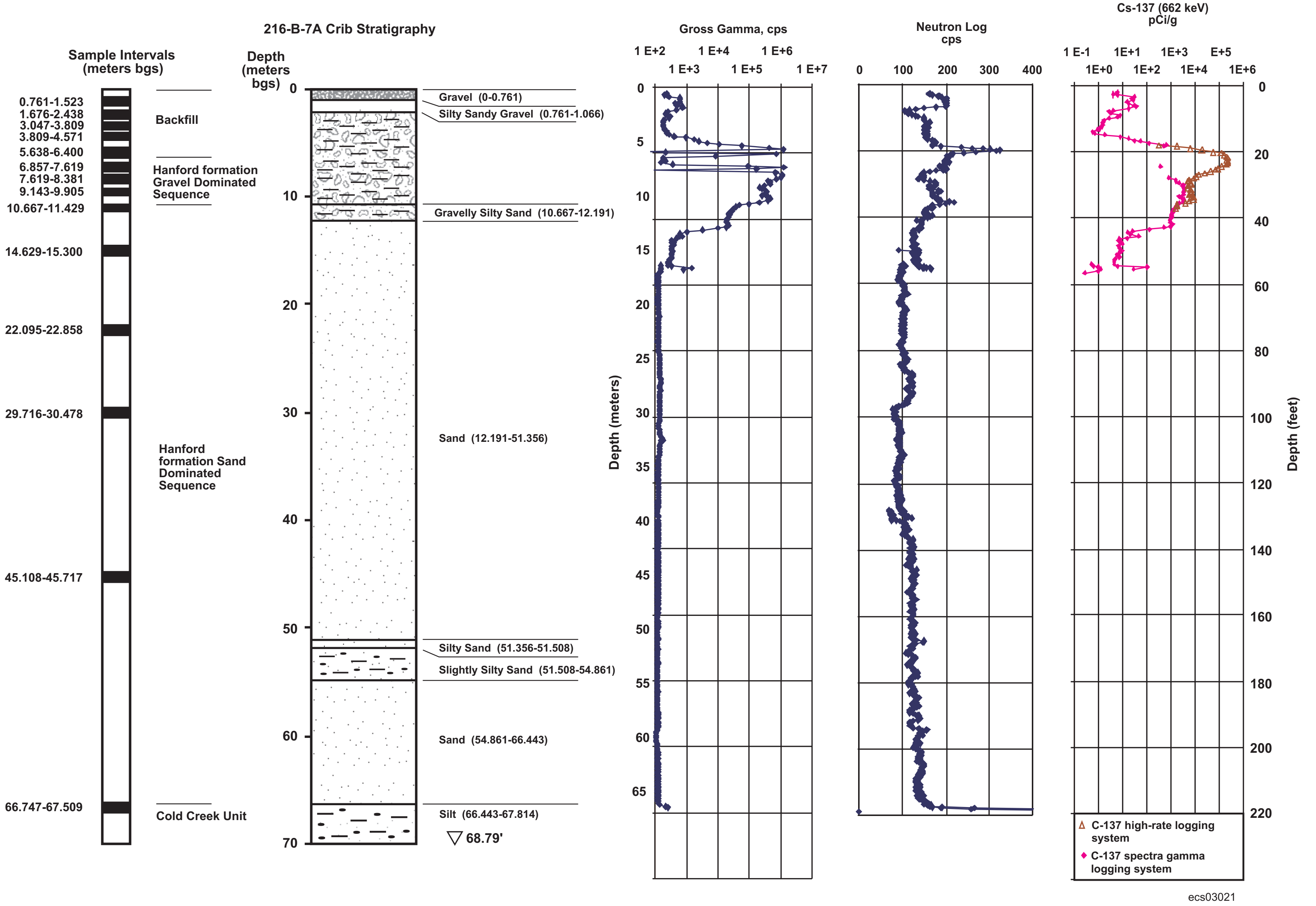


Figure 3.1-5. 216-B-7A Crib Stratigraphy, Sample Locations, Radiological Field Screening Data, and Geophysical Logging Results

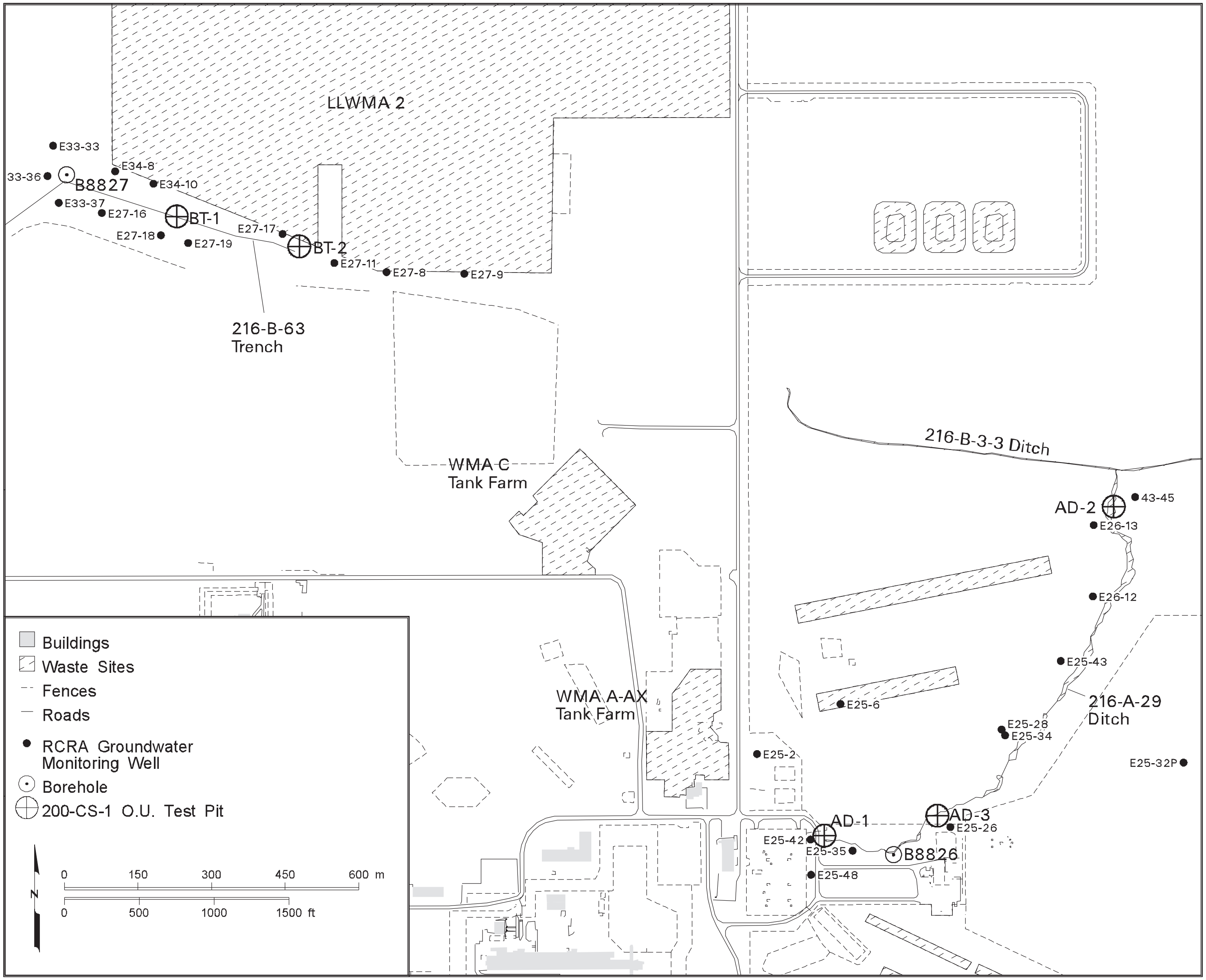


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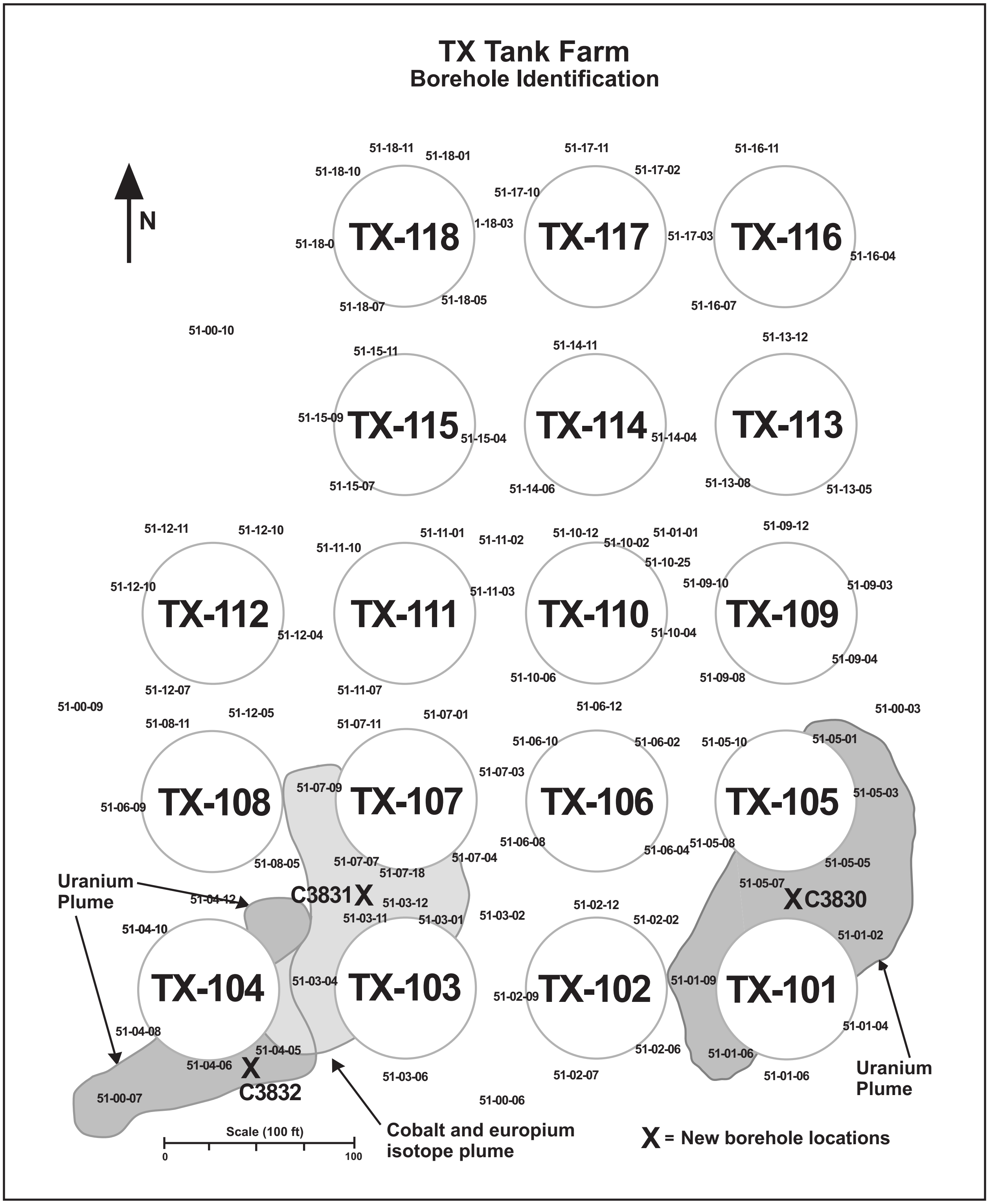
Figure 3.1-6. Locations of Test Pits in the 216-A-29 Ditch and the 216-B-63 Trench at the 200-CS-1 Operable Unit



ecs03018

Figure 3.1-7. Location of Vadose Zone Contaminant Plumes and Vadose Zone Project Characterization Boreholes at the TX Tank Farm

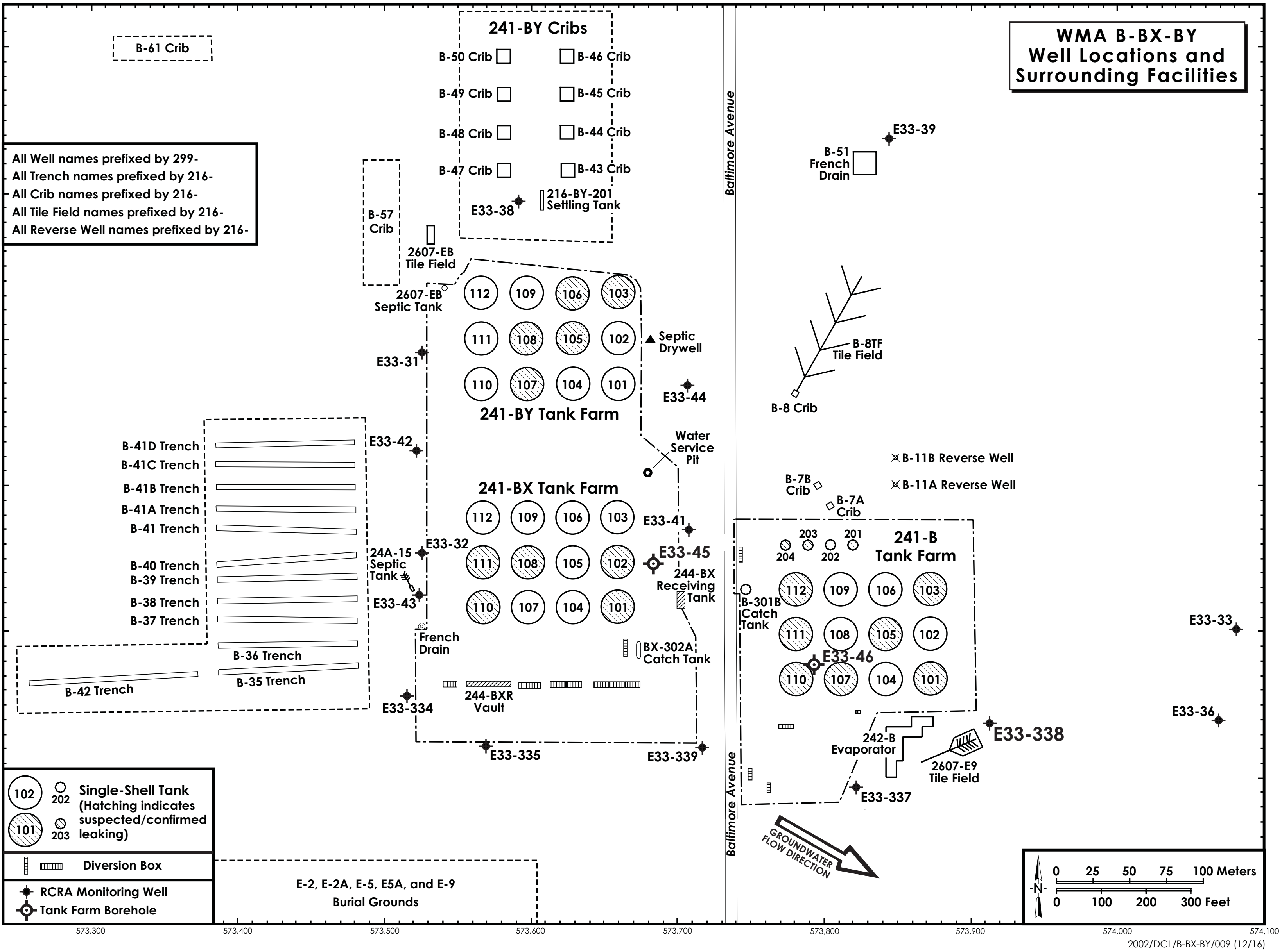


Figure 3.1-8. Locations of Boreholes 299-E33-338, 299-E33-45, and 299-E33-46 at Waste Management Area B-BX-BY

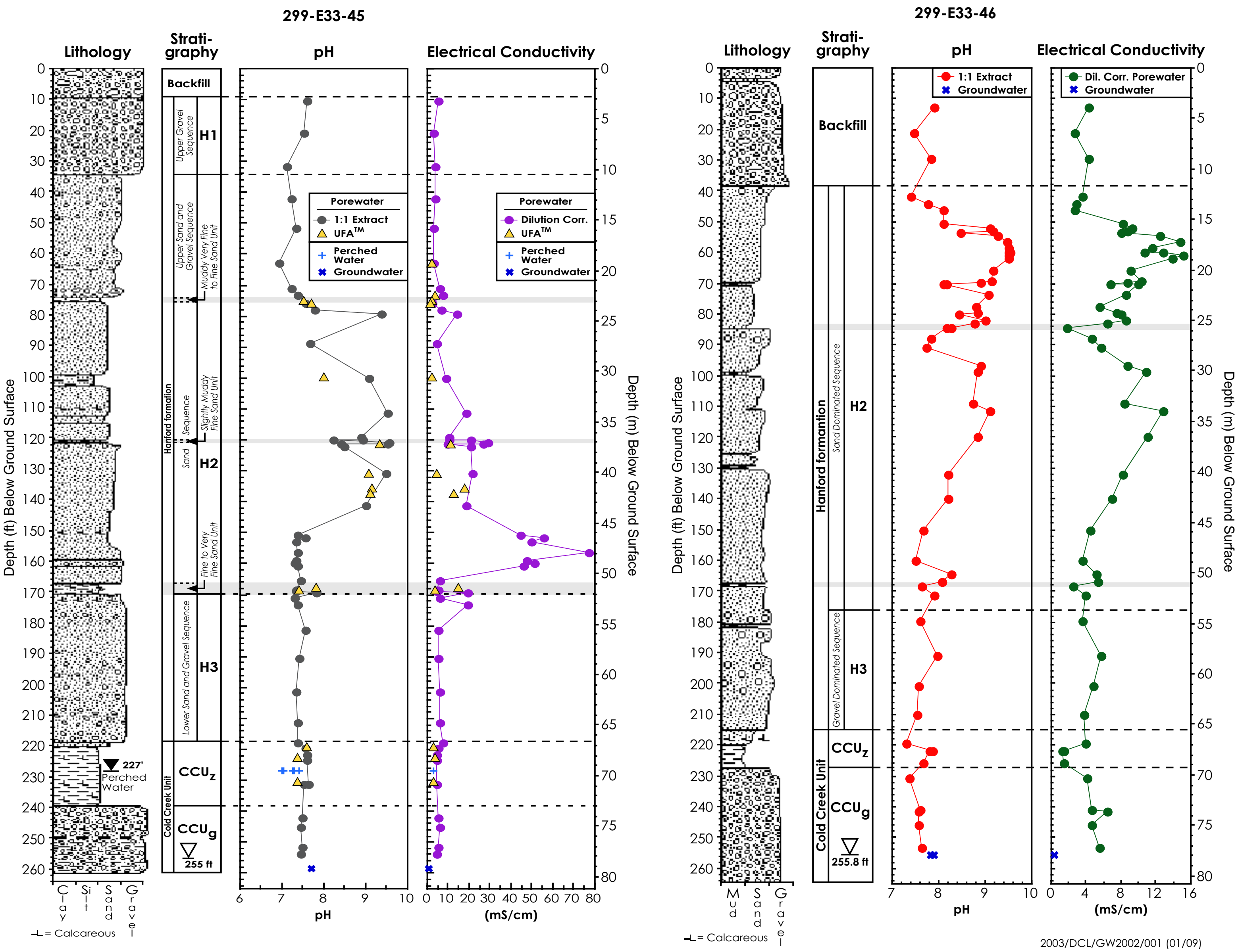


Figure 3.1-9. pH and Electrical Conductivity for Dilution Corrected and Actual Pore Waters from Boreholes 299-E33-45 and 299-E33-46. UFA = Unsaturated flow apparatus.

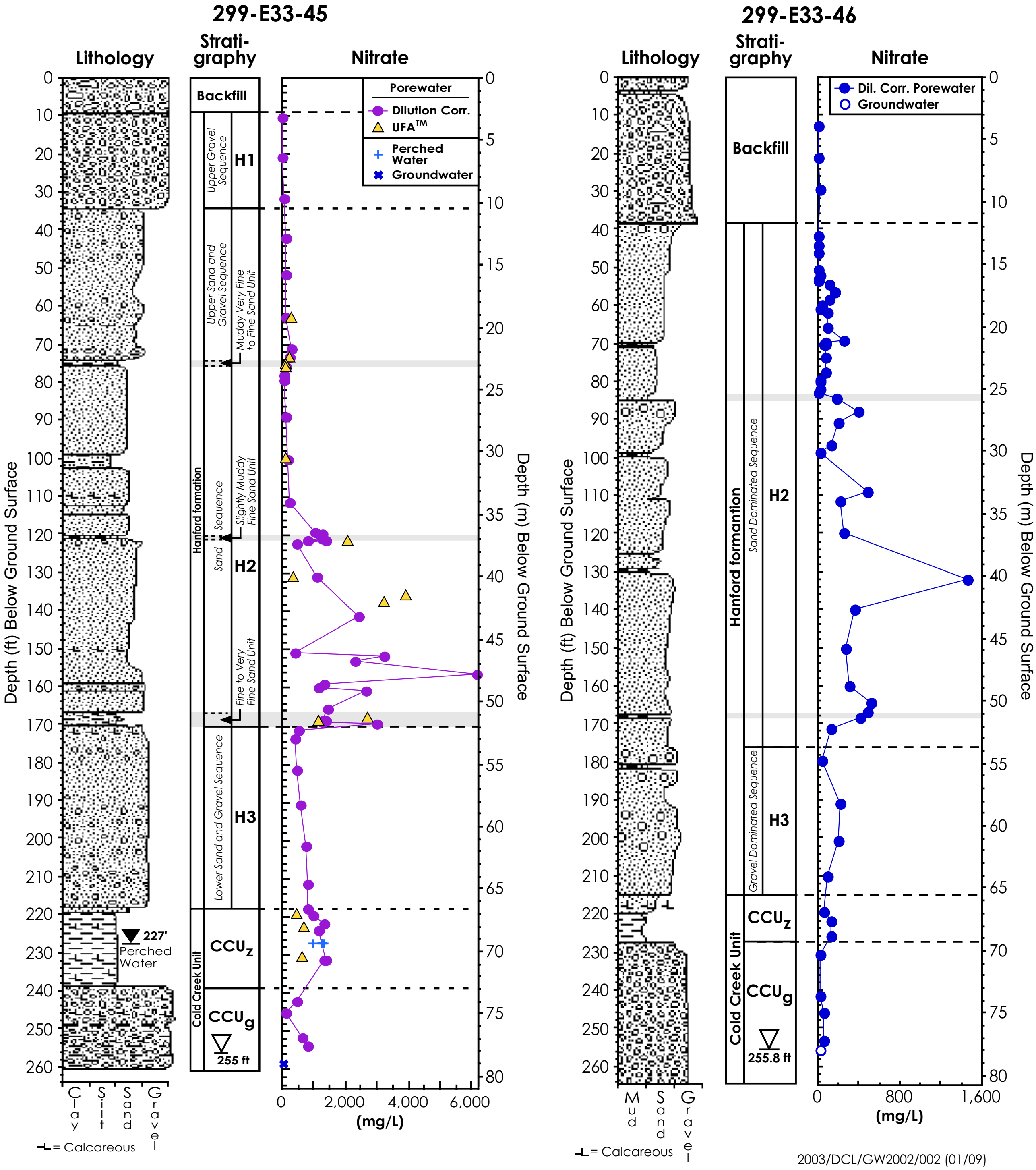


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Figure 3.1-10. Selected Anion Concentrations in Boreholes 299-E33-45 and 299-E33-46. UFA = Unsaturated flow apparatus.

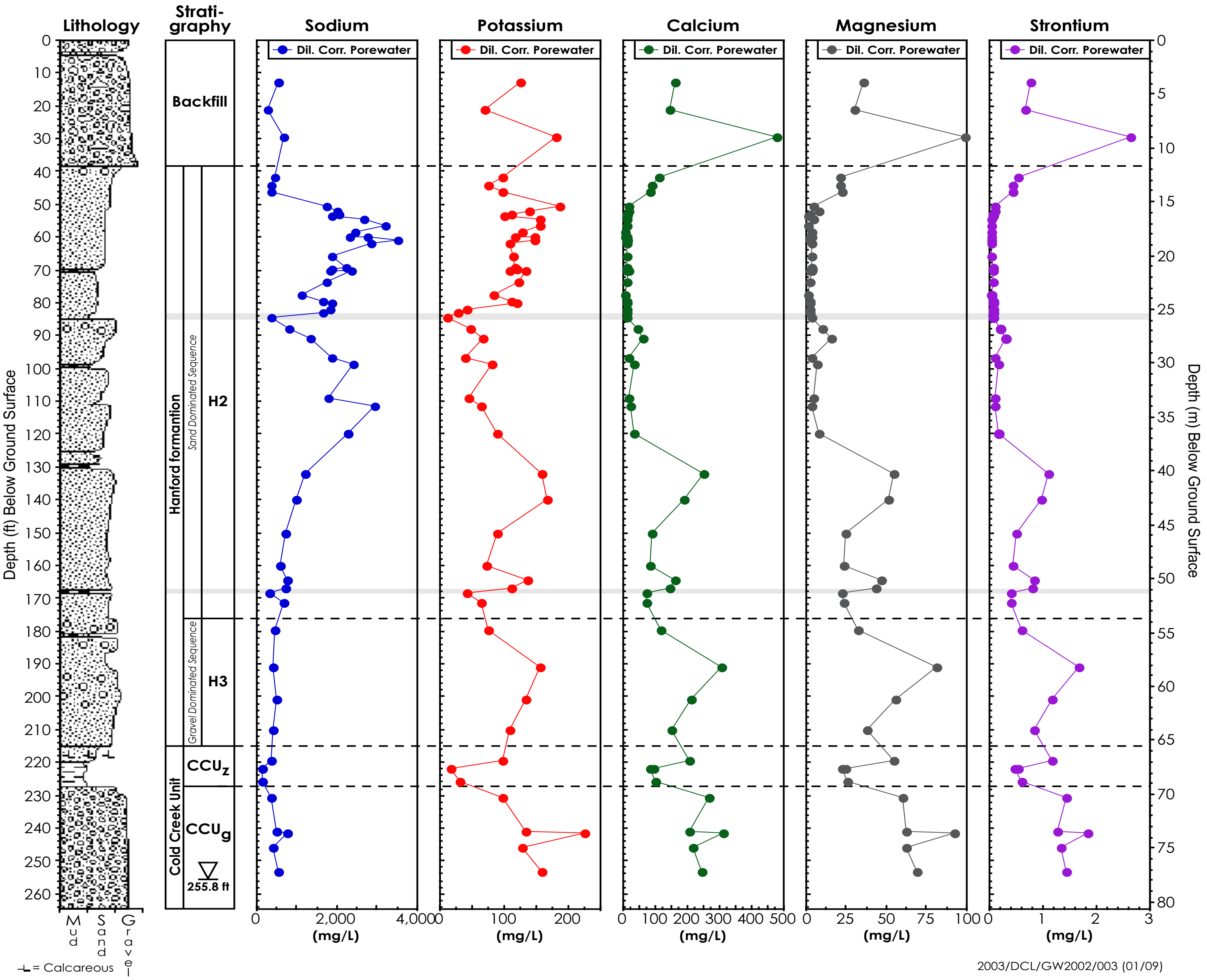


Figure 3.1-11. Alkali and Alkaline Earth Concentrations with Depth in Borehole 299-E33-46

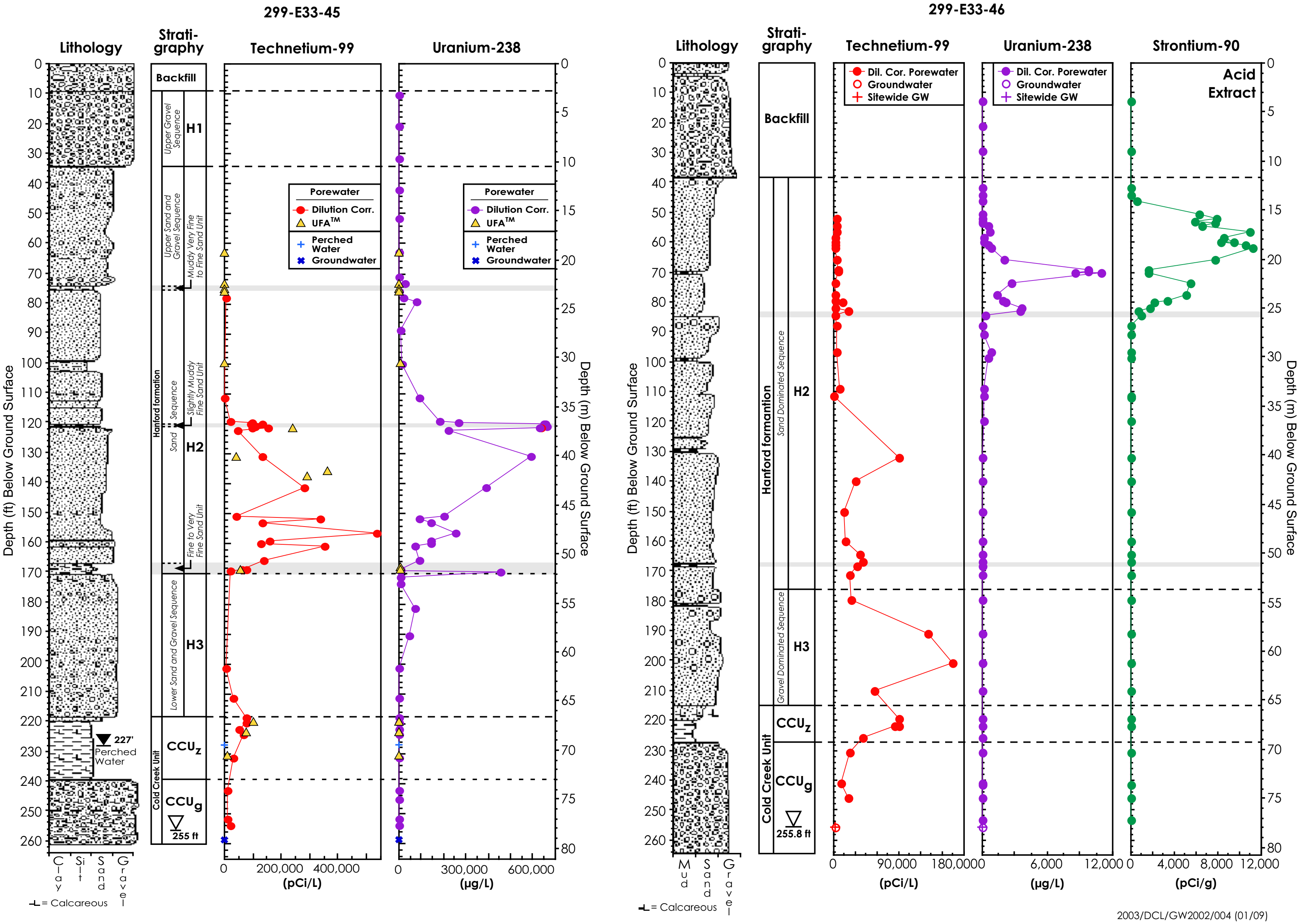


Figure 3.1-12. Selected Radionuclide in Dilution-Corrected Pore Waters from Boreholes 299-E33-45 and 299-E33-46

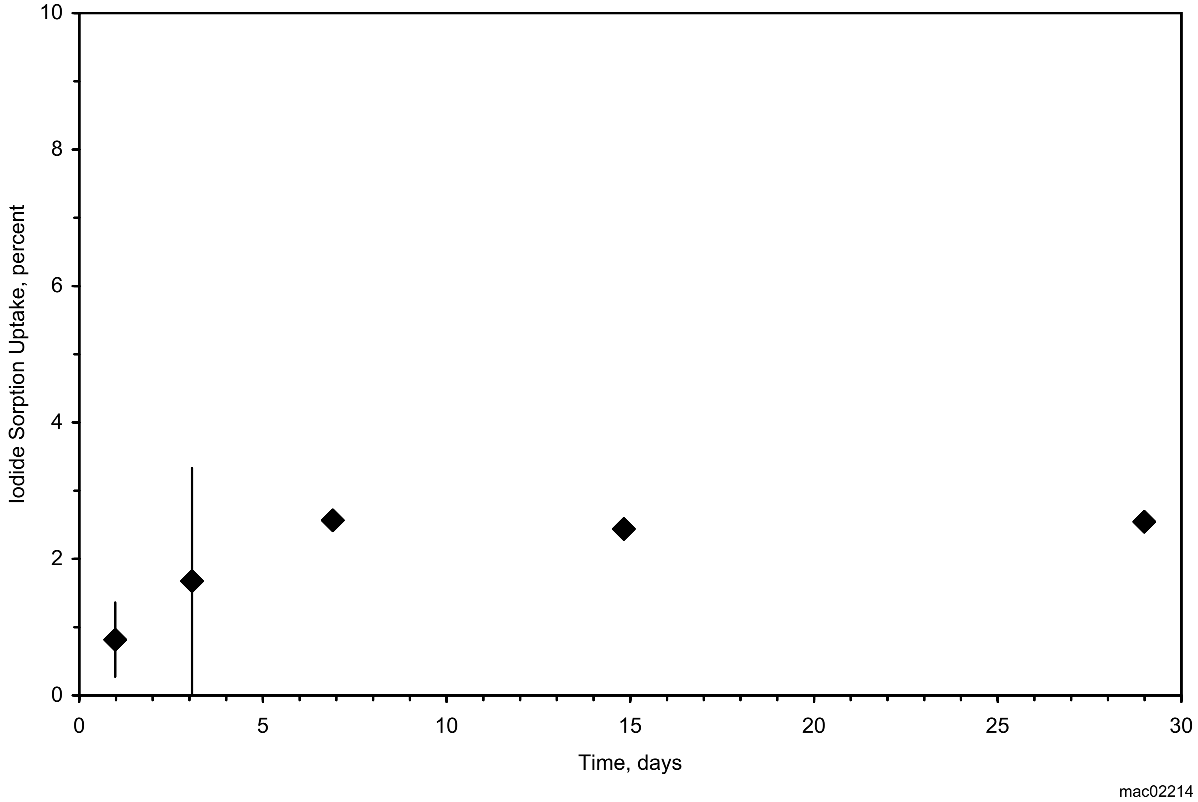


Figure 3.1-13. Iodine-125 Sorption on Hanford Site Sediment as a Function of Time. Error bars represent one standard deviation of two replicates.

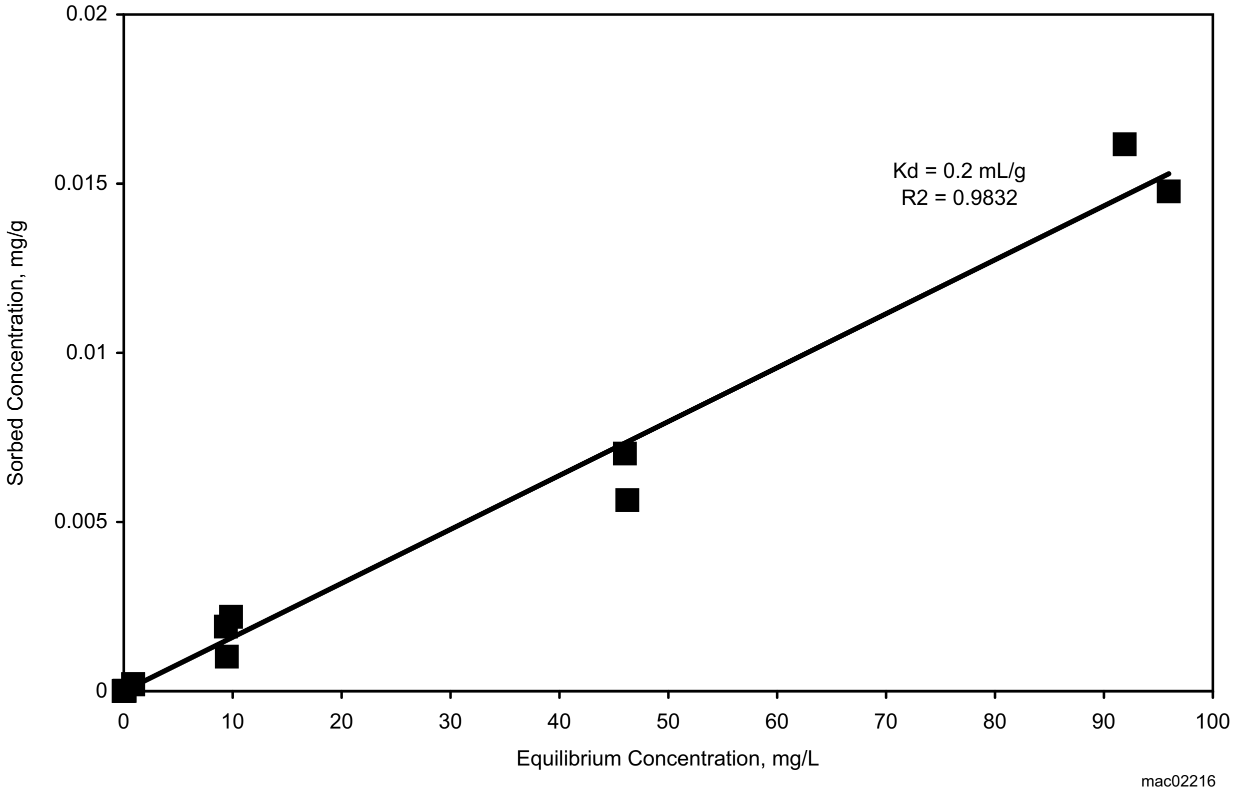


Figure 3.1-14. Sorption Isotherm for Iodine-125 on Hanford Site Sediment at pH 7.5 in Groundwater

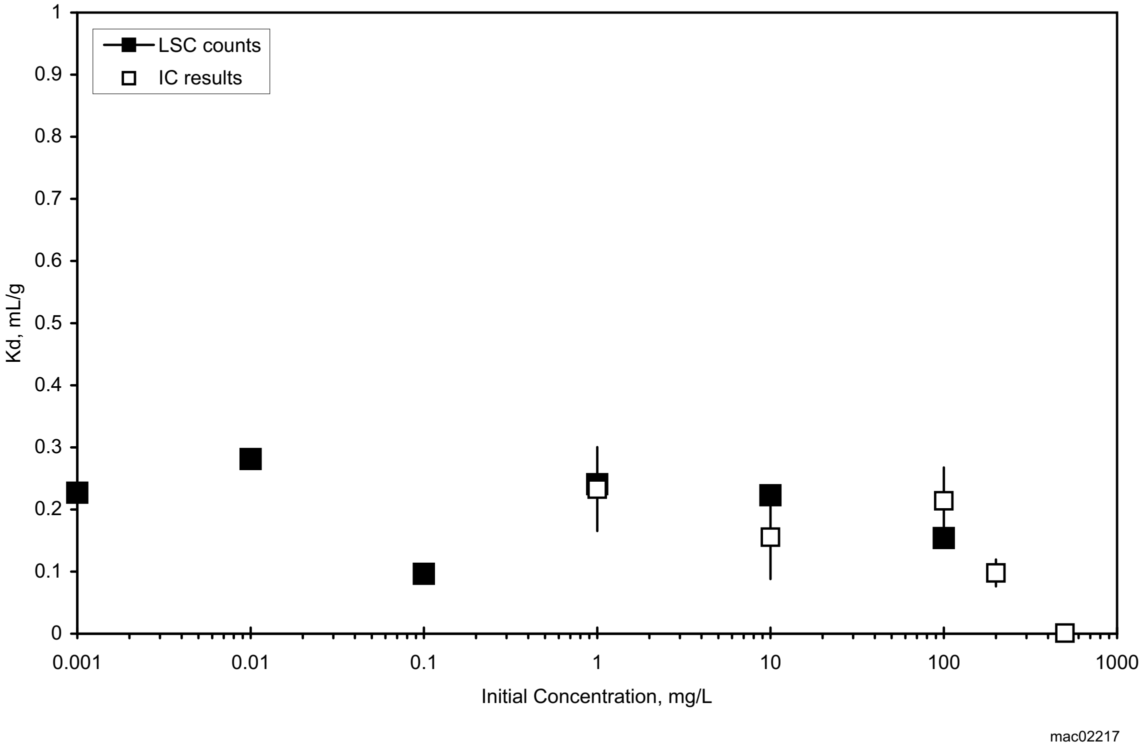


Figure 3.1-15. Linear Distribution Coefficients (K_ds) for Iodine-125 in the Initial Concentration Range of 1 µg/L to 500 mg/L at pH=75 in Hanford Site Groundwater. Filled squares = K_ds based on the radiotracer; open squares = K_ds based on the stable iodide concentrations measured by ion chromatography.

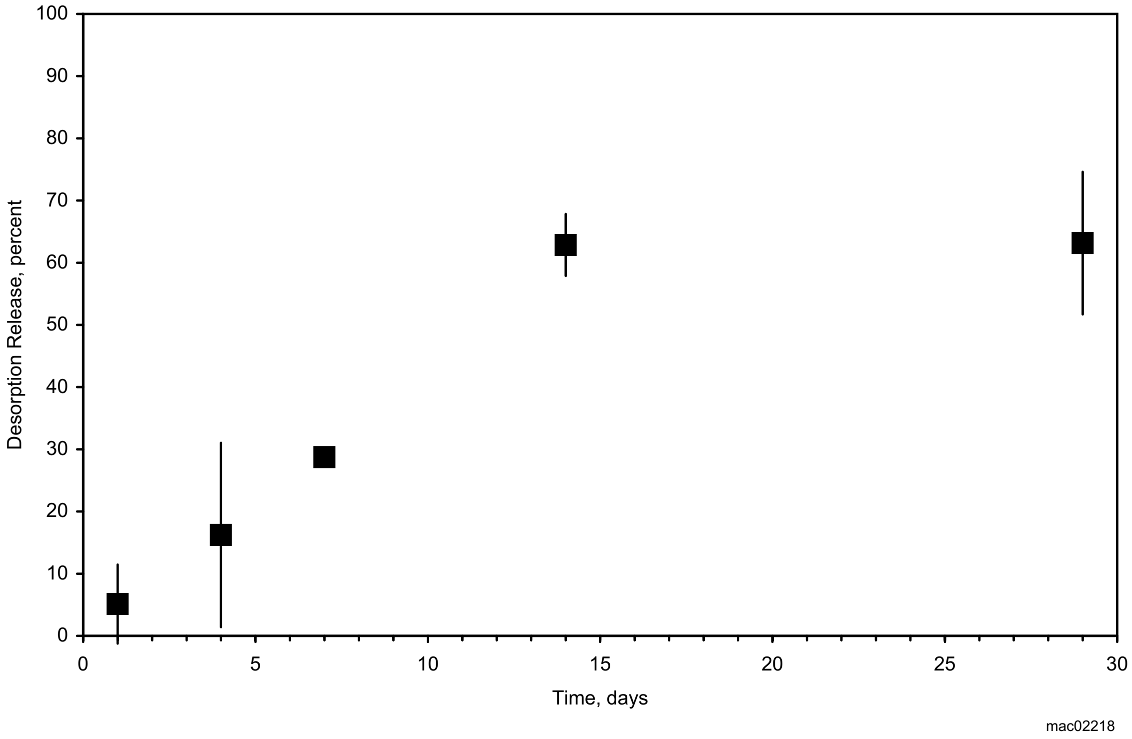


Figure 3.1-16. Desorption Release of Iodine-125 as a Function of Time. Initial iodine-125 sorption uptake was 2% at pH=7.5 groundwater solution. The error bars represent one standard deviation of two replicates.

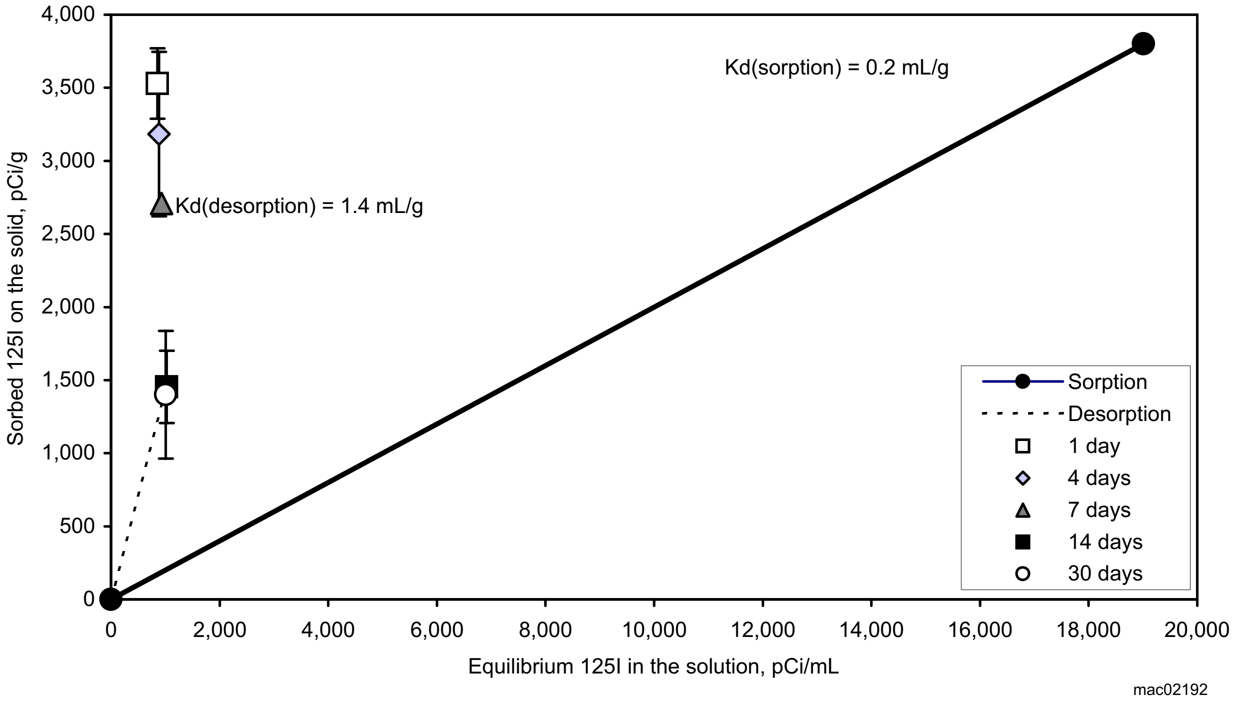


Figure 3.1-17. Sorption and Desorption Isotherms for Iodine-125 on Hanford Site Sediment and Groundwater

3.2 Vadose Zone Monitoring

Vadose zone monitoring occurred at five major areas on the Hanford Site in fiscal year 2002. Leachate and soil-gas monitoring continued at the Solid Waste Landfill and the Environmental Restoration Disposal Facility. Also, soil-gas monitoring at the carbon tetrachloride expedited-response-action site continued during fiscal year 2002.

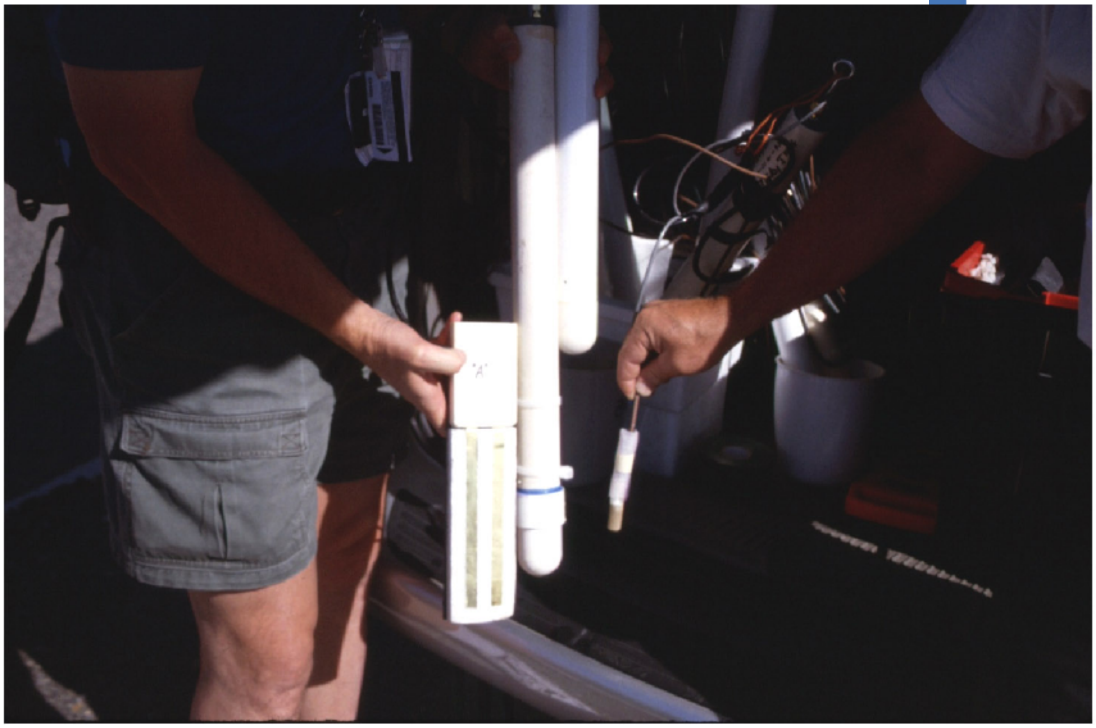
Geophysical borehole monitoring continued at single-shell tank farms to detect leaks and the migration of subsurface contaminants during the fiscal year. Finally, borehole geophysical monitoring (or characterization) of drywells at past-practice liquid disposal sites began in fiscal year 2002. The results of the first monitoring events at each past-practice site will provide a baseline against which to compare subsequent logging events to document subsurface contaminant movement.

3.2.1 Tank Farms Vadose Zone Monitoring Project

P. D. Henwood, A. W. Pearson, and R. G. McCain

A comprehensive monitoring project was established in fiscal year 2001 for existing boreholes in single-shell tank farms to measure movement of radioactive contamination in the vadose zone near the tanks (MAC-HGLP 1.8.1). The logging system used for monitoring is the Radionuclide Assessment System. A baseline record of existing contamination associated with gamma-emitting radionuclides in the vadose zone was established between 1995 and 2000 using the Spectral Gamma Logging System. The Radionuclide Assessment System is a simpler, faster, and more cost-effective logging system for routine monitoring than is the Spectral

In May 2002, cesium-137 was detected in the TY Tank Farm between a depth of 16.8 and 17 meters that was not present during the 1996 logging. This contamination is present at or slightly below the base of the tank farm excavation.



gwf02251

This photo shows the vadose zone monitoring system (without water fluxmeter and temperature sensor) before deployment in B Tank Farm. Sensors from left to right are the modified water content sensor, advanced tensiometer, solution sampler, and heat-dissipation unit.

Gamma Logging System, and measurements collected with the Radionuclide Assessment System can be compared to the baseline data to assess the long-term stability of contaminant profiles. When routine monitoring identifies anomalies relative to the baseline, an evaluation of the anomaly may involve additional logging with the Spectral Gamma Logging System, the High Rate Logging System, and/or the Neutron Moisture Logging System. The Spectral Gamma Logging System can detect and quantify natural and manmade radionuclides from background levels up to a maximum activity on the order of 5,000 to 10,000 pCi/g cesium-137. The High Rate Logging System is designed to operate in zones of high gamma flux where the Spectral Gamma Logging System cannot function and extends the measurement capability to ~1 billion pCi/g cesium-137.

Monitoring is performed on a variable frequency, ranging from quarterly to once in 5 years, depending on the location of a borehole with respect to known or potential contaminant plumes. The intent of the program is to log each borehole at least once in a 5-year period. A prioritized list of available boreholes is developed on the basis of the proximity to known or suspected contaminant plumes, proximity to tanks known to be leaking, and proximity to tanks containing relatively large volumes of drainable liquid.

In fiscal year 2002, 384 spectral gamma logs were obtained with the Radionuclide Assessment System. A total of 497 logs have been obtained with that system since the beginning of the project in June 2001. An additional 24 borehole logs were obtained during fiscal year 2002 with the High Rate Logging System and 7 borehole logs were obtained with the Neutron Moisture Logging System. All high-priority boreholes in tank farms have been monitored at least once since June 2001. A summary of monitoring operations for fiscal year 2002, and the project to date is shown in Table 3.2-1.

Evidence from comparisons of pre-1994 gross gamma logs and subsequent spectral gamma logs suggests possible contaminant movement in 25 boreholes in seven tank farms. Of these 25 boreholes, data collected from only 2 boreholes indicate movement to a degree that can be confirmed with measurements collected over a short period of time. Of the remaining 23 boreholes, it is likely that the elapsed time between spectral gamma monitoring events is too short to substantiate subtle changes in contaminant profiles resulting from slow movement of contaminants in the vadose zone. Table 3.2-2 lists boreholes where evidence of potential contaminant movement has been observed since the beginning of the monitoring project in June 2001. Geophysical logs from the respective boreholes are included in the quarterly reports available at http://www.gjo.doe.gov/programs/hanf/HTFVZ.html. The dominant contaminants detected in these boreholes are cobalt-60 and processed uranium (uranium-235 and -238).

Data collected in September 2002 from borehole 30-08-02 in C Tank Farm exhibited evidence of recent contaminant migration of cobalt-60 at depths of ~15 to 18 meters and at 20.4 to 22.9 meters. The contamination originates between tanks C-108 and C-109 and extends downward and laterally to the east. This plume is probably related to that observed previously in borehole 30-06-10. Evidence of cobalt-60 migration in borehole 30-06-10 was first detected by Spectral Gamma Logging System measurements in 1997 and 1999 and confirmed by Radionuclide Assessment System measurements in 2002. Figures 3.2-1 and 3.2-2 show available log data for boreholes 30-08-02 and 30-06-10. Quarterly monitoring for both boreholes has been established with the next scheduled measurements.

During May 2002, routine Radionuclide Assessment System monitoring in borehole 52-03-06, in the TY Tank Farm, detected prominent gamma activities peak between depths of 16.8 and 17.4 meters that was not present during the baseline Spectral Gamma Logging System logging in 1996 (Figure 3.2-3). This peak was subsequently confirmed by additional spectral gamma logging measurements. A "new" cesium-137 contaminant plume appears to be present at or slightly below the base of the tank farm excavation. Moisture logging was also performed in boreholes in the vicinity of borehole 52-03-06, where the anomalous cesium-137 activity was detected. A 4-meter interval of high moisture (12% to 35%) was detected between depths of 11.6 and 15.6 meters in depth in borehole 52-06-02. This borehole is located ~22.9 meters west of borehole 52-03-06, and may be in the vicinity of a water source that has mobilized contaminants to the location of borehole 52-03-06.

Also, cobalt-60 appears to be relatively constant between depths of 17 and 20 meters, but below 20 meters, cobalt-60 levels appear to have decreased at a rate of about 2 to 4 times faster than can be accounted for by radioactive decay (see Figure 3.2-3).

A special investigation of boreholes around tank U-107 in the U Tank Farm was initiated in 2001 to support pending waste retrieval operations. No significant changes in contaminant profiles have been observed in five monitoring events conducted in boreholes at tank U-107. However, data acquired in a borehole in the vicinity of tank U-107 (60-05-05) exhibited possible changes during routine monitoring in 2002.

3.2.2 Geophysical Logging at Past-Practice Disposal Facilities

S. M. Sobczyk, P. D. Henwood, R. G. McCain, and S. E. Kos

The U.S. Department of Energy's (DOE's) Grand Junction Office began spectral gamma logging in existing boreholes near liquid waste disposal sites and solid waste burial grounds at the Hanford Site 200 Areas during fiscal year 2001. The purpose of the project is to detect and quantify naturally occurring and manmade gamma-emitting radionuclides in the vadose zone. This project is an extension of the baseline characterization work completed in the Hanford Site single-shell tank farms. The resulting geophysical logs are used to identify stratigraphic boundaries and to determine the nature and extent of subsurface radioactive contamination. Also, the newly acquired logs establish a baseline for comparison with future logs allowing an assessment of contaminant mobility. In addition to the baseline logging, geophysical logging is also done in support of remedial investigation projects and the *Resource Conservation and Recovery Act* (RCRA) groundwater monitoring project.

There was good agreement between geophysical logs collected in the 1990s and in 2002 that show the distribution of cobalt-60 and cesium-137. This information indicates that the contaminants have not migrated significantly at the site of the 216-B-35 through 216-B-42 trenches during the last 10 years.

The logging systems used at past-practice disposal facilities are the same as those used at single-shell tank farms (see Section 3.2.1). The logging systems, logging methods, and data collection and analysis procedures are described in MAC-HGLP 1.6.5, MAC-HGLP 1.6.2, and GJO-HGLP 1.6.3. Recent geophysical logging tool calibrations are documented in GJO-2001-250-TAR and GJO-2002-328-TAR.

During fiscal year 2002, vadose zone characterization logging was completed in 70 existing boreholes. Nine of these boreholes were new boreholes logged in support of ongoing remedial investigation projects. Spectral gamma logging also was performed in five RCRA groundwater monitoring wells constructed in fiscal year 2002 and in three new boreholes associated with the immobilized low-activity waste site. High rate logging was performed in 23 boreholes. Results of the Hanford 200 Areas Spectral Gamma Baseline Characterization Project are posted on the Internet at http://www.gjo.doe.gov/programs/hanf/HTFVZ.html.

Data from each borehole were analyzed to determine concentrations of naturally occurring radionuclides (potassium-40, uranium-238, thorium-232, and associated decay progeny), as well as manmade gamma-emitting radionuclides such as cesium-137, cobalt-60, antimony-125, uranium-235/-238, and europium-152/-154. Variations in activities of naturally-occurring radionuclides are used to establish the framework for stratigraphic correlations, and the presence of manmade radionuclides is taken as evidence of contamination. With high-resolution spectral gamma logging, it is possible to differentiate between "natural" and "manmade" uranium on the basis of the gamma energy peaks.

After all available boreholes in a specific area have been logged and evaluated, a Waste Site Summary Report is prepared. These reports incorporate spectral gamma logs, other available borehole logs, driller's reports, geologic data, and any analytical data to summarize vadose zone conditions in the area. During fiscal year 2002, waste site summary reports were issued for the 216-B-8 crib and adjacent areas (GJO-2002-343), the 216-B-35 to 216-B-42 trenches (GJO-2002-322), and the 216-B-5 injection well and 216-B-9 crib (GJO-2002-358-TAC).

Nineteen vadose zone boreholes, 3 WAC 173-160-compliant wells, and 10 wells that are not compliant with WAC 173-160 were logged in the area northeast of Waste Management Area B-BX-BY. This area includes the 216-B-7A and 216-B-7B cribs, the 216-B-8 crib and tile field, and the 216-B-11A and 216-B-11B reverse wells. Cesium-137, cobalt-60, uranium-238, uranium-235, and europium-154 were detected. The predominant contaminant was cesium-137 (Figure 3.2-4), with a maximum concentration of 300,000 pCi/g in the vicinity of the 216-B-7A and 216-B-7B cribs. Contamination that appears to be associated with a specific waste site generally was observed at depths <46 meters, although historical gross gamma logs suggests contaminant breakthrough to groundwater may have occurred prior to 1959.

An area of uranium contamination originating from the BX Tank Farm was identified just above groundwater in well 299-E33-18 at a distance of 122 meters east of its presumed source at tank BX-102 (Figure 3.2-5). This contamination reached wells 299-E33-41 (Figure 3.2-6) and 299-E33-18 between 1991 and 1997. Spectral gamma logging results suggest that manmade uranium concentrations have increased in well 299-E33-18 since 1997. High moisture identified at the bottom of a temporary borehole ~54 meters north of tank B-109 may be related to the deep moisture zone identified in borehole 299-E33-41 and may be the transport mechanism for uranium contamination.

Cobalt-60 and cesium-137 were identified above the water level and within the uppermost aquifer northeast of Waste Management Area B-BX-BY. However, contamination was only observed in wells that are not compliant with WAC 173-160 and were drilled in the 1950s; contamination was not detected in WAC 173-160-compliant wells drilled in the 1990s. The cobalt-60 and cesium-137 detected in the older wells are thought to be associated with rust or scale on the inside of the steel casing.

Eleven boreholes, including six new boreholes drilled along the 216-B-38 trench as part of the 200-TW-1 remedial investigation (discussed in Section 3.1.1.2), and three groundwater wells were logged at the 216-B-35 through 216-B-42 trenches located west of Waste Management Area B-BX-BY (GJO-2002-322; see Figure 2.9-1 for the location of the trenches). Cesium-137 was detected in all boreholes. Three intervals of cesium-137 contamination were identified: (1) 0.3 to 10 pCi/g within 3.7 meters of the top of casing; (2) 0.3 to 100,000 pCi/g between depths of 3.1 and 21.3 meters; and (3) 0.3 to 3.5 pCi/g in a zone immediately above the water table. High gamma-ray intensities saturated the Spectral Gamma Logging System detector in 10 boreholes and wells between depths of ~3.1 and 21.3 meters. These intervals were logged with the High Resolution Logging System; the maximum cesium-137 concentration was ~200,000 pCi/g at a depth of 5 meters beneath the 216-B-38 trench. The deepest cesium-137 was detected at a depth of

85.4 meters in well 299-E33-21, where a maximum concentration of 45 pCi/g was measured. Cobalt-60 was detected from depths of 9.2 to 22 meters beneath the 216-B-36 and 216-B-38 trenches and north of the 216-B-41 trench at concentrations ranging up to 0.6 pCi/g. Antimony-125 was detected in well 299-E33-8 at depths between 9.8 and 10.4 meters at activities ranging from 1 to 2.5 pCi/g.

A comparison between the recently collected log data and spectral gamma data collected in the 1990s (seven boreholes) shows good agreement in the distributions of cobalt-60 and cesium-137 in the vicinity of the trenches. Thus, significant contaminant migration has not occurred during the last 10 years.

3.2.3 Carbon Tetrachloride Monitoring and Remediation

V. J. Rohay

Soil-vapor extraction is being used to remove carbon tetrachloride from the vadose zone in the 200 West Area. The U.S. Environmental Protection Agency and the Washington State Department of Ecology authorized DOE to initiate this remediation in 1992 as a *Comprehensive Environmental Response, Compensation, and Liability Act* expedited response action. The following discussion summarizes fiscal year 2002 activities associated with the carbon tetrachloride removal. For descriptions of past work, see BHI-00720 and Section 3.2 in PNNL-13788. See Figure 3.2-7 for locations of vapor extraction wells.

The 14.2-cubic-meter-per-minute soil-vapor extraction system operated at the 216-Z-9 well field from April 1 through July 22, 2002, and at the combined 216-Z-1A/216-Z-12/216-Z-18 well field from July 24 through September 30, 2002. The system was maintained in standby mode from October 1, 2001, through March 31, 2002. The 28.3- and 42.5-cubic-meter-per-minute soil-vapor extraction systems were maintained in standby mode during fiscal year 2002. Both systems are periodically shut down to allow the systems to recharge and thereby more economically extract carbon tetrachloride.

To track the effectiveness of the remediation effort, soil-vapor concentrations of carbon tetrachloride were monitored at the inlet to the soil-vapor extraction system and at individual online extraction wells during the 6-month operating period. To assess the impact of the soil-vapor extraction system during standby mode, soil-vapor concentrations of carbon tetrachloride were monitored at off-line wells during the fiscal year 2002.

Remediation efforts during fiscal year 2002 also included passive soil-vapor extraction.

3.2.3.1 Soil-Vapor Extraction

Soil-vapor extraction to remove carbon tetrachloride from the vadose zone resumed April 1, 2002, at the 216-Z-9 well field. Initially, on-line wells were selected close to the 216-Z-9 trench. As extraction continued, wells farther away were added. Criteria for adding on-line wells included wells open near the groundwater and wells open near the Cold Creek unit. Initial carbon tetrachloride concentrations measured at the soil-vapor extraction system inlet were ~101 parts per million by volume (ppmv) (Figure 3.2-8). After 16 weeks of operation, concentrations had decreased to ~23 ppmv. The daily mass removal rate increased significantly at least once during this period as a result of adjustments in the mix of on-line wells and the flow rate.

Soil-vapor extraction resumed July 24, 2002, at the combined 216-Z-1A/216-Z-12/216-Z-18 well field. Initial on-line wells were selected within the

As of September 2002, ~77,800 kilograms of carbon tetrachloride had been removed from the vadose zone since extraction operations started in 1991. About 7% of the residual mass at the 216-Z-1A/216-Z-12/216-Z-18 well field and 22% of the mass at the 216–9 well field are estimated to have been removed.

perimeter of the 216-Z-1A tile field. As extraction continued, wells farther away from the tile field were brought on-line. Extraction wells open near the less-permeable Cold Creek unit, where the highest carbon tetrachloride concentrations have consistently been detected in the past, were selected to optimize mass removal of contaminant. Initial carbon tetrachloride concentrations measured at the soil-vapor extraction inlet were ~32 ppmv (see Figure 3.2-8). After 10 weeks of extraction, concentrations had decreased to ~21 ppmv.

As of September 2002, ~77,800 kilograms of carbon tetrachloride had been removed from the vadose zone since extraction operations started in 1991 (Table 3.2-3). Since initiation, the extraction systems are estimated to have removed 7% of the residual mass at 216-Z-1A/216-Z-12/216-Z-18 well field and 22% of the mass at the 216-Z-9 well field. This estimate assumes that all of the mass that has not been lost to the atmosphere (21% of the original inventory), dissolved in groundwater (2% of the original inventory), or biodegraded (1% of the original inventory) is still available in the vadose zone as residual mass (BHI-00720; WHC-SD-EN-TI-101).

3.2.3.2 Monitoring at Off-Line Wells and Probes

During fiscal year 2002, soil-vapor concentrations of carbon tetrachloride were monitored near the ground surface, near the Cold Creek unit (~40 meters below ground surface), and near groundwater (~66 meters below ground surface). Soil-vapor concentrations were monitored near the ground surface and groundwater to evaluate whether non-operation of the soil-vapor extraction system negatively affects the atmosphere or groundwater. The maximum concentration detected near the ground surface (between 2 and 10 meters below ground surface) was 13 ppmv. Near the groundwater, at a depth of 55 meters below ground surface, the maximum concentration was 17 ppmv.

Soil-vapor concentrations also were monitored above and within the Cold Creek unit to provide an indication of concentrations that could be expected during restart of the soil-vapor extraction system. The maximum concentration detected near the Cold Creek unit (between 25 and 44 meters below ground surface) was 297 ppmv in well 299-W18-167 (32 meters below ground surface) within the 216-Z-1A tile field (see Figure 3.2-7 for well locations). During monitoring in fiscal years 1997, 1998, 1999, 2000, and 2001, the highest concentrations in the 216-Z-1A/216-Z-12/216-Z-18 well field also were detected at wells within the 216-Z-1A tile field.

Temporary suspension of soil-vapor extraction in fiscal year 2002 appears to have caused minimal transport of carbon tetrachloride through the soil surface to the atmosphere. Also, suspended operation of the extraction system appears to have had no negative impact on groundwater quality.

At the 216-Z-9 well field, the maximum carbon tetrachloride concentration detected near the Cold Creek unit was 214 ppmv in well 299-W15-217 (35 meters below ground surface; see Figure 3.2-7 for well locations). During monitoring in fiscal years 1997, 1998, 1999, 2000, and 2001, the highest carbon tetrachloride concentrations were also detected in this well. Approximately 90 meters south of the 216-Z-9 trench, the maximum carbon tetrachloride concentration detected was 229 ppmv at soil-vapor probe CPT-28 (27 meters below ground surface; see Figure 3.2-7 for soil-vapor probe locations). Approximately 200 meters north of the 216-Z-9 trench, the maximum carbon tetrachloride concentration detected was 208 ppmv at soil-vapor probe CPT-9A (28 meters below ground surface). The maximum carbon tetrachloride concentration detected in the vadose zone overlying the Cold Creek unit (between 11 and 23 meters below ground surface) was 97 ppmv at soil-vapor probe CPT-21A near the 216-Z-9 trench.

The 6-month temporary suspension of soil-vapor extraction in fiscal year 2002 appears to have caused minimal detectable vertical transport of carbon tetrachloride through the soil surface to the atmosphere. This interpretation is supported by data that shows carbon tetrachloride concentrations did not increase significantly at the near-surface monitoring points. In addition, suspending operations of the soil-vapor extraction system appears to have had no negative impact on groundwater quality, because carbon tetrachloride concentrations did not increase significantly near the water table during that time.

3.2.3.3 Passive Soil-Vapor Extraction

Passive soil-vapor extraction is a remediation technology that uses naturally-induced pressure gradients between the subsurface and the surface to drive soil vapor to the surface. In general, falling atmospheric pressure causes subsurface vapor to move to the atmosphere through wells, whereas rising atmospheric pressure causes atmospheric air to move into the subsurface. Passive soil-vapor extraction systems are designed to use this phenomenon to remove carbon tetrachloride from the vadose zone.

Passive soil-vapor extraction systems were installed at the end of fiscal year 1999 at eight boreholes that are open near the vadose-groundwater interface at the 216-Z-1A/216-Z-12/216-Z-18 well field. The passive systems are outfitted with check valves that only allow soil-vapor flow out of the borehole (i.e., one way movement), and canisters holding granular activated carbon that adsorbs carbon tetrachloride downstream of the check valves before the soil vapor is vented to the atmosphere. The check valve prohibits flow of atmospheric air into the borehole during a reverse barometric pressure gradient, which tends to dilute and spread carbon tetrachloride vapors in the subsurface. Each system initially had an in-line, replaceable cartridge of granular activated carbon for sampling upstream of the canister of granular activated carbon.

Three of eight boreholes initially were instrumented to measure hourly air pressure differentials between the ground surface and the bottom of the boreholes, carbon tetrachloride concentrations, temperature, and flow rates. These data were used to calculate an hourly estimate of the amount of mass removed from the well. The granular activated carbon in the cartridges at all eight boreholes was sampled monthly and analyzed using laboratory analytical services. Analysis of the granular activated carbon in the cartridge was intended to provide a time-integrated estimate of the mass removed while the granular activated carbon was in-line. However, use of these in-line canisters was discontinued in March 2002 because the sample results were found to be unrepresentative of the mass extracted through each well (BHI-00720). The automated hourly measurements also were discontinued.

Four of the eight boreholes were placed on-line to the soil-vapor extraction system in August 2002. As part of soil-vapor extraction operations, the carbon tetrachloride concentration at each well was measured weekly. The initial concentrations measured at each well were: 30 ppmv at well 299-W18-6L; 23 ppmv at well 299-W18-7; 25 ppmv at well 299-W18-246L; and 27 ppmv at well 299-W18-252L.

3.2.4 Leachate Monitoring at the Environmental Restoration Disposal Facility

C. W. Miller, C. S. Wright, and R. S. Edrington

Bechtel Hanford, Inc. operates the Environmental Restoration Disposal Facility to dispose of radioactive, hazardous or dangerous, and mixed waste generated during waste management and remediation activities at the Hanford Site. In fiscal year 2002, Bechtel Hanford, Inc. published the results of groundwater monitoring and sampling at the Environmental Restoration Disposal Facility during the calendar year 2001 (BHI-01641). Part of the published results contains laboratory analyses of leachate collected from beneath the facility. This section discusses those results.

Leachate is collected and analyzed from beneath the Environmental Restoration Disposal Facility to support handling the leachate as non-hazardous waste and to evaluate the constituent list used for groundwater monitoring at the site. Based on analyses of leachate, no additional constituents were recommended for addition to the groundwater monitoring program at the Environmental Restoration Disposal Facility in 2002.

The Environmental Restoration Disposal Facility began operation in July 1996. Located between the 200 East and 200 West Areas (see Figure 2.2-2), the facility is currently operating a second set of two disposal cells that became active during June 2000. Two other cells received waste until September 2000. Interim covers were placed over the used parts of those cells. The four existing cells have an area of ~20 hectares.

Each cell is lined to collect leachate resulting from water added as a dust suppressant and natural precipitation. The liner is sloped to a sump, and the leachate is pumped from the sump to tanks. After ~760,000 liters of leachate are collected, samples are taken and analyzed for 41 volatile organics, 64 semivolatile organics, 23 metals, and 9 radionuclides (gross alpha and gross beta analyses are also done). The number of samples depends on the amount of leachate collected.

The purposes of the data are to provide an inventory to the Effluent Treatment Facility, where the leachate is disposed, and to provide semiannually sampling of leachate for delisting analyses. The purpose of the delisting analyses is to enable handling the leachate as non-hazardous waste. The results are also used to determine whether additional constituents should be added to the groundwater monitoring list.

Composite leachate samples were collected in June and December 2001. Leachate samples contained detectable concentrations of common metals, anions, and mobile radionuclides. Inorganic, radionuclide, and organic analyte lists for the leachate were reduced based on the previously delisting leachate sample results. The remaining target constituents for leachate and the results for 2001 samples are shown in Table 3.2-4.

The constituents detected in samples from the Environmental Restoration Disposal Facility landfill leachate were compared to the groundwater monitoring constituent list to determine if additional constituents should be added to the groundwater monitoring program. The target constituents for the groundwater monitoring program are consistent with the leachate monitoring program. The selected suite of analyses included in the leachate monitoring was developed as a result of extensive sampling and analysis of leachate performed to support delisting of the leachate. At this time, no additional constituents are recommended for addition to the groundwater monitoring program at the Environmental Restoration Disposal Facility landfill based on that evaluation.

3.2.5 Leachate and Soil-Gas Monitoring at the Solid Waste Landfill

R. A. Del Mar

Arsenic, manganese, nickel, and 1,4-dioxane continue to be found in leachate samples from the Solid Waste Landfill. The most notable change occurring during the fiscal year 2002 was an increase in several non-chlorinated organic constituents.

The Solid Waste Landfill is a land disposal facility in the center of the Hanford Site (part of the Central Landfill illustrated on Figure 2.2-2). It covers an area of ~26.7 hectares and began operating in 1973 to receive non-hazardous, non-radioactive sanitary waste generated from Hanford Site operations. The Solid Waste Landfill stopped receiving waste in 1996 and an interim cover consisting of 0.6 to 1.2 meters of soil was placed over all trenches. Current monitoring at the Solid Waste Landfill consists of quarterly sampling of groundwater, soil gas, and leachate. Recent groundwater monitoring results are discussed in Section 2.11. This section summarizes leachate and soil-gas monitoring results.

In all, the Solid Waste Landfill consists of ~70 single disposal trenches, and 14 double disposal trenches. One of the double trenches overlies a lined, basin lysimeter designed to collect leachate generated by infiltration through the overlying refuse. This lysimeter covers an area of ~88 square meters. A discharge pipe continuously drains leachate by gravity flow from the basin to a nearby collection pump. However, because the lysimeter only collects leachate from 1 of 84 trenches and is installed under one of the newer trenches built after implementation of regulations restricting land disposal practices, leachate collected from this lysimeter may not be representative of leachate drainage throughout the entire landfill area. Still, it provides some indication of the rate of infiltration and some of the contaminants that may be entering the vadose zone from the landfill.

Leachate is collected from the basin lysimeter every 10 to 14 days. Figure 3.2-9 shows the rate of leachate generation over the past 4 years. The generation rate has been between 3.8 and 7.6 liters per day, which is consistent with what is expected based on precipitation, soil type, and the vegetative cover.

Figures 3.2-10 and 3.2-11 provide historical data on some of the site-specific contaminants found in the leachate. Some of these contaminants (most notably arsenic, manganese, nickel, and 1,4-dioxane) continue to be found in concentrations exceeding groundwater quality criteria (WAC 173-200) and/or maximum contaminant levels (WAC 246-290). In addition, some of the indicator parameters exceeded groundwater quality criteria and/or maximum contaminant level thresholds, including conductivity, chloride, and total dissolved solids.

The most notable change occurring during the fiscal year 2002 sampling period was an increase in several non-chlorinated organic constituents, including acetone, 2-butanone, 2-hexanone, and 2-pentanone. Concentrations were in the range of 20 to 140 µg/L.

Soil-gas monitoring at the Solid Waste Landfill uses eight shallow monitoring stations located around the perimeter of the landfill. Each station consists of two soil-gas probes at depths of ~2.75 and 4.6 meters. Soil gas is monitored quarterly to determine concentrations of oxygen, carbon dioxide, methane, and several key volatile organic compounds. No contaminants of concern were discovered above reporting limits during the fiscal year 2002 sampling period.

3.2.6 Hydrologic Characterization Using Vadose Zone Monitoring Tools at Hanford

G. W. Gee, A. L. Ward, J. B. Sisson, J. M. Hubbell, D. A. Myers, and H. A. Sydnor

Hydrologic characterization of the vadose zone is needed to assess contaminant migration from buried wastes. The Pacific Northwest National Laboratory, under contract with DOE's EM-50 (Subsurface Contamination Focus Area), and in collaboration with CH2M HILL Hanford Group, Inc., Idaho National Engineering and Environmental Laboratory, and Duratek Federal Services, deployed a suite of vadose-zone instruments for characterization and monitoring at the Hanford Site. Several new instruments were tested. One instrument, the advanced tensiometer, developed at Idaho National Engineering and Environmental Laboratory, measures soil-water pressures in the vadose zone, and was tested successfully at a Hanford Site field location by both auger placement and by drive cone (penetrometer) placement. Another new instrument, the water fluxmeter (Figure 3.2-12), adapted from conventional lysimeter technology, measures drainage flux directly, and was successfully tested and subsequently deployed at the Hanford Site and a number of other sites including the Savannah River Site. The purpose of the vadose zone deployments was to obtain in situ hydrologic characterization data, to verify drainage potential, and to obtain estimates of current recharge fluxes under a range of surface conditions.

As multiple years of data are collected, vadose zone field monitoring systems with water fluxmeters will be able to provide direct measures of annual recharge within tank farms and other waste sites, thus providing early warning to potential future groundwater contamination.

A series of tests to confirm performance and longevity of vadose zone monitoring sensors has been ongoing since 1999. Data have been archived and updated on a current web page, http://vadose.pnl.gov. The results reported on the web page from tests at the VZFS300N field site indicate that the tensiometer systems have been reliable and have required little or no servicing for periods up to 3 years or longer, for all sensors tested. A nearly continuous record has been maintained since sensor installation. The site contains a set of 7.6-meter-deep lysimeters designed to simulate waste burial-ground conditions. The tensiometer data exhibit unit-gradient conditions confirming that drainage persists at the site in spite of the arid climate. The data also clearly show that water pressure pulses, generated by net infiltration of winter rains, are dampened with depth and do not appear to penetrate much below 2 meters, so that near steady-state conditions prevail below this depth. Water storage measurements in the top 1 meter appear to capture most of the transient changes in water content within the sediment profile. Measured drainage for the past three years has averaged about 55 millimeters per year, similar to predictions using past measurements from a drainage experiment where instantaneous profile data of water contents and soil water pressures were taken on an adjacent lysimeter. Estimates of drainage or recharge using textural analysis, laboratory methods, and a permeameter method have been less successful in predicting actual drainage. The data suggest that direct measurements of drainage either by water fluxmeter or by profile monitoring (instantaneous methods) may be required to obtain reliable estimates of the hydraulic properties of at least some Hanford Site sediments.

Two deployments within the Hanford Site tank farms were completed during the past 2 years. In fiscal year 2001, eight sensor nests, ranging in depth from 67 meters below ground surface to 0.9 meter below ground surface were placed in contact with vadose zone sediment inside an uncased borehole (C3360) located adjacent to tank B-110. The sensor sets are part of the Vadose Zone Monitoring System for the Hanford tank farms and include advanced tensiometers, heat dissipation units, water content reflectometers, thermal probes, and vadose zone solution samplers. A water fluxmeter was deployed within the top meter of the surface to directly measure net infiltration of meteoric water (rain and snowmelt). In addition, a rain gage was located within the tank farm to document onsite precipitation. All sensor units, with the exception of the solution samplers, were connected to a solar-powered data logger located within the B Tank Farm. Data collected from these sensors were accessed by modem and cell phone. Tensiometer data collected to date show that unit gradient (steady) conditions have persisted at the B Tank Farm since installation of the instruments more than a year ago (Figure 3.2-13). The persistence of unit-gradient conditions supports the case for drainage at this site. The coarse gravel surface and lack of vegetation on the tank farm promote drainage conditions. The tensiometer data show the direction of water movement and indicated drainage is occurring, but the data do not provide a direct measure of drainage rates, which can only be estimated if the unsaturated hydraulic conductivity of the sediments is known. The water fluxmeter provides data on net infiltration of meteoric water but does not capture lateral spreading of water in the subsurface. The fluxmeter was calibrated in late March 2002 and indicated that it was responding properly to water inputs (Figure 3.2-14). Since the seasonal precipitation has been below normal, little drainage has occurred during the spring and summer of 2002 in this coarse sediment. Thermal profiles from the sensor nests appear normal and show little effect of heating, and enhanced evaporation, due to radioactivity in the subsurface (Figure 3.2-15). Solution samples collected from the subsurface by a combined vacuum/pressure system are currently being analyzed.

In fiscal year 2002, four sensor nests ranging in depth from 30.1 to 1.5 meters below ground surface were placed in an uncased borehole (C3830) located between tank TX 101 and tank TX 105 in the TX Tank Farm. Because of the reduced size of the borehole (0.18-meter diameter for the TX borehole versus 0.26-meter diameter for the B borehole), the sensor sets were limited to advanced tensiometers and thermocouples placed at each of four depths. Due to drilling restrictions, water fluxmeters were placed outside the tank farm. Two water fluxmeters were placed directly south of the TX borehole C3830 just outside the fenced perimeter of the tank farm. Data collected from the sensor nests and fluxmeters are currently being accessed remotely. Tensiometer data collected from the TX Tank Farm are similar to those at the B Tank Farm and indicate that unit-gradient conditions exist and the tank farm is draining. Water fluxmeter data collected over the course of the next three years will be made available to estimate drainage rates within the TX Tank Farm.

Data from vadose zone monitoring provide direct measures of soil water pressures, temperatures, and water fluxes. Vadose zone monitoring can document waste site responses to changes in meteoric inputs of precipitation (rain and snowmelt), to assess the impacts of water-line leaks, or support tank leak detection during retrieval operations. Since most flux rates in the vadose zone are relatively low and changes generally occur slowly, most results will not be instantaneous. Meaningful data sets will require an extended monitoring period (several years or more). Based on current observations, however, data from the tensiometers indicate that drainage is occurring within the two monitored tank farms at the Hanford Site. Similar drainage conditions are expected at other tank farms at Hanford, where surfaces are coarse-textured and bare. As multiple years of data are collected, vadose zone field monitoring systems with water fluxmeters will be able to provide a direct measure of annual recharge within tank farms and other waste sites, thus providing an early warning to potential future groundwater contamination.

Table 3.2-1. Summary of Monitoring Operations for the Tank Farm Vadose Zone Monitoring Project

	Quarter				FY 2002	Project to Date
	1	2	3	4	Cumulative Total	Cumulative Total
Borehole Logs	54	74	113	143	384	497
Main Log Total Length (m)	311	398	510	822	2,041	2,600
Rerun Log Total Length (m)	18	18	26	38	100	138
Total Length Logged (m)	329	416	536	860	2,141	2,738

FY = Fiscal year.

Table 3.2-2. Summary of Monitored Boreholes that Appear to Exhibit Changes in Contaminant Profiles

Tank Farm	Borehole Number	Radionuclide	Determined	Number of Logging Events	Assessment	Assigned Logging Frequency
BX	21-27-08	Uranium-235/uranium-238	March 13, 2002	3	Not confirmed	6 months
BY	22-03-04	Cobalt-60	November 15, 2001	2	Not confirmed	6 months
	22-07-02	Cobalt-60	November 29, 2001	2	Not confirmed	6 months
	22-07-05	Cobalt-60	December 12, 2001	2	Not confirmed	6 months
	22-08-05	Cobalt-60	March 30, 1999	2	Not confirmed	6 months
C	30-06-10	Cobalt-60	March 3, 1997	1	Possible confirmation	3 months
	30-08-02	Cobalt-60	September 11, 2002	2	Definite change	3 months
SX	41-02-02	Cesium-137/strontium-90	September 7, 2001	3	Not confirmed	6 months
T	50-01-09	Cobalt-60	July 30, 2001	4	Not confirmed	6 months
	50-06-02	Cobalt-60/europium-154	July 18, 2001	4	Not confirmed	6 months
	50-06-03	Cobalt-60	July 18, 2001	4	Not confirmed	6 months
	50-06-18	Cobalt-60	September 3, 2002	3	Possible increase	3 months
	50-04-10	Cobalt-60	January 28, 2002	3	Possible confirmation	3 months
	50-09-01	Cobalt-60/europium-154	July 23, 2001	4	Not confirmed	6 months
	50-09-02	Cobalt-60	January 8, 2002	2	Not confirmed	6 months
	50-09-10	Cobalt-60/europium-154	July 23, 2001	4	Not confirmed	6 months
TX	51-03-11	Cobalt-60	May 20, 2002	1	Possible increase	3 months
TY	52-03-06	Cesium-137	May 2, 2002	3	Definite change	3 months
	52-06-05	Cobalt-60	May 14, 2002	1	Possible increase	3 months
U	60-04-08	Uranium-235/uranium-238	July 16, 2001	5	Not confirmed	3 months
	60-05-05	Uranium-235/uranium-238	August 27, 2002	2	Possible increase	3 months
	60-07-01	Uranium-235/uranium-238	July 12, 2001	5	Not confirmed	3 months

Table 3.2-3. Carbon Tetrachloride Inventory in Primary Disposal Sites

Well Field	Estimated Mass Discharged 1955 to 1973[a] (kg)	Estimated Mass Lost to Atmosphere 1955 to 1990[b] (kg)	Mass Removed Using Soil-Vapor Extraction 1991 to 2002 (kg)
216-Z-1A	270,000	56,700	24,000[c]
216-Z-9	130,000 to 480,000	27,300 to 100,800	53,798
216-Z-18	170,000	35,700	
Total	570,000 to 920,000	119,700 to 196,800	77,798

(a) Based on DOE/RL-91-32.
(b) Based on WHC-SD-EN-TI-101.
(c) Includes mass removed from 216-Z-18 site; reported as a combined value because the well fields overlap.

Table 3.2-4. Leachate Analysis Results for 2001 Sampling at the Environmental Restoration Disposal Facility

Constituent	June Sampling Event	December Sampling Event	Constituent	June Sampling Event	December Sampling Event
		Volatile Organic Compounds (mg/L)			
Carbon tetrachloride	5 (U) (5 U)[a]	5 (U) (5 U)			
Metals (mg/L)					
Arsenic[b]	10.7 (11.3)	46.5 U (46.5 U)	Tin[b]	3.5 U (3.5 U)	18.8 U (18.8 U)
Barium	82.7 (86.3)	103 (95.1	Vanadium	23.7 (21.9)	14.6 (16.1)
Chromium	183 (19.9)	18.9 (18.3)	Zinc	17.3 (8.0)	24.3 (10.2)
Lead[b]	2.6 U (2.6 U)	27.8 U (27.8 U)	Uranium	212 (220)	272 (260)
Selenium[b]	3.6 (10.2)	50.4 U (50.4 U)			
		Ions and Physical Characteristics (mg/L, except pH in units, specific conductance in µS/cm)			
Total dissolved solids	1,670 (1,650)	2,130 (2,190)	Chloride	239 (245)	305 (302)
pH	7.9 (7.9)	8 (8)	Sulfate	343 (354)	602 (593)
Specific conductance	2,170 (2,180)	2,780 (2,750)	Nitrate	238 (240)	271 (252)
Bromide	2.5 U (2.5 U)	2.5 U (2.5 U)	Nitrite	12.5 U (12.5 U)	25 U (25 U)
Fluoride	5 U (5 U)	5 U (5 U)			
		Radionuclides (pCi/L)			
Total alpha from radium[c]	-0.077 U (-0.105 U)	0.054 U (0.138 U)	Technetium-99	504 (488)	956 (849)
Carbon-14	0 U (23.1 U)	8.79 U (-2.96 U)	Gross alpha	88.6 (129)	180 (179)
Iodine-129[c]	-2.24 U (-0.925 U)	0.273 U (0.054 U)	Gross beta	330 (337)	580 (505)

(a) Duplicate results are shown in parentheses.
(b) Results represent an elevated reporting limit in December samples.
(c) Negative values are consistent with counting error at low concentrations.
U = Undetected, the associated value is the laboratory detection/reporting limit.

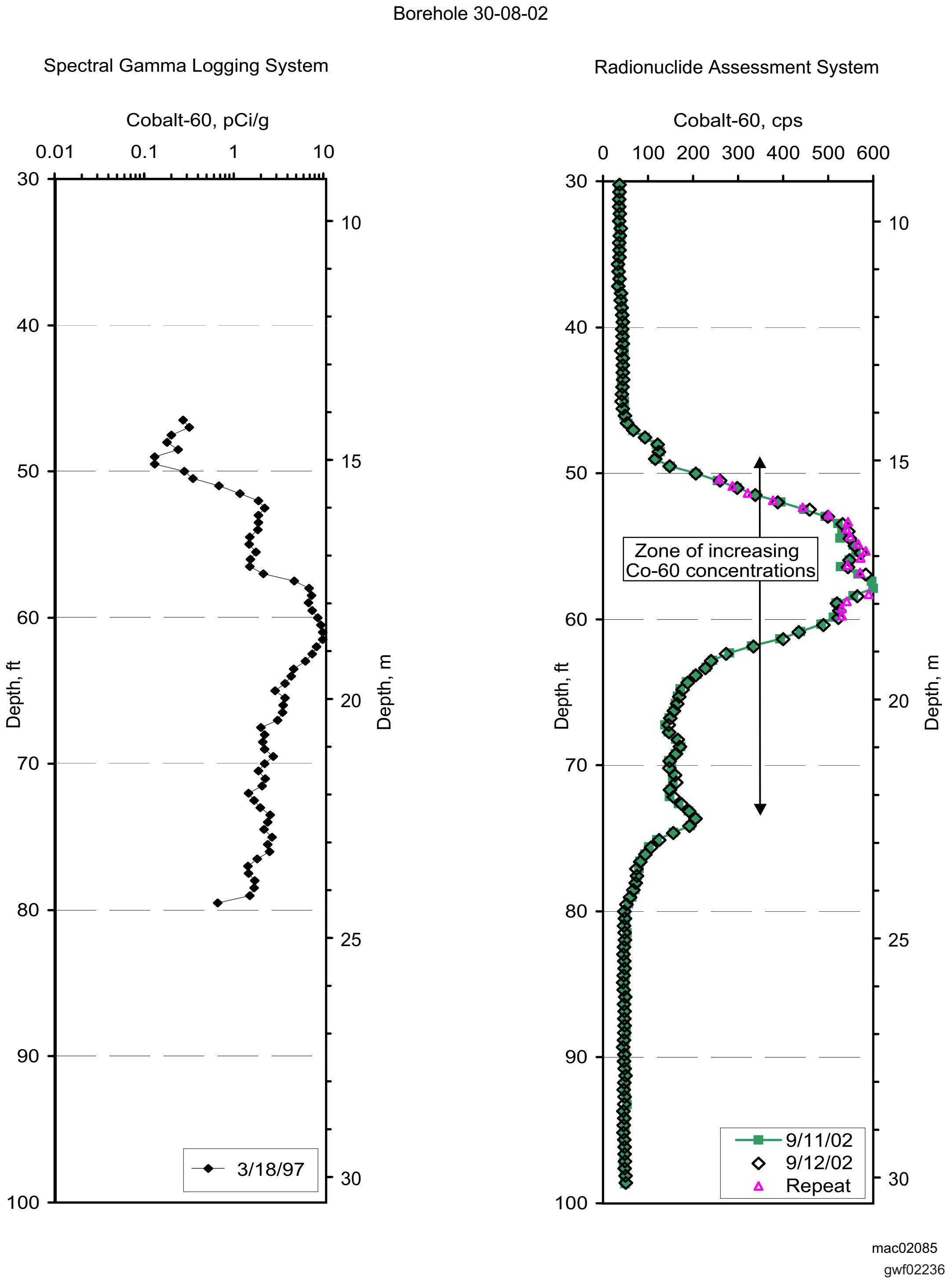


Figure 3.2-1. Comparison of 1997 and 2002 Spectral Gamma Logs from Borehole 30-08-02 in the C Tank Farm

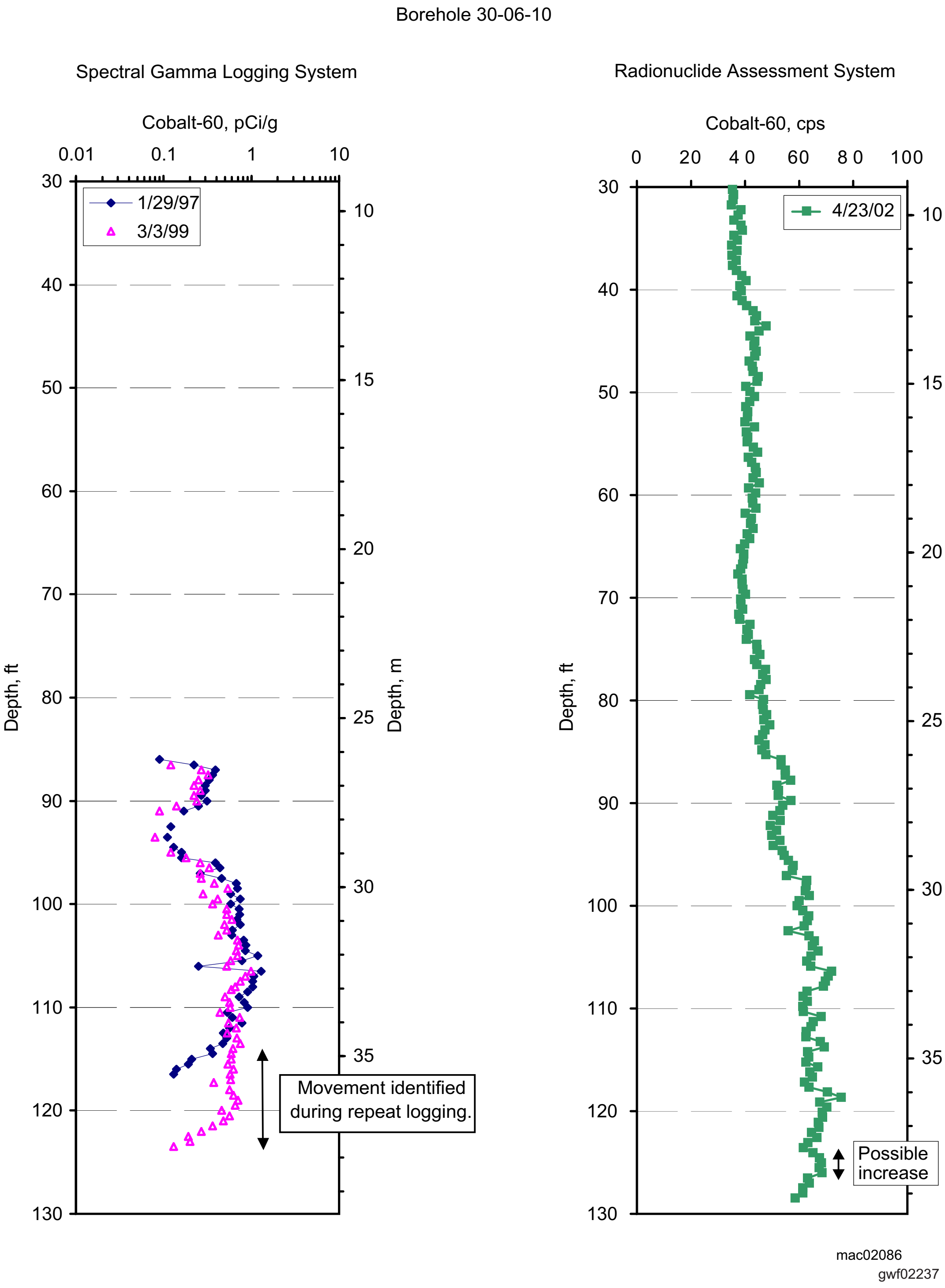
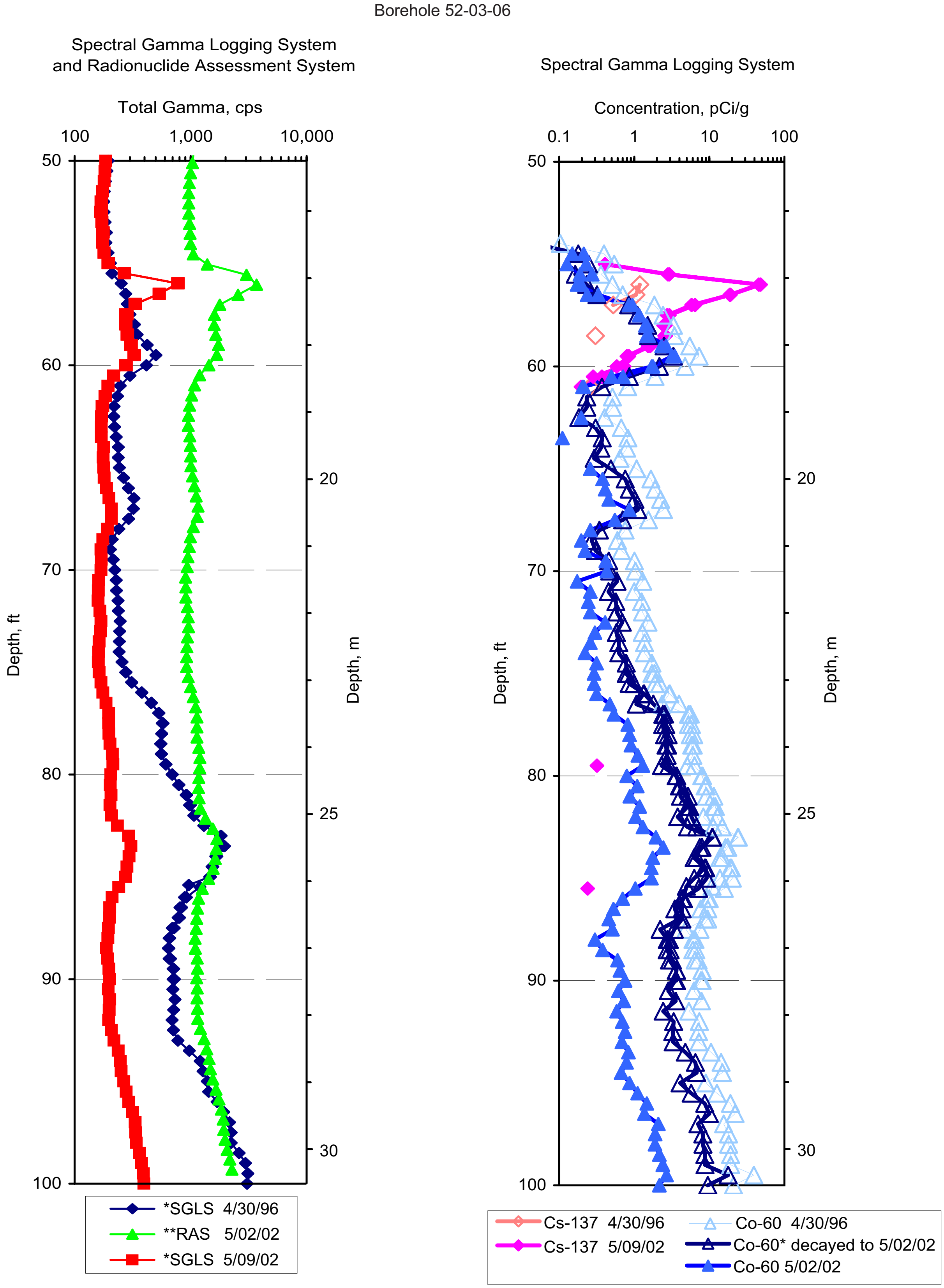


Figure 3.2-2. Comparison of 1997, 1999, and 2002 Spectral Gamma Logs from Borehole 30-06-10 in the C Tank Farm



*Spectral Gamma Logging System (SGLS)
**Radionuclide Assessment System (RAS)

mac02087

Figure 3.2-3. Comparison of 1996 and 2002 Spectral Gamma Logs from Borehole 52-03-06 in the TY Tank Farm

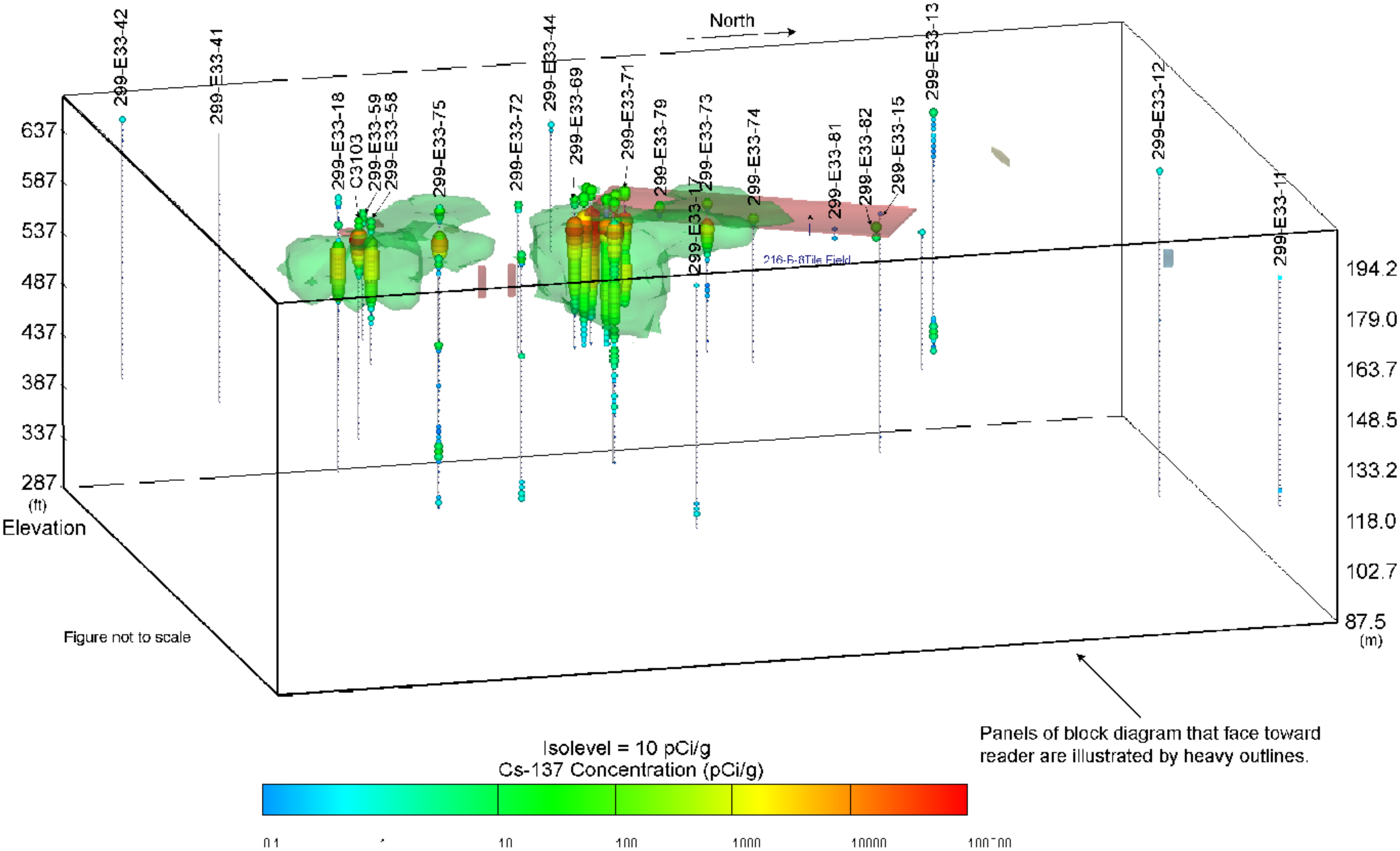


Figure not to scale

Panels of block diagram that face toward reader are illustrated by heavy outlines.

gwf02240

Figure 3.2-4. Cesium-137 Contamination in the Area of the 216-B-8, 216-B-7A, and 216-B-7B Cribs and the 216-B-11A and 216-B-11B Reverse Wells Northeast of Waste Management Area B-BX-BY

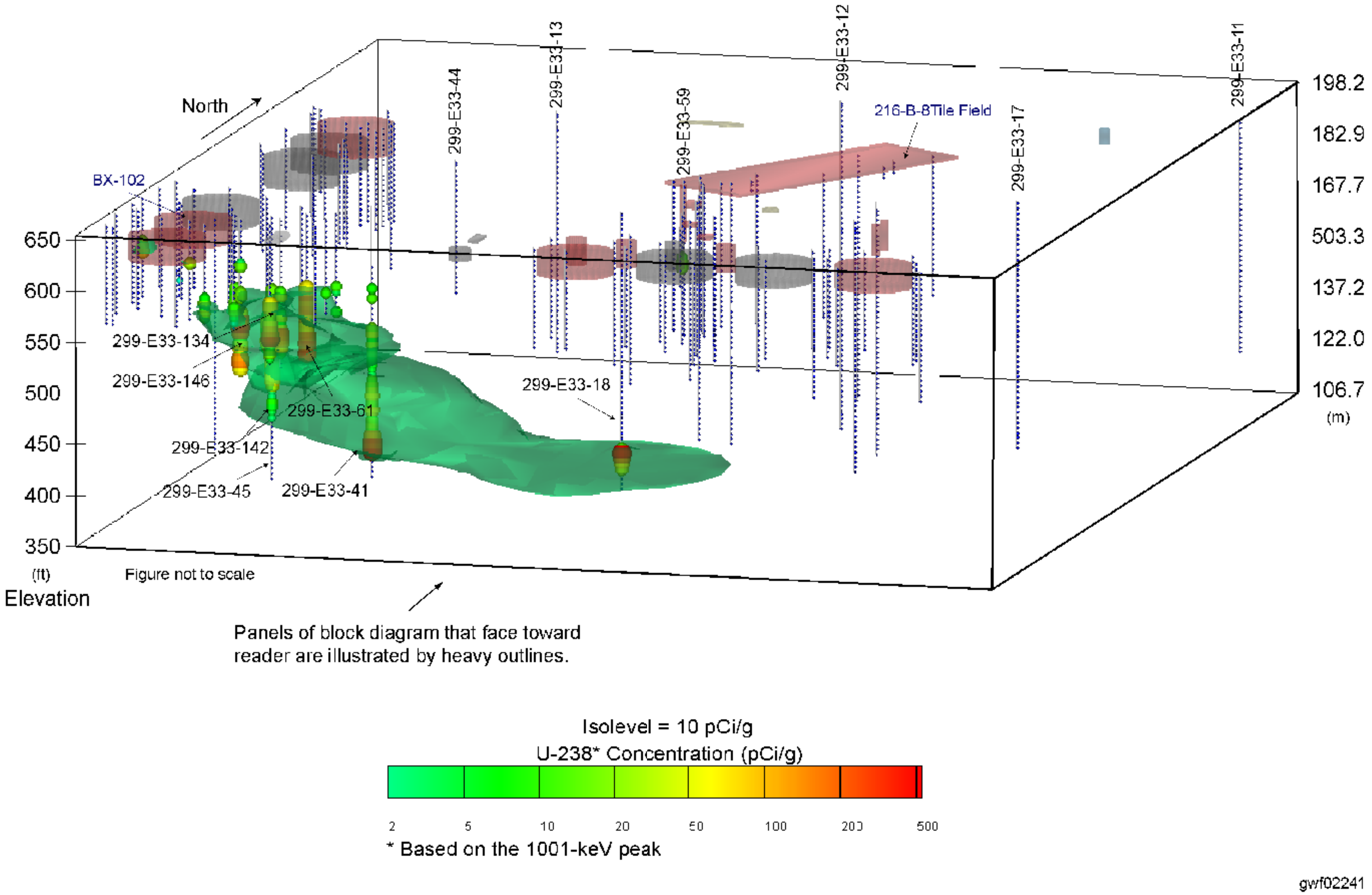


Figure 3.2-5. Uranium-238 Contamination North of the BX Tank Farm

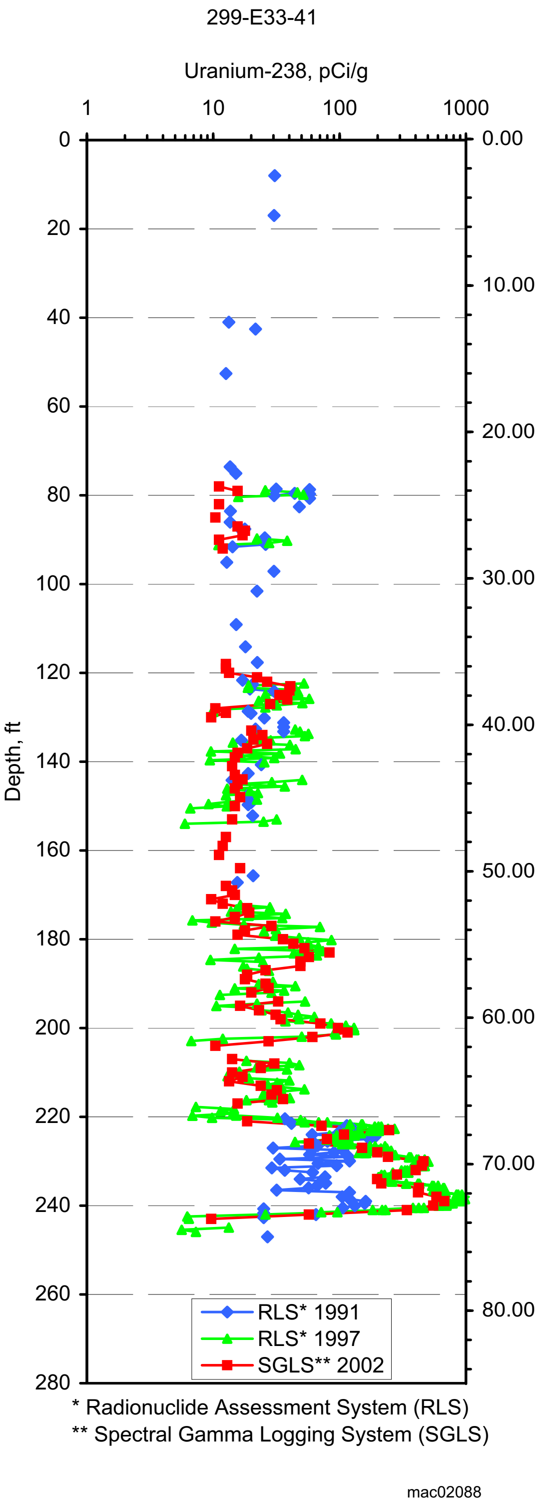


Figure 3.2-6. Comparison of 1991, 1997, and 2002 Spectral Gamma Logs from Borehole 299-E33-41, East of the BX Tank Farm

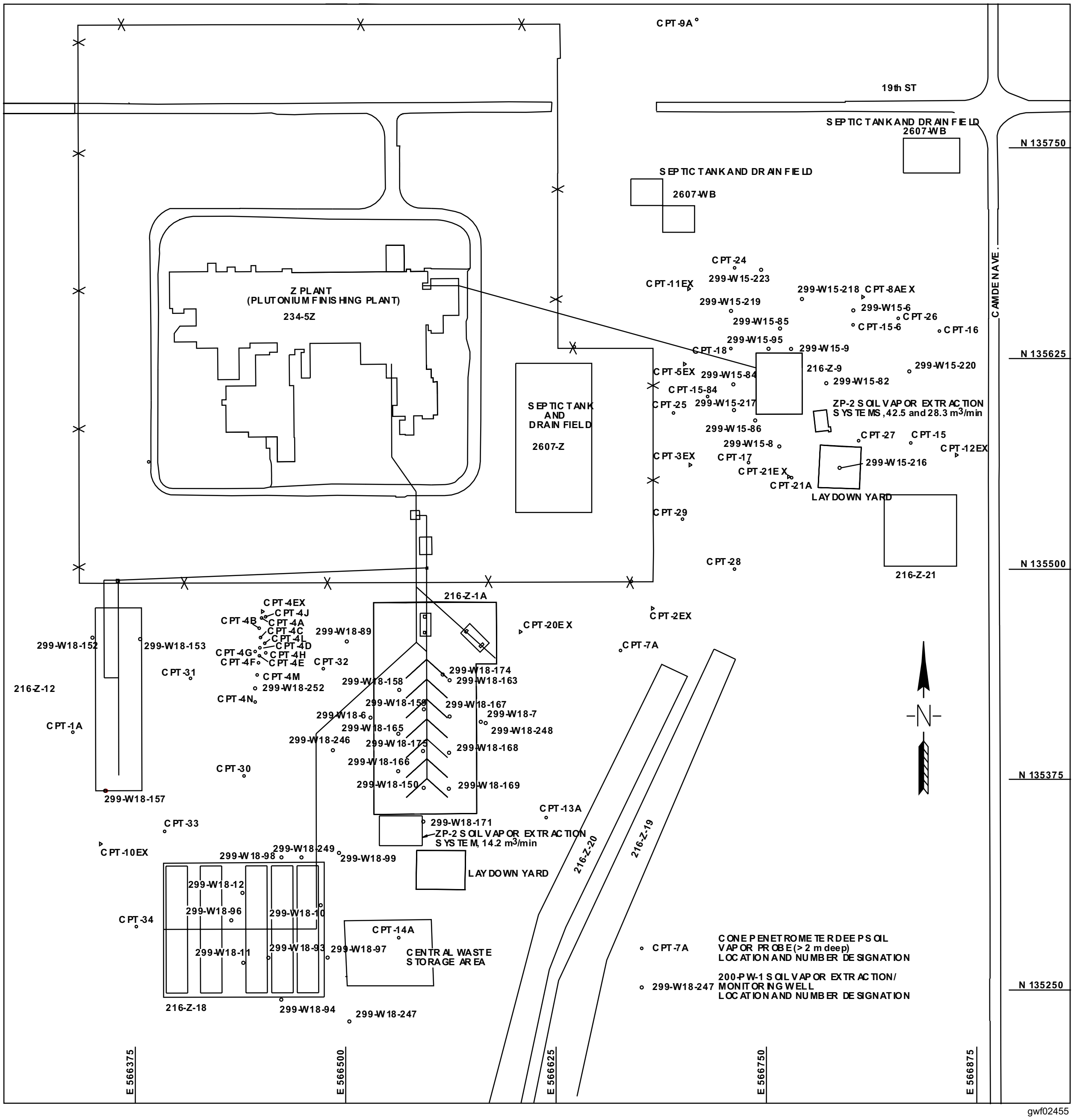


Figure 3.2-7. Locations of Carbon Tetrachloride Vapor-Extraction Wells at the 216-Z-1A/216-Z-12/216-Z-18 and 216-Z-9 Well Fields

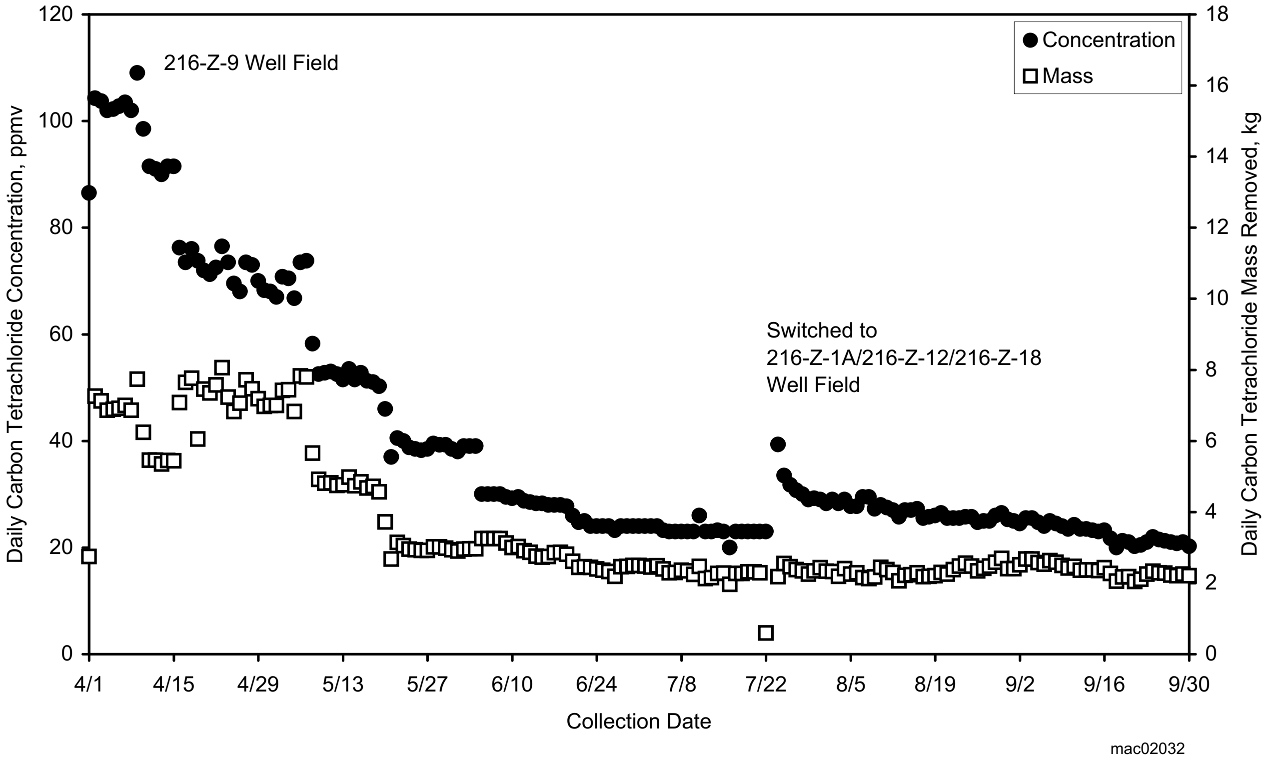


Figure 3.2-8. Time Series Concentrations of Carbon Tetrachloride in Soil Vapor Extracted from the 216-Z-9 Well Field and the 216-Z-1A/216-Z-12/216-Z-18 Well Field

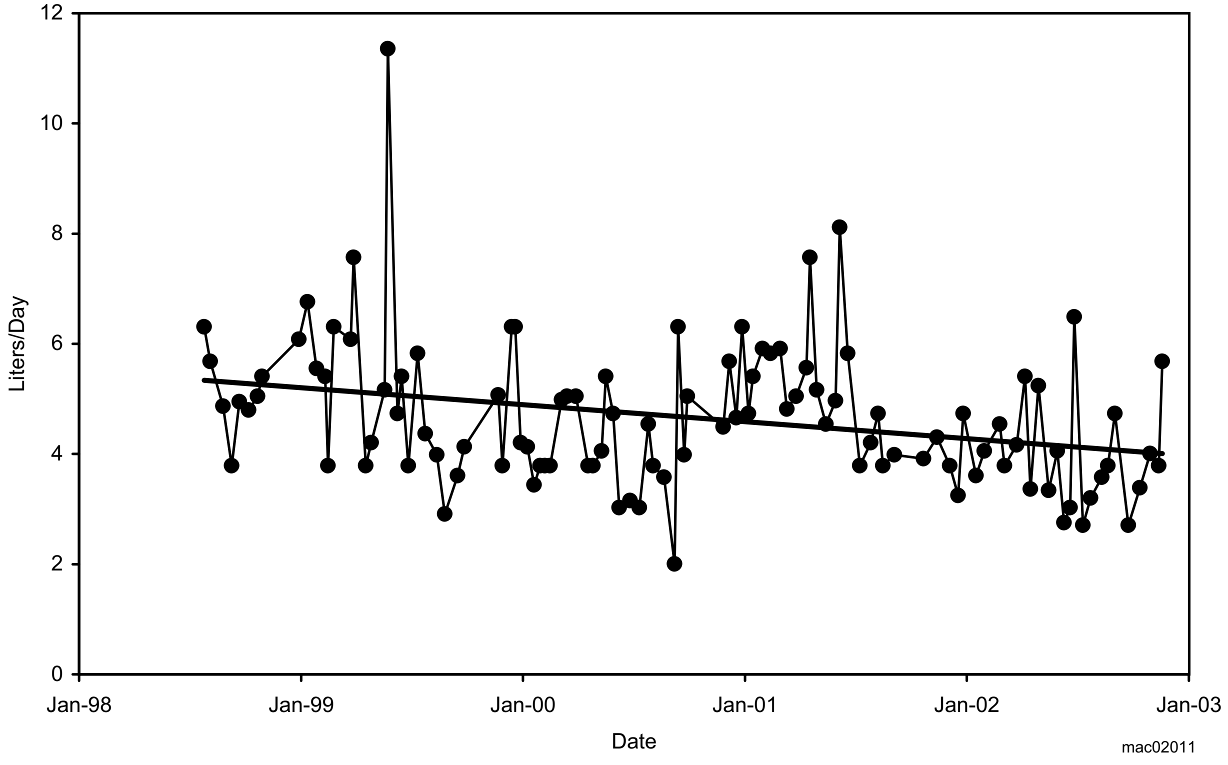


Figure 3.2-9. Leachate Volumes Collected from Solid Waste Landfill

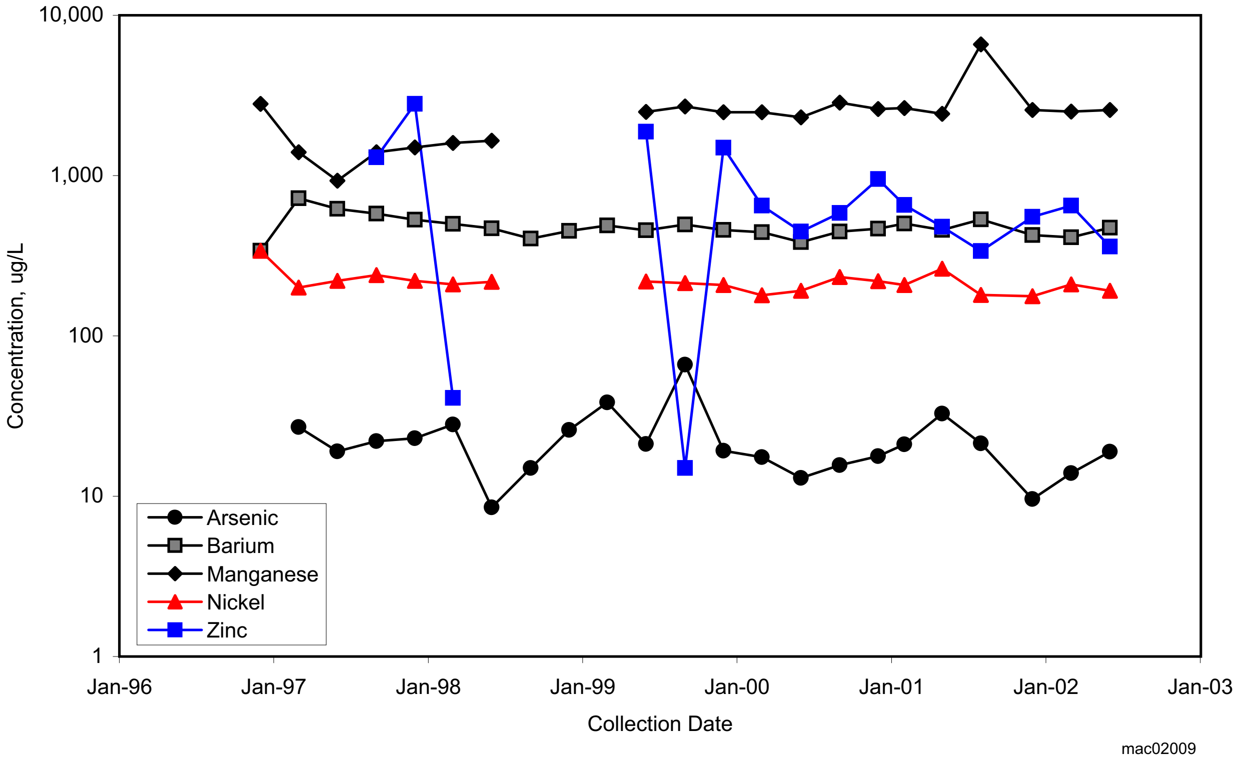


Figure 3.2-10. Concentrations of Selected Metals in Leachate from the Solid Waste Landfill

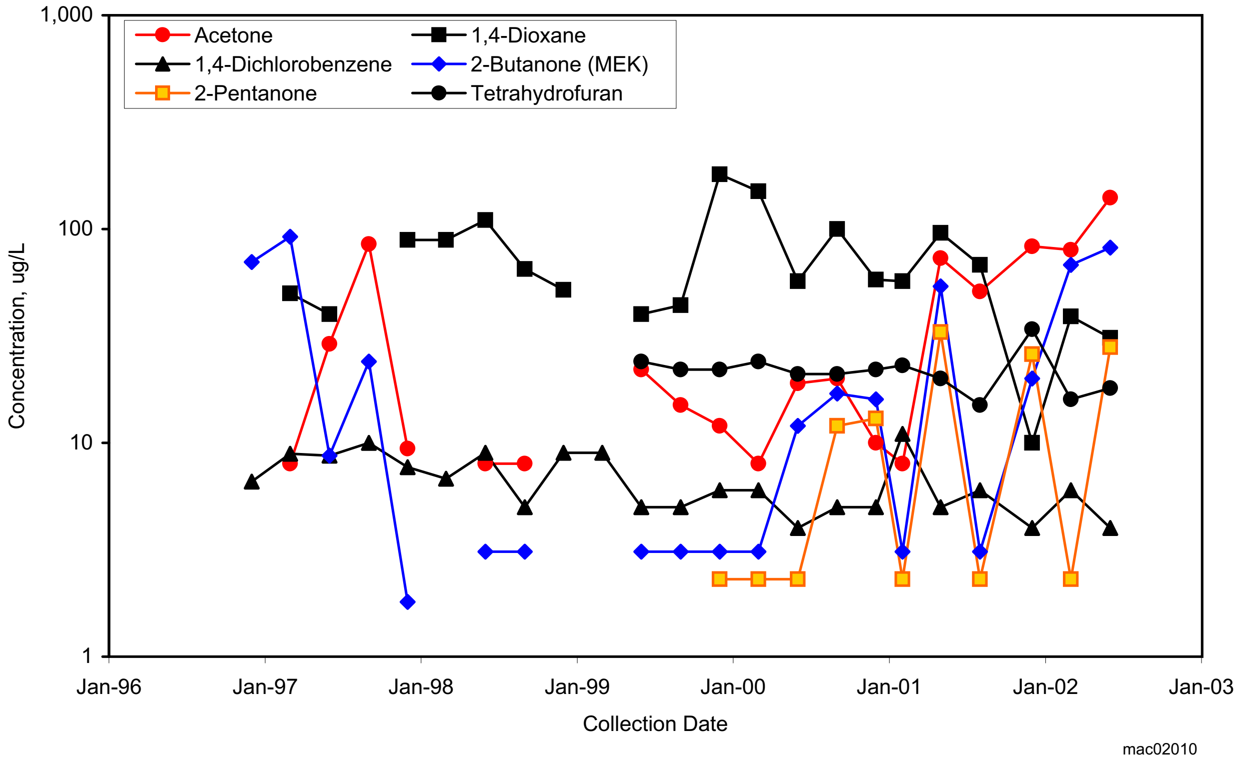


Figure 3.2-11. Concentrations of Selected Organic Compounds in Leachate from the Solid Waste Landfill

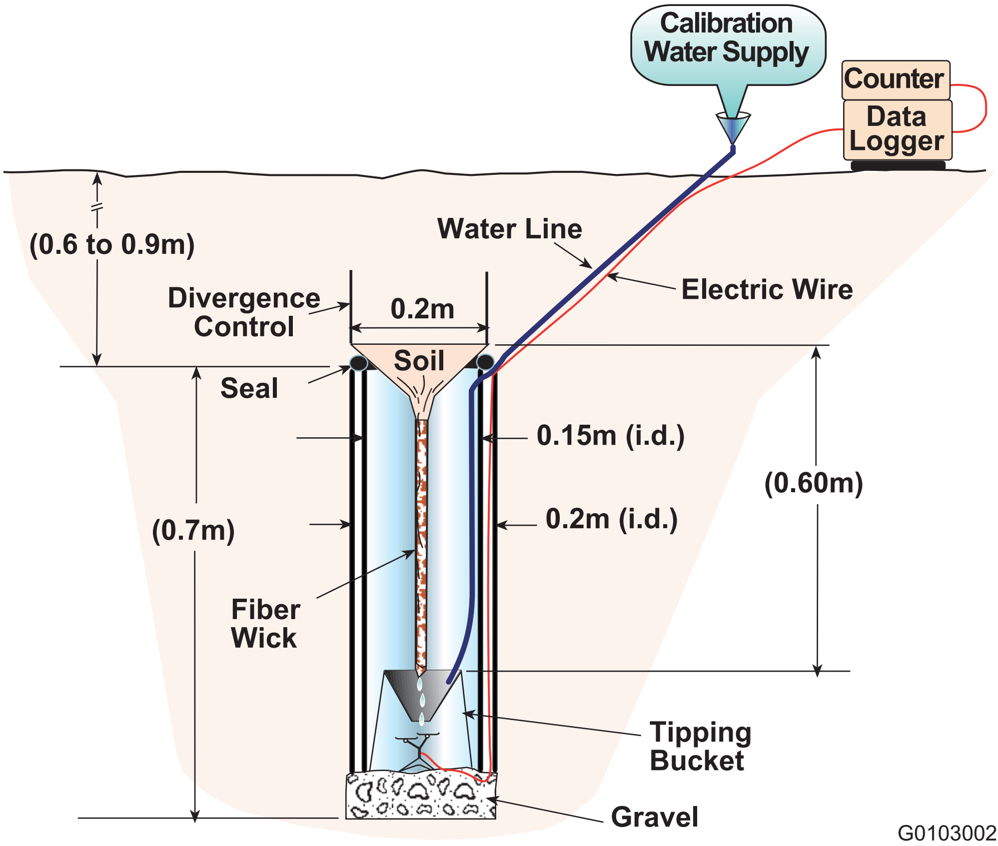


Figure 3.2-12. Schematic View of the Pacific Northwest National Laboratory Water Fluxmeter. The divergence control for all drainage tests was at least 60 centimeters deep. For bare soil conditions including tank farms, the divergence control was brought to the surface or within a few centimeters of the surface to minimize any lateral flow.

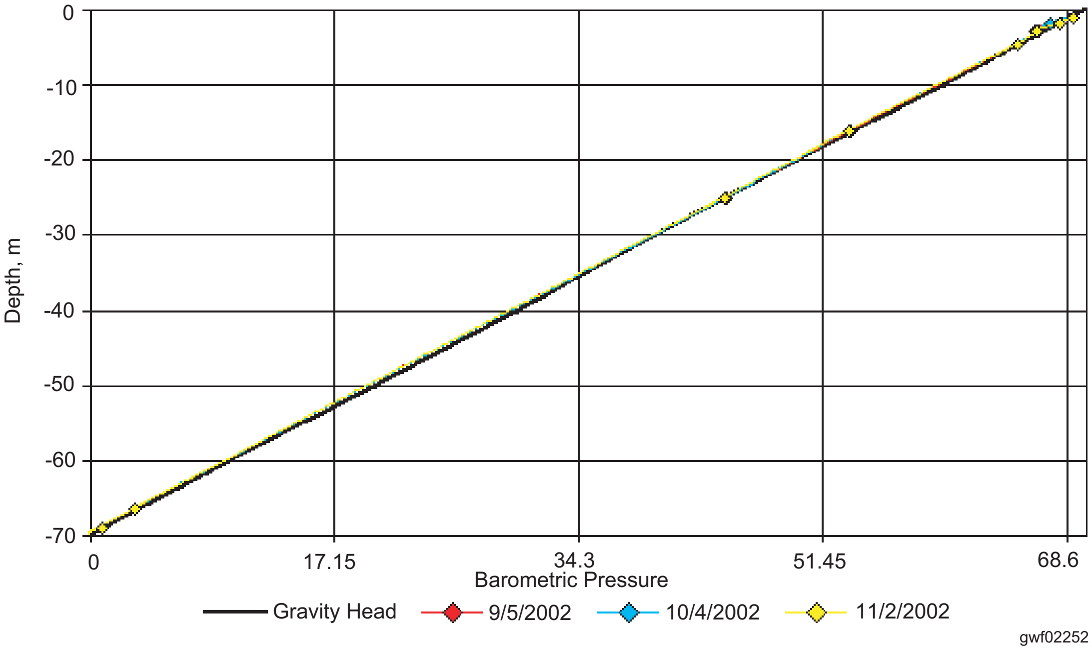


Figure 3.2-13. Total Head Profile Near Tank B-110 in the B Tank Farm Showing Unit Gradient Conditions

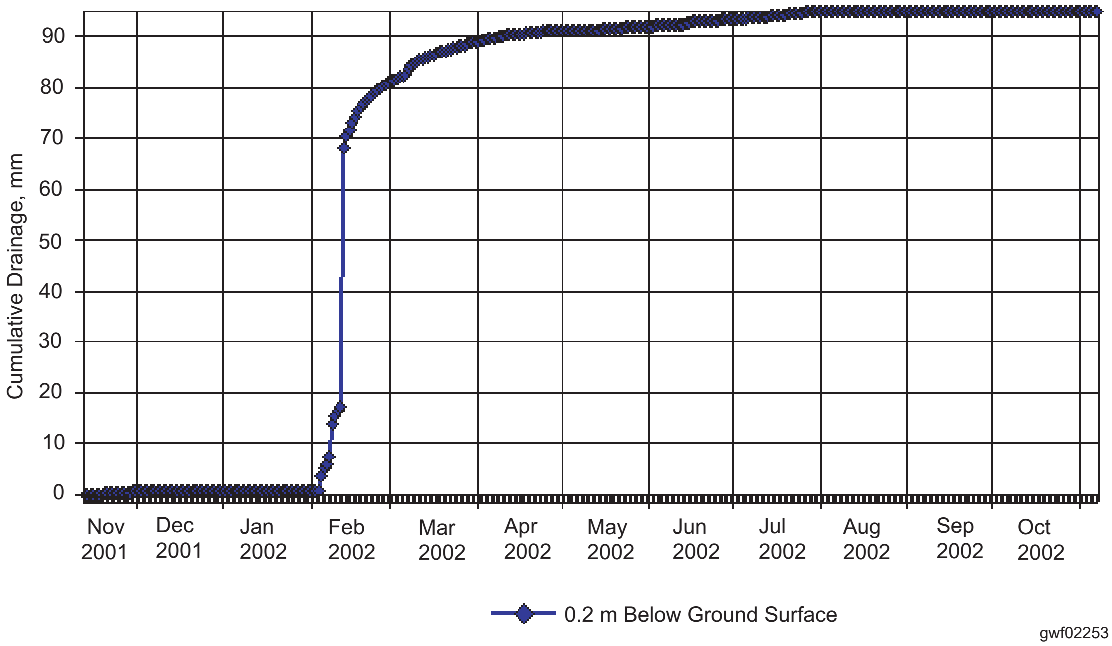


Figure 3.2-14. Water Fluxmeter Data Including a Test Application of ~60 Millimeters Water in Mid-February 2002. Data indicates that over 30 millimeters of actual drainage has occurred near tank B-110 since February 2002.

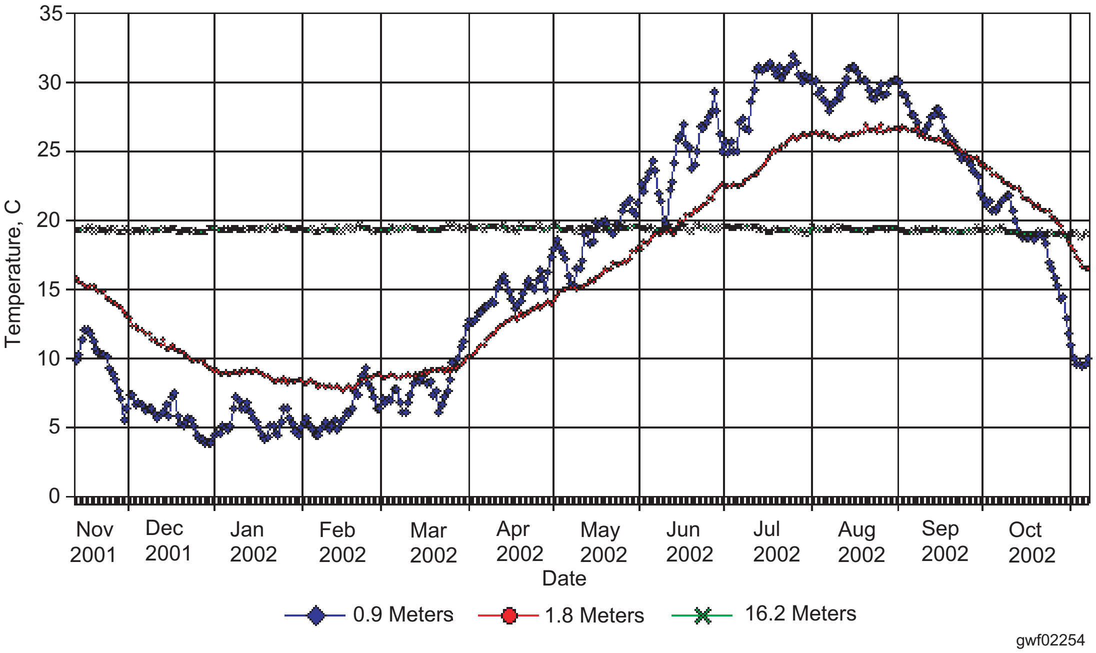


Figure 3.2-15. Subsurface Temperature Data from B Tank Farm Near Tank B-110

3.3 Other Vadose Zone Activities

This section summarizes the activities and results of several technical studies done at the Hanford Site in fiscal year 2002 to better understand the vadose zone sediments, vadose zone hydrology, and vadose zone contamination. These studies are designed to result in new, innovative methods for cleanup and monitoring at the Hanford Site. These studies include the application of various geophysical methods to vadose zone monitoring, infiltration studies at a monitored prototype surface barrier site, and laboratory studies of immobilization of chromium, technetium-99, and uranium.

3.3.1 Correlation of Strontium-90 Concentration and Gamma Log Response

R. G. McCain and C. Koizumi

Contaminant movement in the vadose zone depends on waste chemistry and volume, the amount of sediment moisture, mineral chemistry, and whether the sediment is gravel, sand, or clay.

A subsurface zone of strontium-90 contamination was postulated for a region northeast of tank B-110, where anomalous gamma activity had been detected with no evidence of gamma energy specific gamma-emitting radionuclides (GJO-99-113-TAR, GJO-HAN-28). This is illustrated in Figure 3.3-1 by two typical gamma energy spectra. Spectrum 3A2A1076 is typical of an uncontaminated portion of a borehole. Spectrum 3A2A1036 is an example of a portion of a borehole exhibiting anomalous gamma activity. Note that there are no clearly defined gamma energy peaks other than those associated with natural radionuclides. Both spectra in Figure 3.3-1 show about the same concentrations of natural radionuclides, and yet 3A2A1036 has a gross count rate approximately three times greater than that of

From mid-July through early November 2002, scientists evaluated two electrical geophysical methods to detect leaks beneath buried tanks. The photo above shows placement of the steel sheet wall to simulate a tank adjacent to the mock tank.

3A2A1076 at energies below 600 KeV. Brodzinski and Nielson (1980) and Wilson et al. (1997) suggested that these low energy counts may result from bremsstrahlung radiation associated with the interaction between high-energy beta particles from strontium-90/yittrium-90 and the steel casing. (Bremsstrahlung refers to radiation emitted by deceleration of charged particles [beta particles] as they pass through a field of atomic nuclei [steel casing].)

Borehole 299-E33-46 was drilled in May 2001 to investigate Waste Management Area B-BX-BY and to collect samples for laboratory analysis (see Section 3.1.2.2). Strontium-90 concentrations in samples at selected depths were measured in the Applied Geology and Geochemistry Laboratory at the Pacific Northwest National Laboratory. The analytical results showed high concentrations of strontium-90 that appeared to correlate with anomalous gamma activity. The borehole was, therefore, viewed as a facility to test theories about the bremsstrahlung contributions to passive gamma-ray spectra and the correlations between bremsstrahlung and strontium-90 concentrations.

Spectral shape factor analysis was developed primarily as a means to assess the distribution of cesium-137 and cobalt-60 with respect to distance from a borehole (Wilson et al. 1997). For both cesium-137 and cobalt-60, a shape factor, called shape factor 1, was defined as the ratio between the energy peaks and the increased spectral noise due to Compton scattering. (The scattering that occurs when an incident photon ejects an electron from an atom causing a lower energy photon to be emitted from the atom). A second shape factor, shape factor 2, was defined as the ratio of the counts in the 60- to 350-keV range (counts from bremsstrahlung sources) divided by the counts in the 350- to 650-keV range (counts from gamma emitters). Shape factor 2 is sensitive to differences in the number of counts from gamma emitters and from bremsstrahlung sources. Wilson's studies indicated "...for virtually all gamma-emitting contaminants and for all possible source distributions, shape factor 2 never exceeds a value of about 5." A shape factor 2 value greater than 5 is evidence for the presence of a bremsstrahlung-producing beta emitter, such as strontium-90/yittrium-90 (Wilson et al. 1997). Other reports (GJO-96-13-TAR, GJO-HAN-7; GJO-97-25-TAR, GJO-HAN-15) have suggested that shape factor 2 values may be as high as 20 in zones with significant strontium-90 concentration.

Figure 3.3-2a shows a plot of total gamma count rate and the count rate in the 60- to 350-keV range for the 15.2- to 36.6-meter-depth interval in borehole 299-E33-46. Figure 3.3-2b shows laboratory measured strontium-90 concentrations versus depth. Figure 3.3-2c shows shape factor 2 and an alternate factor, shape factor 2*, calculated using gross (uncorrected) counts in the 60- to 350-keV and the 350- to 650-keV ranges. A correlation appears to exist between laboratory-measured strontium-90 concentrations and both total gamma count rate and count rate for 60- to 350-keV range. Although shape factor 2 becomes erratic when no strontium-90 is present, shape factor 2* has a value of about 3.3 to 3.6 in uncontaminated areas, rising to greater than 6 in high strontium-90 concentrations. Both shape factor 2 and shape factor 2* appear to approach limiting values with increasing strontium-90 concentration.

Figure 3.3-3 shows a plot of total and net counts in the 60- to 350-keV range as a function of strontium-90 concentration. Above ~500 pCi/g, both total and net counts show a clear correlation with strontium-90 values. The results of this investigation may lead to a method for quantitative measurement of strontium-90 in the subsurface.

3.3.2 Test of Hanford Site 1,000-Year Surface Barrier Design

G. W. Gee, A. L. Ward, and C. D. Wittreich

The study of surface barriers at the Hanford Site has been ongoing since 1985. A prototype surface barrier was constructed in 1994 over an existing waste site as part of a CERCLA treatability test. The barrier was designed to be used in arid climates and to have a 1,000-year performance. Test results show that for the Hanford Site's arid climate, a well-designed surface barrier limits drainage to near-zero amounts. Data collected under extreme conditions (excess precipitation) provides confidence that the surface barrier design has the ability to meet its performance objectives for the 1,000-year design life. This information can help DOE and regulators make decisions about remedial actions necessary during Hanford Site cleanup.

The U.S. Department of Energy (DOE) has been actively pursing technology for surface barrier design at the Hanford Site for over two decades (RHO-CD-1142; Wing and Gee 1994; Ward and Gee 2000; BHI-01551; Link et al. 1995). A field-scale prototype surface barrier was constructed in 1994 over an existing waste site as part of a *Comprehensive Environmental Response, Compensation and Liability Act* (CERCLA) treatability test. The barrier was designed to be used at waste sites in arid climates and to have a 1,000-year performance. An analysis of the first 4 years of data monitoring the long-term performance of the barrier was reported in the Hanford groundwater monitoring report for fiscal year 1999 (PNNL-13116). This section updates that report and includes data collected since that time.

Because of the demand for a barrier that could perform for at least 1,000 years without maintenance, natural construction materials (e.g., fine soil, sand, gravel, cobble, basalt riprap, and asphalt) were selected to optimize barrier performance and longevity. Most of these natural construction materials are available in large quantities on the Hanford Site and are known to have existed in place for thousands of years. The current barrier consists of a fine-soil layer overlying other layers of coarser materials, such as sands, gravels, and basalt riprap, and is designed to limit recharge to <0.5 millimeter per year (Figure 3.3-4). The layers and the purpose of each layer are more fully discussed in PNNL-13116.

A simplified water balance for the 1,000-year prototype surface barrier requires that the amount of natural precipitation must equal the sum of the moisture diverted out of the soil cover by asphalt, plus vertical drainage past the asphalt layer, plus surface runoff, plus any change in soil water storage, plus evapotranspiration. Evapotranspiration is the only component not measured at the Hanford Site prototype barrier, but can be calculated from the other variables just mentioned.

Water-balance monitoring of the surface barrier was carried out using rain gages to measure irrigation and precipitation, neutron probe for soil water content (water storage), and pan or basin-type lysimeters for drainage collection. Piping carries the drainage water from each of 12 collection zones to basins where it is monitored with a resolution of a few liters or less (i.e., <0.1 millimeter). Figure 3.3-5 shows a plan view of the barrier and the collection zones, six each for irrigated (north end) and non-irrigated (south end) areas. Details of the monitoring are described elsewhere (Ward and Gee 1997; DOE/RL-99-11).

From November 1994 through October 1997, the north half of the prototype barrier was subjected to irrigation amounting to three times the long-term average annual precipitation.

The irrigation treatment included applying sufficient water on 1 day during the last week of March for 3 years (1995 through 1997) to mimic a 1,000-year storm event (70 millimeters of water) and periodic applications to achieve 480 millimeters per year precipitation for the entire water year (November 1 through October 31).

Figure 3.3-6 compares temporal changes in mean soil water storage on the irrigated and non-irrigated parts of the prototype barrier for 8 years (September 1994 through September 2002).

All irrigation and natural precipitation plus all plant-available stored soil water was removed via evapotranspiration during the first year of operation. This process was repeated so that over the remaining years, water was removed annually from the entire soil profile by late summer. There was a hiatus of water-storage monitoring between September 1998 and May of 2000, so no data are available for that time period. However, the trends before and after clearly show that evapotranspiration was effective in keeping the water storage well below the estimated drainage limit of 600 millimeters for the 2-meter silt-loam surface. Soil-water content in both irrigated and non-irrigated plots reached a relatively uniform lower limit of 5 to 8 vol. % throughout the soil profile by September of each year. Correspondingly, water storage was reduced to levels of 100 to 150 millimeters, i.e., the lower-limit of plant-available water, for both the irrigated and non-irrigated soil surfaces.

The amount of water stored in the fall is about one-fifth the amount of water required for drainage from a 2-meter silt-loam surface layer. This suggests that extreme winter precipitation, the prime cause of drainage at the Hanford Site, can be readily stored in the engineered soil profile until spring when it is subsequently lost from the soil by evapotranspiration. Table 3.3-1 shows the seasonal precipitation for the past 8 years at the Hanford Meteorological Station and represents the precipitation input on the surface barrier. Two of the 8 years (1995 and 1996) had record precipitation. Even if these 2 years had repeated themselves over the remaining 6 years, it is unlikely that the 2-meter-thick soil surface barrier would have drained. However, based on the observed storage changes (see Figure 3.3-6) on the non-irrigated area, it appears that drainage would have occurred in 1995 and 1997 (wettest years) if the surface layer were reduced to a 1-meter-thick silt loam. This supports the case for designing a surface barrier with sufficient water-storage capacity to assure that under extreme conditions, the surface barrier will still perform adequately.

The positive response of the barrier to remove water and limit drainage demonstrates the benefits of having vegetation on the surface. Evapotranspiration for the irrigated plots was nearly double that for the non-irrigated plots, suggesting that vegetation is capable of adjusting to water applications. The capacity of vegetation for water consumption was not exceeded even at the 3 times the precipitation rates. This further supports the hypothesis that the combination of vegetation and soil storage capacity is more than sufficient to remove all applied water under the test conditions. Within a year after the irrigation was terminated, the water storage in the irrigated and non-irrigated plots became similar. During the past 2.5 years, the water storage in all soil plots was virtually the same (see Figure 3.3-6).

Drainage did not occur from the soil-covered part of the prototype surface barrier until the third year, and then only a small amount for one of the soil plots that was subjected to the 3 times the natural precipitation treatment. No additional drainage has occurred from the silt-loam covered area, so the total drainage over the 8 years of testing is <5% of the prescribed limit of 0.5 millimeter per year. The drainage was attributed to lateral flow from water diverted off an adjacent roadway. In contrast, both side slope configurations drained because they were barren of vegetation, although the amount of drainage was significantly less than predicted, based on lysimeter testing with coarse materials (PNL-8391).

Horizontal neutron logging confirmed that no accumulation of water occurred under the asphalt pad. However, water shedding was observed at the edge of the side slope, indicating that lateral drainage of water from the gravel and riprap can occur. Details of the observed lateral drainage can be found in Ward and Gee (1997) and DOE/RL-99-11.

The rapid establishment of vegetation on the soil surface was thought to be responsible for at least three positive benefits to surface barrier performance. First, the vegetation was dominant in the water-removal process from the surface soils. Second, the surface was stabilized against water erosion and runoff. Runoff from the 1,000-year storm in 1995 was 1.8 millimeters (about 2% of the 70 millimeters applied). There was no runoff in 1996. The improvement was attributed to plant establishment and vegetative growth. Third, there has been a positive benefit in controlling wind erosion. After plant establishment in November 1994, there have been no measurable losses of soil from the surface of the prototype barrier by wind erosion. This is attributed to the vegetation and lack of surface disturbance since the cover was established. Soil, gravel, and rock surfaces were found to be stable and, for the 8-year test-period, subsidence were not observed.

Eight years of testing provide important but limited information for long-term barrier-performance estimates. Because only a finite amount of time exists to test a barrier that is intended to function for a minimum of 1,000 years, the testing program has been designed to stress the prototype so that barrier performance can be determined within a reasonable time. To date, the results are very encouraging and support the premise that a barrier can be subjected to extreme stresses, for example, 1,000-year storms, and still perform successfully. Continued monitoring of the performance of the prototype barrier for extended periods is desirable because the succession of vegetation types, the full development of root profiles, and the natural colonization of the barrier surface by burrowing animals will occur over a longer time period.

Test results obtained to date show that in the Hanford Site's arid climate, a well-designed capillary barrier limits drainage to near-zero amounts. A subsurface asphalt layer provides additional redundancy. Data collected under extreme conditions (excess precipitation) provides confidence that the surface barrier has the capability to meet its performance objectives for the 1,000-year design life.

3.3.3 Electromagnetic Induction and Ground Penetrating Radar to Monitoring Soil-Water Storage in a Prototype Surface Barrier

A. L. Ward, W. P. Clement, and G. W. Gee

A multi-year barrier-development program was started at the Hanford Site in 1985 to develop, test, and evaluate the effectiveness of various surface barrier designs (see Section 3.3.2). The lack of cost-effective robust monitoring technologies for long-term monitoring and the difficulty in projecting field-scale performance from short-term point measurements are major challenges to barrier deployment. For this reason, electromagnetic induction and ground penetrating radar were investigated as techniques for non-intrusive measurements of soil water content and storage in an engineered surface barrier. The objective was to investigate how electromagnetic induction and ground penetrating radar responded to spatial and temporal variations in soil water storage in a surface barrier.

Ground penetrating radar and electromagnetic induction show considerable promise as tools for high-resolution mapping of soil water content and water storage in surface barriers. These non-invasive techniques offer significant advantages over traditional methods: high speed of data acquisition, lower costs, high resolution of sampling, and integration of multiple spatial scales. Furthermore, the non-intrusive nature of these technologies minimizes damage to barrier integrity from sensor installation or degradation. These methods may provide an attractive way to monitor large numbers of field-scale surface barriers.

The study was conducted on a prototype surface barrier on the Hanford Site. The prototype is a vegetated capillary barrier comprised of eight distinct layers of natural materials and has been monitored continuously for the last 8 years (Ward and Gee 1997). A cross section of the barrier is shown in Section 3.3.2.

Geophysical surveys were conducted using electromagnetic induction and ground penetrating radar. Electromagnetic induction measurements were made with the Geonics EM-38 and EM-31 ground conductivity meters. Measurements with the EM-38 were done to achieve penetration depths of 0.75 and 1.5 meters. Measurements were also made at elevations of 0, 26, 54, 74, 94, 109, 124 centimeters above the barrier surface to estimate variations in apparent electrical conductivity with depth. The EM-31 survey achieved a penetration depth of 6 meters. Measurements to determine the apparent electrical conductivity as a function of depth also were made and from three additional elevations of 154, 176, and

204 centimeters. Spatial and temporal variations in bulk apparent electrical conductivity were correlated with water content and storage. Neutron probe measurements of water content as a function of depth were used for comparison.

The ground penetrating radar surveys were conducted with a PulseEKKO 1000 GPR system with a 200-volt transmitter (with two sets of antennae with center frequencies of 100 and 200 MHz). After the first survey, data from the 200 MHz antennae proved inappropriate for site conditions, and subsequent measurements were made with the 100 MHz antennae.

Water storage over the ground penetrating radar sampling depth was calculated as the product of the mean water content and depth. Soil-water content also was measured using time domain reflectometry to a depth of 1.8 meters, and with a neutron probe to a depth of 1.9 meters (BHI-100381).

Figure 3.3-7 is a plan view of the barrier surface. The surface was mapped on a 3- by 3-meter grid during each electromagnetic induction survey.

The presence of metallic components at and below the surface suggested that electromagnetic measurements might be adversely affected at some locations. Figure 3.3-8 compares the EM-31 data from the September 1994 and September 2001 surveys. Areas of anomalous high electrical conductivity extend in an east-west direction at northings of 26 and 63 meters and in a north-south direction down the middle of the barrier. These anomalies are most likely due to metallic components (e.g., sensors, cables and access tubes) of the monitoring stations in the barrier. After the initial survey in 1994, many of the cables, particularly down the middle of the plot, were encased in polyvinyl chloride (PVC) conduit. This, plus generally drier conditions, caused the decline in the electrical conductivity seen in the 2001 survey (see Figure 3.3-8).

EM-31 measurements on transects N1 and N2 (see Figure 3.3-7) showed an increase in electrical conductivity toward the north, most likely due to a large irrigation system at the north end of the plot. There were also differences between the profiles of the N1 and N2 surveys with the N1 profile showing slightly higher electrical conductivity values. This is consistent with observed differences in water storage between the northeast and northwest quadrants, which appear to be due to differences in plant water uptake. Plant population density measurements show the northeast quadrant to be dominated by shallow rooted grasses and consistently higher water storage compared to the rest of the barrier where sagebrush and rabbit brush dominate (BHI-100381).

Outliers due to the effects of buried metallic structures were removed from the data set to identify the relationship between apparent electrical conductivity and water content or soil water storage. This filtering procedure reduced the data set from 338 data points to 44 data points (refer to black dots on Figure 3.3-7). Figure 3.3-9 shows the relationship between apparent electrical conductivity (standardized to 25°C) from the filtered EM-31 data and soil water storage from neutron probe measurements.

Conductivity maps from the 2001 to 2002 survey suggest that irrigation on the north end of the barrier between November 1994 and September 1997 might have caused an increase in conductivity from the initial condition in 1994. To minimize the number of variables affecting electrical conductivity, the relationship in Figure 3.3-9 is based entirely on measurements from the south, non-irrigated section of the barrier. The analysis shows a linear relationship for the range of water storage, measured by neutron probe, and apparent electrical conductivity from the EM-31 survey, with a coefficient of determination of over 60%.

The small size of the data set may limit use of this relationship for predicting the full range of soil water storage from electrical conductivity measurements. However, it does suggest that the method may hold promise for field-scale monitoring of water storage. The mobility of these instruments, the speed with which measurements can be made, and the success of aerial electromagnetic induction surveys in mapping large areas makes this method an attractive option for monitoring large field-scale surface barriers.

Ground penetrating radar surveys showed slower velocities for the March and January 2001 surveys than for the May and September 2001 surveys. These changes reflect changes in water content in the silt-loam layer with higher water content during the winter and spring than in the summer and fall.

As with the ground penetrating radar surveys, the electromagnetic surveys showed temporal trends in water content. Figure 3.3-10 show plots of the temporal changes in velocity of the ground wave and the water content along the transect E1. There was a notable increase in velocity and a decrease in water content from March 2001 to May 2001. There was a subsequent decrease in velocity and an increase in water content from September 2001 to January 2002. These data also show a negative gradient in moisture content from west to east. The nature of the gradient is unknown, but may be due to drier conditions on the east side of the barrier caused by advective drying near the riprap side slope.

As with the electromagnetic induction measurements, the data set for ground penetrating radar is quite limited. Nevertheless, the data show a linear relationship between water storage from ground penetrating radar measurements and water storage from neutron probe measurements (Figure 3.3-11b). The relationship between water storage from ground penetrating radar measurements (Figure 3.3-11a) and that determined from time domain reflectometry is somewhat better with the coefficient of determination about twice that for the neutron probe relationship. A plot of water storage determined from ground penetrating radar, time domain reflectometry, and neutron probe measurements showed that the neutron probe generally underestimated water content and water storage relative to ground penetrating radar and time domain reflectometry estimates (see Figure 3.3-11). This is because ground penetrating radar and time domain reflectometry measure essentially the same variable (i.e., dielectric permittivity), whereas the neutron probe responds to the presence of hydrogen, which is assumed to be due only to the presence of water.

In summary, the results of these investigations showed relationships between non-intrusive electromagnetic induction and ground penetrating radar survey results and the spatial and temporal variations in soil water storage in a field-scale surface barrier. Electromagnetic measurements showed anomalous values due to metallic components in the Hanford surface barrier. Nevertheless, data filtering allowed the development of a reasonable relationship between water content and water storage with electrical conductivity.

Ground penetrating radar also shows considerable promise for high-resolution mapping of soil water content and storage distributions in surface barriers. Changes in the ground penetrating radar response correlated well with changes in soil moisture over time. Water storage as measured by ground penetrating radar was highly correlated with the well-established time domain reflectometry method, but less so with neutron probe results.

Non-invasive techniques offer significant advantages over traditional methods: high speed of data acquisition, lower costs, high resolution of sampling, and integration of multiple spatial scales. Furthermore, the non-intrusive nature minimizes damage to barrier integrity from sensor installation or degradation. The potential for airborne deployment of electromagnetic induction and ground penetrating radar make these methods attractive for monitoring large field-scale barriers. The improved understanding of the nonlinear dependence of large-scale processes on local-scale water content that can be gained from these data is an important step toward the use of remote sensing for monitoring barrier performance.

3.3.4 Evaluation of Electrical Leak-Detection Methods at the Hanford Site Mock Tank — Fiscal Years 2002-2003

D. B. Barnett, M. D. Sweeney, M. D. Johnson, and G. W. Gee

From mid-July through early November 2002, Pacific Northwest National Laboratory and CH2M HILL Hanford Group, Inc. (and subcontractors) evaluated performance parameters for two electrical geophysical methods to detect leaks beneath buried tanks. The 109-day test involved a series of blind, leak/no leak events and continuous monitoring by electrical resistivity methods. The fiscal year 2002 evaluation is a follow-up to a broader evaluation of several geophysical methods conducted in fiscal year 2001 (PNNL-13818). Only preliminary results are presented here, as detailed analysis of the collected data is still in progress.

DOE contractors are evaluating geophysical methods to detect leaks beneath buried tanks. The methods are tested at a mock tank site in the 200 East Area. Preliminary results from fiscal year 2002 indicate the tested materials are sensitive to leak detection and volume estimation.

The M-45 series of milestones under the Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement; Ecology et al. 1998) requires removal of waste from single-shell tanks and other miscellaneous underground tanks for storage in the double-shell tank system. Under the Tri-Party Agreement, CH2M HILL Hanford Group, Inc. is demonstrating several retrieval methods to dislodge, mobilize, and remove the waste. During retrieval operations, conditions beneath and in the single-shell tanks may be monitored as an additional precaution to protect the vadose zone beneath the tanks. To evaluate monitoring options, CH2M HILL Hanford Group, Inc. and their subcontractors have assessed a variety of potential in-tank and out-of-tank technologies to develop a leak detection and monitoring system for use during waste-retrieval operations.

The evaluations were conducted at the Hanford Site 105-A mock tank facility in the 200 East Area of the Hanford Site (Figure 3.3-12). The tank was constructed in 1994 to 1995 and previously used to test the applicability and effectiveness of an array of electrical resistivity sensors to provide tomographic images of simulated fluid leaks beneath the tank.

Leak detection studies at the mock tank have been conducted since 1995 (UCRL-JC-122180; UCRL-JC-122875; WHC-SA-3035-VA; WHC-SD-EN-TA-004). In fiscal year 2001, the mock tank was used to simultaneously test six leak detection methods. Of these, two primary methods were selected for further evaluation during an appraisal/elimination process completed in January 2002. Principal investigators of the methods selected for fiscal year 2002 and 2003 evaluation were Lawrence Livermore National Laboratory using electrical resistivity tomography and HydroGEOPHYSICS, Inc. using high-resolution resistivity—steel casing resistivity technique. Additional infrastructure was added in fiscal year 2002 and consisted of one new shallow, steel-cased borehole and a steel sheet wall (to simulate an adjacent buried tank). An example of 1 of the 16 electrode arrays, in relation to a partial profile of the mock tank, is shown in Figure 3.3-13, along with various features used to dispense solutions and make electrical measurements.

The additional drilling and construction activities took place in May and June 2002. The photo on page 3.3-1 shows the placement of the steel wall near the southwest edge of the mock tank. Steel panels were welded together and buried to ~3.3-meter depth. The surface edge of the steel wall was alternately connected to and disconnected from the mock tank to evaluate the effects of a large conductive feature such as an adjacent tank.

The geophysical methods that were applied in the fiscal year 2002 to 2003 test are:

1. electrical resistivity tomography
    - long electrode technique
    - point electrode technique
2. high resolution, resistivity-steel casing resistivity technique
    - tank-to-steel casing
    - tank-to-fused electrode arrays (simulated casing)
    - steel casing to steel casing or fused arrays
    - tank to surface electrodes

These methods were applied daily during the test period and alternated sequentially so as not to interfere with one another. Steel casings and fused-array (simulated casings) were used alternately by both electrical resistivity tomography and the high-resolution resistivity technique to collect data.

Data sets from the fiscal year 2002 to 2003 evaluation testing at the mock tank are currently being analyzed. Preliminary results indicate that the methods performed within the expected ranges of sensitivity for leak detection. Early indications from the high resolution, steel casing resistivity technique suggest that configurations involving connection to the tank (as a receiver or transmitter) appear to be very sensitive to both leak detection and volume estimation. Final results from this testing are expected to be available in early calendar year 2003.

3.3.5 Tank Farm Vadose Zone Project – Corrective Measures

D. A. Myers

The Tank Farm Vadose Zone Project under CH2M HILL Hanford Group, Inc. took a series of major interim measures in the 200 East Area during fiscal year 2002. These measures consisted of providing protection to the tank farms from upgradient surface water run-on. All single-shell tank farms in the area were provided protection against the nominal 30-year storm as well as against potential leaks from pressurized water lines within the drainage areas above the tank farms. Of particular note in this effort is the reworking of Baltimore Avenue that runs north-south between B Tank Farm and the BX and BY Tank Farms (see Figure 2.8-1). When a transfer line between B and BX Tank Farms was built in the 1970s, the construction left a berm that held water in a pond upstream of the transfer line and west of Baltimore Avenue. Since the transfer line was built, a total of six rapid snowmelt events have taken place. These events are likely the sources of recharge that mobilized vadose zone contamination resulting in groundwater contamination in this area. A culvert system was designed and installed to carry the water from this area to the north fence line of the 200 East Area. Berms were constructed to direct water away from the farms.

The Tank Farm Vadose Zone Project took a series of major interim measures in the 200 East Area during fiscal year 2002. These measures divert or eliminate infiltration of surface water or leaking water lines.

Water lines servicing the 200 East Area single-shell tank farms were tested to ascertain their integrity; all lines passed the pressure tests. Those lines for which no future use was found were cut and capped outside the waste management area boundaries to prevent any inadvertent release of water to the tank farms.

During fiscal year 2002, the final water-control, interim measure was taken in the 200 West Area. This consisted of cutting and capping a water line servicing the 244-TX double-contained receiver tank. During fiscal year 2001, tests determined this line was losing water at a rate of 0.19 gallon per minute. However, the water line was needed to complete a flush of waste from the Plutonium Finishing Plant to the SY Tank Farm. After this flush was finished, the line was cut and capped outside the waste management area boundary.

3.3.6 Immobilization of Chromium, Technetium, and Uranium by Gaseous Reduction in Soil from the Hanford Site

E. C. Thornton, V. L. Legore, and K. B. Olsen

Chromium, technetium-99, and uranium-233, -234, -235, -236, and -238 are vadose zone contaminants at Hanford that could be leached from the soil and reach groundwater by surface water infiltration. A promising technology for immobilizing these contaminants is in situ gaseous reduction. Laboratory tests were done to determine (1) if sediment contaminated with technetium and uranium can be treated effectively by exposure to diluted hydrogen sulfide gas and (2) if sediment treated with hydrogen sulfide can retard the migration of chromium, technetium, and uranium in solutions infiltrating through the treated zone. Results from these tests became available in fiscal year 2002. Both contaminated and uncontaminated soil samples from the Hanford Site were used to assess the treatment efficiencies.

The study of immobilization of chromium, technetium-99, and uranium offers insight that may be used to protect the vadose zone from contamination during waste retrieval at the single-shell tanks.

In situ gaseous reduction of the vadose zone has two different applications for waste in the vadose zone. The first is to stabilize pre-existing contamination. This involves reduction of chromium, technetium, and uranium and possible fixation by forming coatings or precipitates. The second application is creation of a permeable reactive barrier by reduction of ferric to ferrous iron in vadose zone sediments. This provides a way to capture contamination from possible future waste tank leaks.

3.3.6.1 Gaseous Treatment of Technetium-99 Contaminated Sediment

Technetium-99 contaminated sediment was treated in column tests to determine whether technetium can be reduced from the +VII to +IV oxidation state and immobilized with diluted hydrogen sulfide. Treated and untreated sediment was then leached with water, and the rates of sediment reoxidation and technetium-99 release were monitored.

The technetium-contaminated sediment used in these tests was collected from borehole 299-W23-19 south of the S-SX Tank Farm (PNNL-13757-2). The sediment contained 0.02 to 0.03 µg/g (350 to 500 pCi/g) technetium-99 and high concentrations of soluble nitrate (700 to 4,000 µg/g) and calcium (10,000 to 15,000 µg/g).

The tests involved packing four columns with the technetium-contaminated sediment. One column was an untreated control and was leached with oxygenated water. A second column was treated with hydrogen sulfide diluted in air, and the third and fourth columns were treated with hydrogen sulfide diluted in nitrogen.

The release of technetium versus time during leaching of the untreated sediment is illustrated in Figure 3.3-14. The first sample contained 155 µg/L technetium; subsequent samples had much lower concentrations. Technetium was not detected in samples collected after 6 hours (6 column pore volumes). A cumulative amount of 0.020 microgram of technetium was leached per gram of sediment. About 98% of this was leached from the column in the first sample.

The second column was treated with 200-mg/L hydrogen sulfide in air. Most of the hydrogen sulfide was consumed in the first 24 hours. The treated sediment was then leached with aerated water. The oxygen concentration of the effluent and influent were similar, indicating that there was no reductive capacity in the sediment as the result of hydrogen sulfide in air treatment.

The release of technetium from the column during the water-leaching step is shown in Figure 3.3-15. The technetium concentration in the first effluent sample was 34.4 µg/L, about 22% of that of the first sample collected from the untreated sediment. Technetium continued to be leached over the next 2 weeks but was below the detection limits (0.02 µg/L) by the end of the test. A cumulative amount of 0.0107 µg technetium was leached per gram of sediment. Thus, about 49% of the technetium was immobilized as a result of gas treatment.

The third and fourth columns were duplicate tests that were treated with 200-mg/L hydrogen sulfide in nitrogen. Most of the hydrogen sulfide was consumed within the first 24 hours. A significant amount of reductive capacity resulted from the treatment of the sediment with the hydrogen sulfide/nitrogen mixture. Technetium release from the column during the water-leaching step is shown in Figure 3.3-16 for one of the tests. The concentration of technetium in the first effluent sample was 10.1 µg/L, about 6.5% of that of the first sample collected in the untreated test. Technetium continued to be leached from this experiment over the next 2 weeks, but decreased to a concentration of only 0.03 µg/L by the end of the test. A cumulative amount of 0.00947 microgram of technetium was leached per gram of sediment. Thus, about 51% of the technetium was immobilized as a result of gas treatment compared to water-leaching results from the untreated sediment.

Treatment of the vadose zone with hydrogen sulfide in air could provide a way to partially stabilize technetium contamination present in the vadose zone beneath single-shell tanks. However, treatment of the vadose zone sediment with hydrogen sulfide in air would not be useful in generating a permeable reactive barrier. Hydrogen sulfide in nitrogen, however, may stabilize technetium contamination in the vadose zone and create a permeable reactive barrier.

The test results indicate that ~50% of the technetium present in the contaminated sediment was immobilized by treatment with diluted hydrogen sulfide. No reductive capacity resulted from treatment of the sediment with hydrogen sulfide/air. A limited amount of reductive capacity was generated by treatment with hydrogen sulfide/nitrogen. The relatively low reductive capacity of the hydrogen sulfide/nitrogen treated sediment may be related to low available iron in the sediment. The relatively high flow rate (0.4 millimeter per minute) used during the reoxidation/leaching stage for one test may also have resulted in a measured reductive capacity less than the true reductive capacity.

Treatment of the vadose zone with hydrogen sulfide in air could provide a means to partially stabilize technetium contamination present beneath single-shell tanks in the vadose zone. The partial immobilization of technetium due to the hydrogen sulfide in air treatment test may result from incorporation of reduced technetium in iron oxide phases or to the formation of a coating (e.g., elemental sulfur on sediment grains). These processes would retard technetium movement through the vadose zone and lower the amount reaching groundwater. Treatment of the vadose zone sediment with hydrogen sulfide/air would not be useful in generating a permeable reactive barrier since no reductive capacity appeared to result.

Hydrogen sulfide in nitrogen treatment, however, may stabilize technetium contamination in the vadose zone and create a permeable reactive barrier. A permeable reactive barrier would result from the reductive capacity generated by reduction of the iron component present in vadose zone sediment. The longevity of the barrier would be a function of the reducible iron content of the sediment and the rate of barrier reoxidation. Barrier reoxidation occurs in response to the flux of oxygen, which is related to water infiltration rates and the diffusion of oxygen through the vadose zone.

3.3.6.2 Gaseous Treatment of Uranium-Contaminated Sediment

Uranium-contaminated sediment was treated in column tests to determine whether uranium can be immobilized and reduced from the +VI to the +IV oxidation state by treatment with diluted hydrogen sulfide. Treated and untreated sediment was then leached with water and the rate of sediment reoxidation and uranium release was monitored.

The uranium-contaminated sediment used in these tests was collected from borehole BX-102 in the BX Tank Farm. The sediment was collected from the Hanford formation sand-dominated sequence. The total uranium content of the sediment is about 150 µg/g. The sediment contains low to non-detect concentrations of water-extractable technetium-99 (<0.001 µg/g) and chromium (<0.05 µg/g).

Only about 15% of the uranium in leach tests was immobilized as a result of hydrogen sulfide gas treatment. Treatment of the vadose zone with hydrogen sulfide in air would probably not provide a way to stabilize uranium contamination. Treatment with hydrogen sulfide in nitrogen, however, may stabilize uranium contamination present in the vadose zone to some extent.

Testing involved packing three columns with the uranium-contaminated sediment. One column was an untreated control and was leached with aerated water. The second column was treated with hydrogen sulfide diluted in air and the third with hydrogen sulfide diluted in nitrogen.

Uranium release during leaching of the untreated sediment is shown in Figure 3.3-17. Uranium was detected in all samples collected for the 2-week duration of the test. However, a steady-state concentration of about 40 µg/L uranium-238 was reached after the first 6 days. A cumulative amount of 9.05 micrograms of uranium was leached per gram of sediment, suggesting that most of the uranium is present in low solubility mineral phases (the total uranium content is ~150 µg/g).

The second column, treated with hydrogen sulfide and subsequently leached with aerated water, had similar oxygen concentrations in both the effluent and influent samples, indicating that no reductive capacity of the sediment resulted from the gas treatment. Uranium release during the water-leaching step is shown in Figure 3.3-18. The uranium concentration (8,741 µg/L) in the first effluent sample (0.7 column pore volumes) was similar to the first sample collected from untreated sediment. A cumulative amount of 7.66 uranium was leached per gram of sediment. Thus, only about 15% of the uranium was immobilized as a result of gas treatment.

Uranium release during water leaching of the column treated with hydrogen sulfide in nitrogen is shown in Figure 3.3-19. A significant amount of reductive capacity resulted from treatment of the sediment with the hydrogen sulfide/nitrogen mixture. The concentration of uranium in the first effluent sample was ~30% of that of the first sample in the untreated test. A cumulative amount of 8.24 micrograms of uranium was leached per gram of sediment versus 9.05 micrograms for the untreated sample. Thus, less than 10% of the uranium was immobilized as a result of gas treatment compared to the amount of uranium released for the test with the untreated sediment.

Treatment of the vadose zone with hydrogen sulfide in air would probably not provide a way to stabilize uranium contamination. Treatment with hydrogen sulfide/nitrogen, however, may stabilize uranium contamination present in the vadose zone to some extent as well as create a permeable reactive barrier.

3.3.6.3 Evaluation of the In Situ Gaseous Reduction Permeable Reactive Barrier Concept for Immobilization of Chromium, Technetium, and Uranium in the Vadose Zone

Uncontaminated Hanford formation sand-dominated sediment used in these tests was collected from well 299-W22-50 southeast of the SX Tank Farm. The testing involved packing two columns with the uncontaminated sediment. One column was an untreated control and a 200-mg/L hydrogen sulfide mixture was passed through the second column.

An aerated solution containing 1,000 µg/L of chromium (VI), 2,400 µg/L of technetium (VI), and 900 µg/L of uranium (VI) was pumped through both columns. The concentrations of total chromium, hexavalent chromium, technetium, and uranium in the effluent from the treated column were compared to that of the untreated column to determine the degree of immobilization associated with gas treatment.

The concentration of total chromium, technetium-99, and uranium-238 in the effluent from the column containing the untreated sediment is shown in Figure 3.3-20. The chromium concentration from the untreated column ranged from 732 to 1,002 µg/L, which was similar to that of the influent. Chromium (VI) concentrations ranged from 890 to 980 µg/L, indicating that all of the chromium in the influent and effluent was in the hexavalent oxidation state. Technetium-99 concentration in the effluent was also similar to that of the influent, indicating no adsorption or precipitation had occurred. Uranium-238 concentration in the untreated column effluent was initially low, <20 µg/L, but increased to ~300 µg/L after several weeks. Also, the pH of the effluent was near neutral through most of the experiment, due to the high buffering capacity of the sediment, but decreased slowly with time. This suggests that uranium (VI) may have precipitated as a carbonate phase.

Test results suggest that a permeable reactive barrier generated by a hydrogen sulfide/nitrogen gas mixture would be a very effective way to immobilize chromium(VI) in the vadose zone. The barrier lifetime is estimated to be hundreds to several thousands of years depending on the sediment iron content, the barrier thickness, and the rate of oxygen movement through the vadose zone.

The second column, treated with hydrogen sulfide in nitrogen, showed a significant amount of reductive capacity in the sediment. The composition of the column effluent is presented in Figure 3.3-21. The chromium (VI) and total chromium concentrations were low during the period when the system was reduced (prior to 25 hours) but increased subsequent to reoxidation (compare Figures 3.3-20 and 3.3-21). Thus, chromium (VI) was reduced and precipitated while the system was depleted of oxygen, but was unaffected once the system became oxygenated. The concentration of technetium in the effluent was only 107 µg/L in the first sample at 0.7 hours but increased as reoxidation progressed. It was approximately equal in concentration to the influent (2,400 µg/L) at 25 hours. Uranium concentrations in the column effluents of both tests were similar.

The results suggests that a permeable reactive barrier generated by a hydrogen sulfide/nitrogen gas mixture would be very effective at immobilizing chromium (VI) in the vadose zone because once reduced, chromium is not readily remobilized. However, the barrier would no longer be effective for immobilizing additional chromium (VI) once the sediment is reoxidized. The barrier lifetime is estimated to be hundreds to several thousands of years depending on sediment iron content, barrier thickness, and transport rates of oxygen through the vadose zone.

The results also indicate that limited immobilization is possible for technetium (VII) using an in situ gaseous reduction vadose zone permeable reactive barrier. It appears that the degree of immobilization is high when the reductive capacity of the treated sediment is great, but decreases as the sediment is reoxidized. This is related to the lower oxidation potential of the technetium (VII)/technetium (IV) couple relative to that of chromium. Also, the technetium couple is reversible under natural conditions and, thus, technetium could be remobilized from the barrier once it is reoxidized. This suggests that an in situ gaseous reduction permeable reactive barrier could be useful as a short-term measure to capture technetium (VII) that might be released during waste tank closure operations. The long-term viability of the barrier, however, is difficult to assess. It is possible that a mid- to long-term barrier useable lifetime could be achieved if the barrier is periodically recharged by treatment with additional hydrogen sulfide.

Uranium also was immobilized in both the untreated and treated column tests. The mechanism responsible for the relatively low mobility of uranium (VI) is not clear. Uranium may have precipitated in the columns as a carbonate or hydroxide phase.

3.3.6.4 Evaluation of the Potential for Long-Term Chromium Reoxidation in an Hydrogen-Sulfide-Treated Sediment

The longevity of the treatment for the contaminant immobilization is a critical issue. Chromium (VI) is readily reduced to chromium (III) by reaction with hydrogen sulfide. It is generally regarded as stable in the chromium (III) form in the natural environment and relatively insoluble. A long-term test was conducted to determine whether or not reoxidation of chromium can occur after chromium (VI) is reduced by hydrogen sulfide treatment in contaminated sediment.

A chromate-contaminated sediment sample from the 100-K Area was treated with diluted hydrogen sulfide gas then leaked with water. The sediment sample was leached with water for one hour; then the amount of chromium (VI) was measured in the leachate.

The treated sample was exposed to air under humid conditions and periodically sampled and analyzed to determine if the chromium (VI) concentration changed with time. Results from the 835-day test showed that levels of chromium (VI) in the sediment dropped from about 3.3 mg/kg in the first year to a level ranging from 2.1 to 2.6 mg/kg. Samples collected at 492, 653, and 835 days all contained about 2.1 mg/kg, suggesting a steady-state concentration was attained. Data obtained from this test suggests that reduced chromium will not reoxidize to the hexavalent state.

3.3.7 Water Monitoring of the Tree Shelterbelt at 200 West Area

G. W. Gee, J. S. Carr, J. O. Goreham, and C. E. Strickland

Water input to the vadose zone, from irrigation of a tree shelterbelt in the 200 West Area of the Hanford Site (Figure 3.3-22), was monitored during the summer of fiscal year 2002. Water flux and soil-water contents were measured within the shelterbelt and at two locations just east of the shelterbelt (Figure 3.3-23) to assess the effect of the irrigation on the vadose zone and to assist in optimizing the irrigation applications. In May 2002, sensors were placed in auger holes and backfilled with local soil. The sensors were connected to a computer system and data were gathered via digital modem. Data files and graphics were made web accessible for instantaneous retrieval. Precipitation, drip irrigation, deep-water flux, soil water content, and soil water pressures have been monitored on a nearly continuous basis from the tree-line site since June 26, 2002.

An irrigated tree shelterbelt was established to control wind-blown sand resulting from the June 2000 range fire on the Hanford Site. Continued monitoring of irrigation water infiltration helps assess the effect of drainage on adjacent areas such as solid waste burial grounds. From June to September 2002, there were 3,100 millimeters of drainage from apparent over-irrigation.

There was little rain (6 millimeters) between July and September 2002, so water applied to the soil was almost exclusively from irrigation. During the first 65 days of monitoring (June 26 through August 30, 2002), the measured application rate averaged 751 liters per day per tree, over 13 times the design rate of 57 liters per day per tree. Feedback from the monitoring data has resulted in subsequent reductions in both application and drainage rates within the tree line. Recent adjustments have reduced the water application rate to 159 liters per day. Drainage within the tree line from irrigation has exceeded 3,100 millimeters of water for the 80-day monitoring period (Figure 3.3-24). The drainage rate has been reduced more than half, from 36 millimeters per day for the first 65 days, to 17 millimeters per day for the past 7 days (i.e., through September 24, 2002). In spite of these improvements, the irrigation and drainage rates are still not optimized as irrigation exceeds the design rate by almost a factor of three. Monitoring of two adjacent sites found no drainage during the 80-day monitoring period. Continued monitoring within and adjacent to the tree line not only will provide an evaluation of the overall efficiency of the irrigation system but will also help assess the effect of drainage on adjacent areas such as solid waste burial grounds.

3.3.8 Soil-Gas Investigation at the 618-10 Burial Ground

K. B. Olsen, P. E. Dresel, and R. E. Peterson

The 618-10 burial ground received waste similar to waste in the 618-11 burial ground. In 1999, groundwater samples from the 618-11 burial ground contained 1.86 million pCi/L of tritium. Soil-gas investigations were done at the 618-10 burial ground to assess its potential for similar tritium contamination of groundwater. These results became available in fiscal year 2002.

The use of helium-3/helium-4 ratios in soil gas to successfully detect and delineate tritium contamination at the 618-11 burial ground is described in PNNL-13675. The method is based on the decay of tritium to helium-3, which is a stable, inert isotope.

Slightly elevated helium-3/helium-4 ratios at two locations along the fence at the 618-10 burial ground may represent a tritium source in the vadose zone or tritium in the underlying groundwater. However, no major contaminant plume was found.

When tritium-bearing waste comes in contact with soil moisture, tritium is incorporated in the soil moisture, which may migrate away from the tritium source. The tritiated soil moisture mixes with infiltrating moisture from precipitation (e.g., rainfall, snowmelt), or moisture from anthropogenic activities (e.g., dust control, irrigation), and migrates downward to subsequently enter groundwater. Concurrent with tritium's release to the vadose zone, its daughter isotope, helium-3, begins to build up in the vadose zone and/or the underlying groundwater at the rate of tritium decay. The helium-3 then diffuses away from its source and migrates toward the surface. Helium-3, thus, acts as a non-reactive tracer for tritium.

Because of similarities in the historical use of the 618-10 and the 618-11 burial grounds, the possibility existed that a tritium plume, similar to that present at the 618-11 site, was present beneath and downgradient of the 618-10 site. A soil-gas investigation for helium isotopes and volatile organic compounds was conducted around the perimeter of 618-10 burial ground during September 2002 to determine if a tritium plume originated from the burial ground and to assist in choosing locations for two new groundwater monitoring wells. Soil-gas sampling points were installed and soil-gas samples were collected and analyzed for helium isotopes and volatile organic compounds. The results of the soil-gas investigation are presented here.

Historical information on the 618-10 burial ground (originally named the 300 North Solid Waste Burial Ground) is presented in the *Technical Baseline Report for the 300-FF-2 Operable Unit* (BHI-00012). The 618-10 burial ground is located ~4 miles northwest of the 300 Area (see Figure 2.2-2). The burial ground was operated between 1954 and 1963 and received a wide variety of solid, dry, radioactive waste. There is no evidence of significant quantities of liquid waste being placed in the burial ground, although small amounts of various liquid waste may have been included with the solid materials. Also, several range fires occurred at the burial ground during which significant quantities of water may have been applied to the ground surface. In 1982, during stabilization of the burial ground surface, a black, oily substance was noted. However, no further characterization of this substance was conducted.

The locations of the soil-gas survey sampling points are shown in Figure 3.3-25. Sampling points were installed at a depth of ~6 meters below ground surface using a GeoProbe direct push system. The 14 sample locations chosen for the survey were intended to detect helium-3 in soil gas near the potential source and in adjacent areas downgradient of the burial ground. One location upgradient of the burial ground was included to provide background levels of the targeted parameters for the soil-gas samples. Six soil-gas locations were selected for the sampling of volatile organic compounds (see Figure 3.3-25).

The result of the analysis identified numerous C10-C13 hydrocarbon compounds and several chlorinated hydrocarbons compounds in all six of the soil-gas samples but they appear to represent problems with sampling methods. Total concentrations ranged from 789 ng/L at sample point C4077 to 3,211 ng/L at sample point C4074. A blank sample from the polyethylene sample tubing (with a similar length to that connecting the soil-gas sampling point to the surface) was obtained after purging with air or nitrogen. Total concentrations of C10-C13 hydrocarbon compounds ranged from 0.931 to 1.849 µg/L. Because soil-gas analyses showed only low levels of volatile chlorinated compounds, they are probably not of concern for routine monitoring in groundwater.

The volatile chlorinated compounds carbon tetrachloride (2.9 to 28.2 ng/L), trichloroethene (4.1 to 82.7 ng/L), and tetrachloroethene (4.5 to 241.8 ng/L) were found in the soil-gas samples. Analysis of the tubing blank did not identify any of these volatile chlorinated compounds. The lowest concentration of these compounds consistently occurred at sampling point C4085 located along the southwest corner of the burial ground (see Figure 3.3-25) and the highest concentrations occurred at sampling points C4074 and C4077, located along the southeast corner of the burial ground. The result of the soil-gas analysis for volatile chlorinated compounds failed to provide compelling evidence to recommend locations for two additional groundwater monitoring wells in the vicinity of the 618-10 burial ground.

The use of helium-3/helium-4 ratios in soil gas can be used to detect tritium contamination. This method was used at the 618-10 burial ground in September 2002 to help determine the best location for two new groundwater monitoring wells. An exact location could not be conclusively determined from test results. However, one new monitoring well will be installed downgradient from the burial ground and a second new monitoring well will be installed farther west to monitor the westernmost part of the burial ground to help detect tritium.

Soil-gas samples were collected and analyzed for helium isotopes following procedures established previously during investigations at the 618-11 burial ground (PNNL-13675). The helium-3/helium-4 ratios did not indicate high levels of tritium along the perimeter of the 618-10 burial ground. The highest observed helium-3/helium-4 ratio was 1.178 (ambient air ratio is 1.000). By comparison, helium-3/helium-4 ratios observed in soil gas near the 618-11 burial ground were much higher – up to 62 near the suspected buried sources and up to 1.68 over the tritium groundwater plume that extends downgradient from that burial ground.

Slightly elevated helium-3/helium-4 ratios were present at two locations (C4077 and C4078) along the southeast perimeter 618-10 burial ground fence, along the presumed downgradient flow path from the tritium source. The elevated ratios at these sampling sites could represent helium-3 enrichment from a tritium source in the vadose zone and/or tritium in the underlying groundwater. However, the elevated ratios are only slightly higher than the uncertainty range associated with the analytical results.

The cause for the slightly elevated helium-3/helium-4 ratios at the two locations cannot be conclusively determined on the basis of the soil-gas data alone. One possibility is a release of tritium gas from buried irradiated material. If that is the case, it is occurring at a much smaller scale than at the 618-11 burial ground. A second possibility is that helium-3 has migrated upward from an underlying tritium plume in the groundwater from 200 East Area sources.

There appears to be little contribution of volatile organic compounds to the soil gas at the 618-10 burial ground based on the volatile chlorinated organic compounds results on the soil-gas samples. It was not possible to determine whether there were hydrocarbon compounds present in the soil gas because of the pervasiveness of contamination from the sample tubing.

One additional monitoring well will be installed downgradient from the sampling point with the maximum helium-3/helium-4 in soil gas (C4078). A second monitoring well will be installed farther west to monitor the westernmost part of the burial ground for possible future releases.

3.3.9 Standardized Stratigraphic Nomenclature

S. P. Reidel

The Groundwater Protection Program, formerly the Groundwater/Vadose Zone Integration Project, has as one of its main goals the integration of vadose zone and groundwater activities. Historically, the stratigraphy of the vadose zone sediment at the Hanford Site has been described by several nomenclature schemes such that there has been little consistency in naming and correlating the vadose zone sediment. In fiscal year 2002, the Groundwater Protection Program oversaw the publication of a standardized stratigraphic nomenclature for post-Ringold Formation deposits. The standardized nomenclature was needed to support and integrate hydrogeologic characterization and performance assessment modeling at the Hanford Site. This section summarizes the documentation of the standardized nomenclature.

A standardized nomenclature for post-Ringold Formation deposits was introduced to provide consistency in naming and correlating the vadose zone sediment at the Hanford Site. Sedimentary units formerly known as the Plio-Pleistocene unit and the early "Palouse" soil are now referred to as the Cold Creek unit.

Most projects completed at the Hanford Site through the 1990s covered small areas and were done by various contractors with their own geologic staff. This resulted in site-specific nomenclatures without regard to regional relationships or variations. The numerous site-specific nomenclatures resulted in confusion and made it difficult to compare the stratigraphy encountered across the Hanford Site. For this reason, in fiscal year 2002, DOE developed a consistent, standardized nomenclature for late Pliocene- and younger-age sediments found at the Hanford Site (DOE/RL-2002-39). Figure 3.3-26 shows the new nomenclature and compares it to the Hanford Site-wide nomenclatures developed by DOE in 1988 and modifications widely used in the 1990s.

Attempts to unify the various Hanford Site stratigraphic nomenclatures into a consistent, standardized nomenclature began in the 1980s and quickly progressed in the 1990s and 2000s as intact samples were collected and various lithofacies were recognized across the Hanford Site (e.g., Lindsey et al. 1994). As a result, an informal nomenclature began to be developed by geologists that was widely but not universally adopted. The new standardized nomenclature represents a consensus that was reached by Hanford Site geologists during fiscal year 2002. Figure 3.3-27 shows the relationship between the new nomenclature and the older informal one that was in general use for the Hanford Site prior to 2002.

Table 3.3-1. Seasonal Precipitation for the Hanford Site, 1994 Through 2002

	Precipitation (mm)				
Year	Total	Winter[a]	Spring[b]	Summer[c]	Autumn[d]
1995	313	106	83	30	69
1996	310	126	48	5	96
1997	162	138	35	18	57
1998	164	69	28	22	42
1999	95	52	10	24	19
2000	205	58	58	18	56
2001	172	35	43	36	55
2002	NA	48	16	21	NA
Long-Term Average	172	66	38	25	45

(a) December of previous year plus January and February of current year of interest.
(b) March – May of current year of interest.
(c) June – August of current year of interest.
(d) September – November of current year of interest.
NA = Not available..

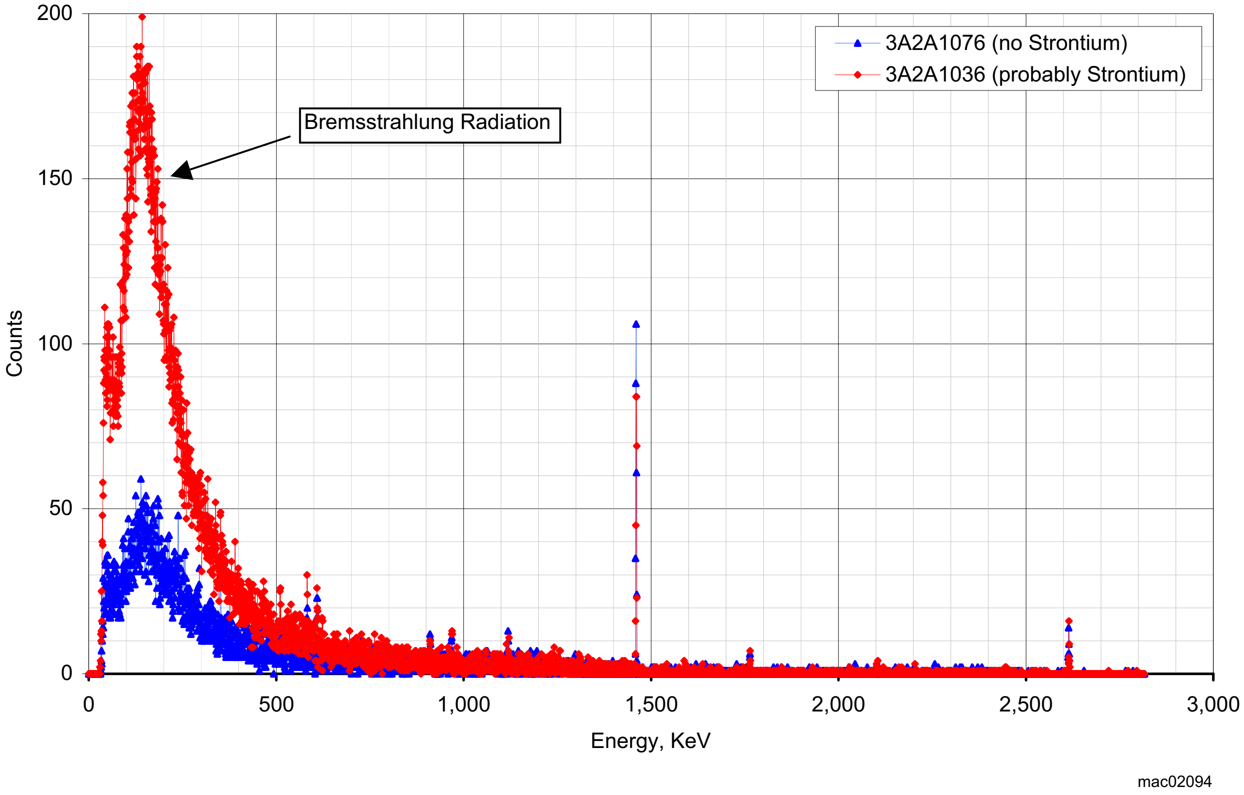


Figure 3.3-1. Gamma Photon Spectra for an Uncontaminated Portion of a Borehole (blue) and a Strontium-90 Contaminated Portion of a Borehole (red). The red spectrum shows bremsstrahlung radiation at low energies.

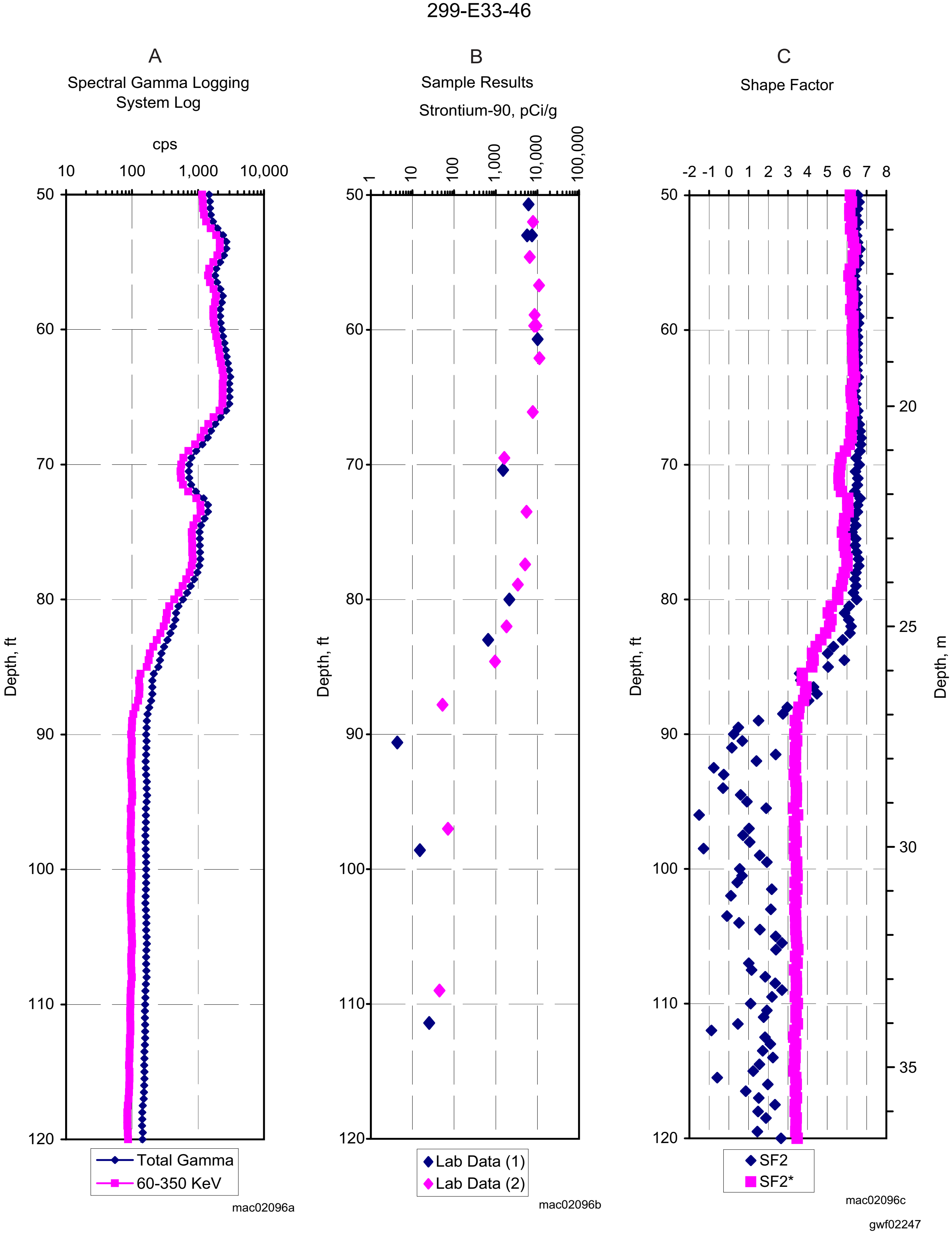


Figure 3.3-2. Gamma Spectra from Borehole 299-E33-46. A = Total gamma and 60 to 350 keV gamma versus depth; B = laboratory analyses of strontium-90 versus depth; C = shape factors versus depth. See text for discussion.

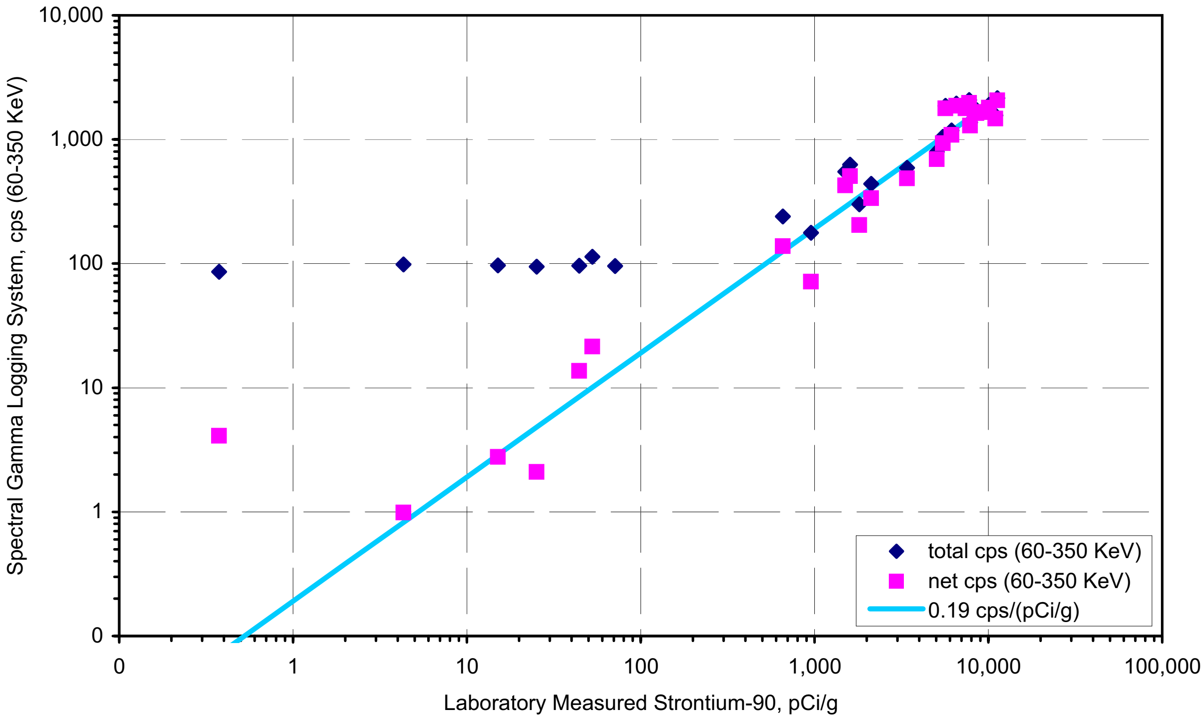


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Figure 3.3-3. Total Gamma Counts and Net Gamma Counts in the 60- to 350-keV Range as a Function of Strontium-90 Concentration

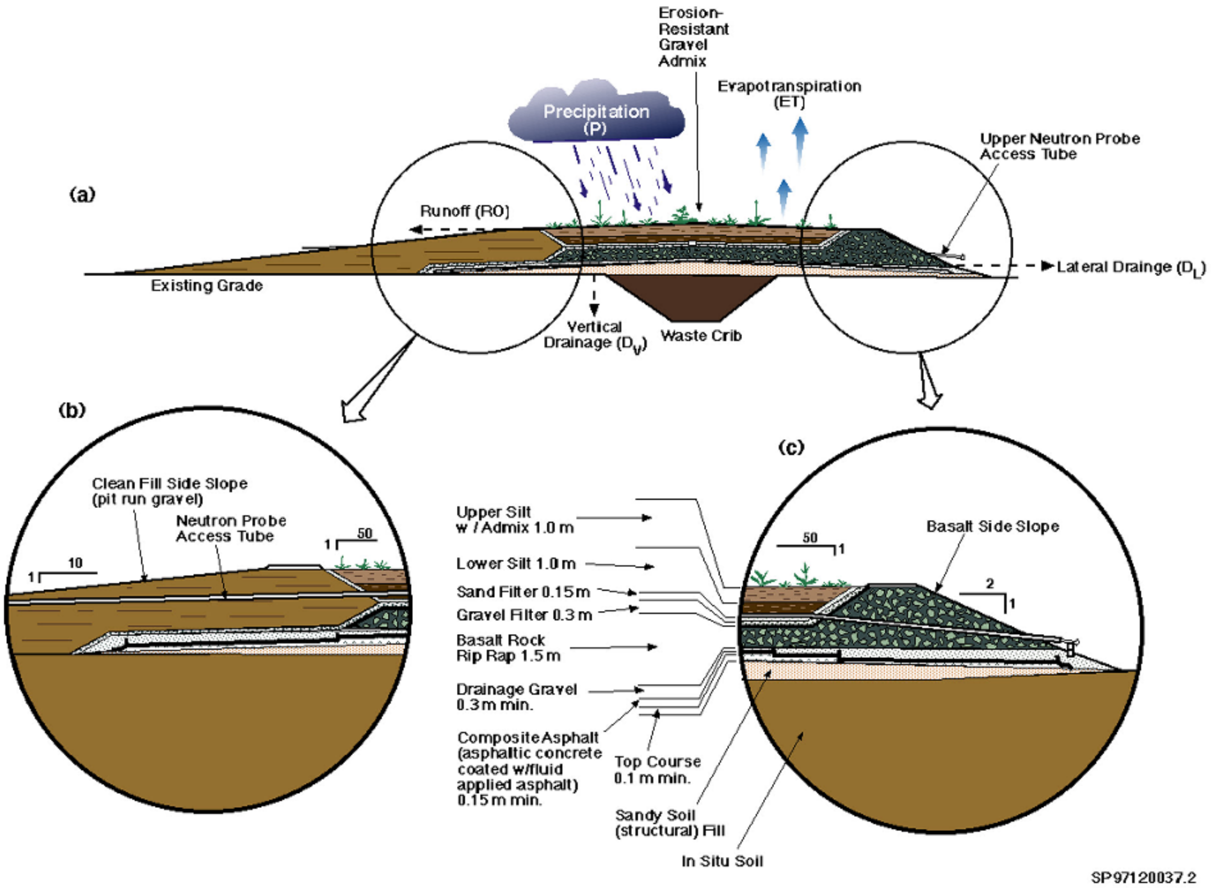

Figure 3.3-4. Cross Section of the Hanford Site Prototype Barrier Showing (a) Interactive Water Balance Processes, (b) Gravel Side Slope, and (c) Basalt Riprap Side Slope

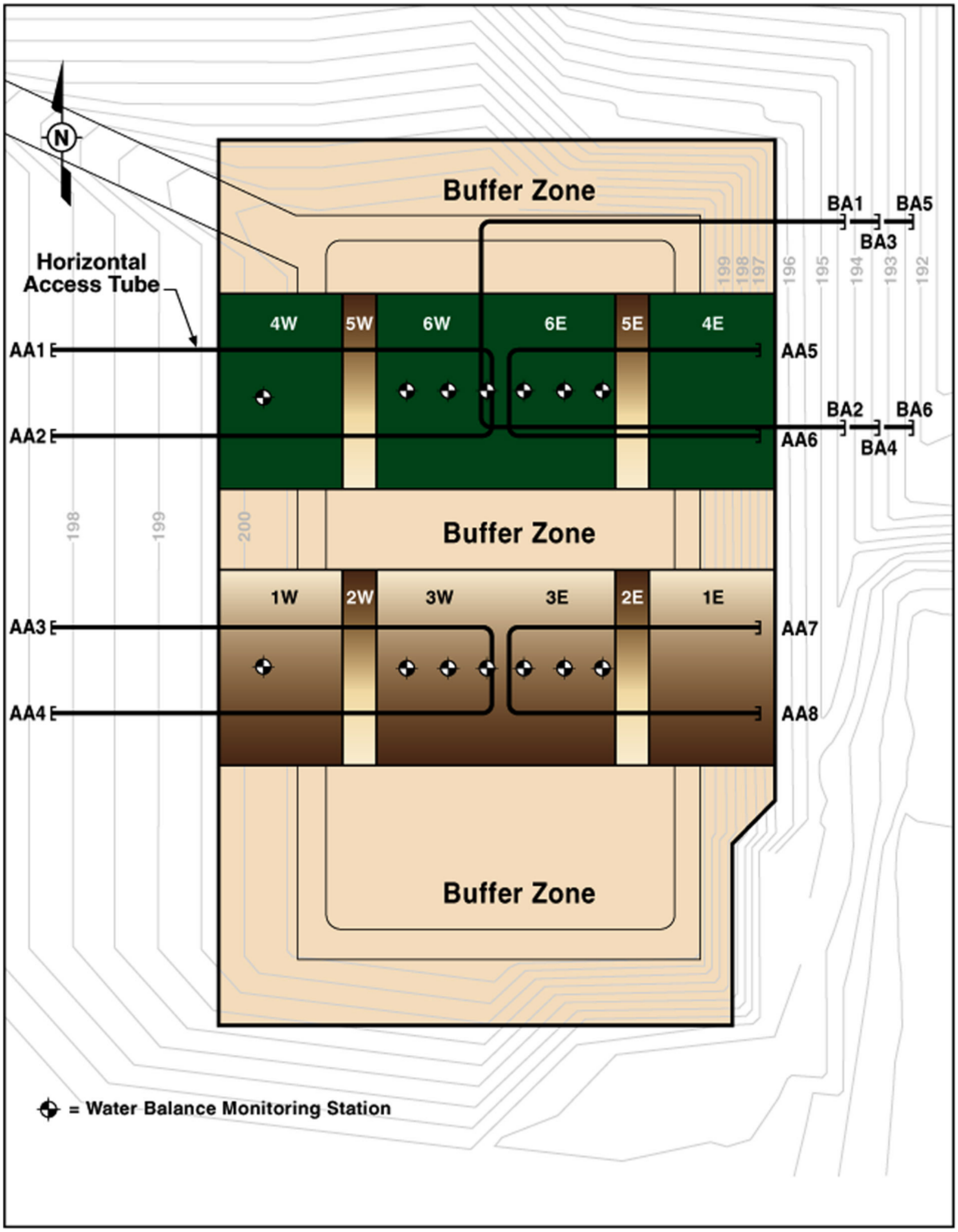

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Figure 3.3-5. Plan View of the Hanford Site Prototype Surface Barrier. Twelve individual collection areas for the irrigated (north) and non-irrigated (south) sides of the barrier are represented by the designations 1W through 6E. Water-balance monitoring stations are shown for each test area as well as horizontal neutron probe access tubes for monitoring below the silt loam and asphalt layers. Contour interval is 0.5 meter.

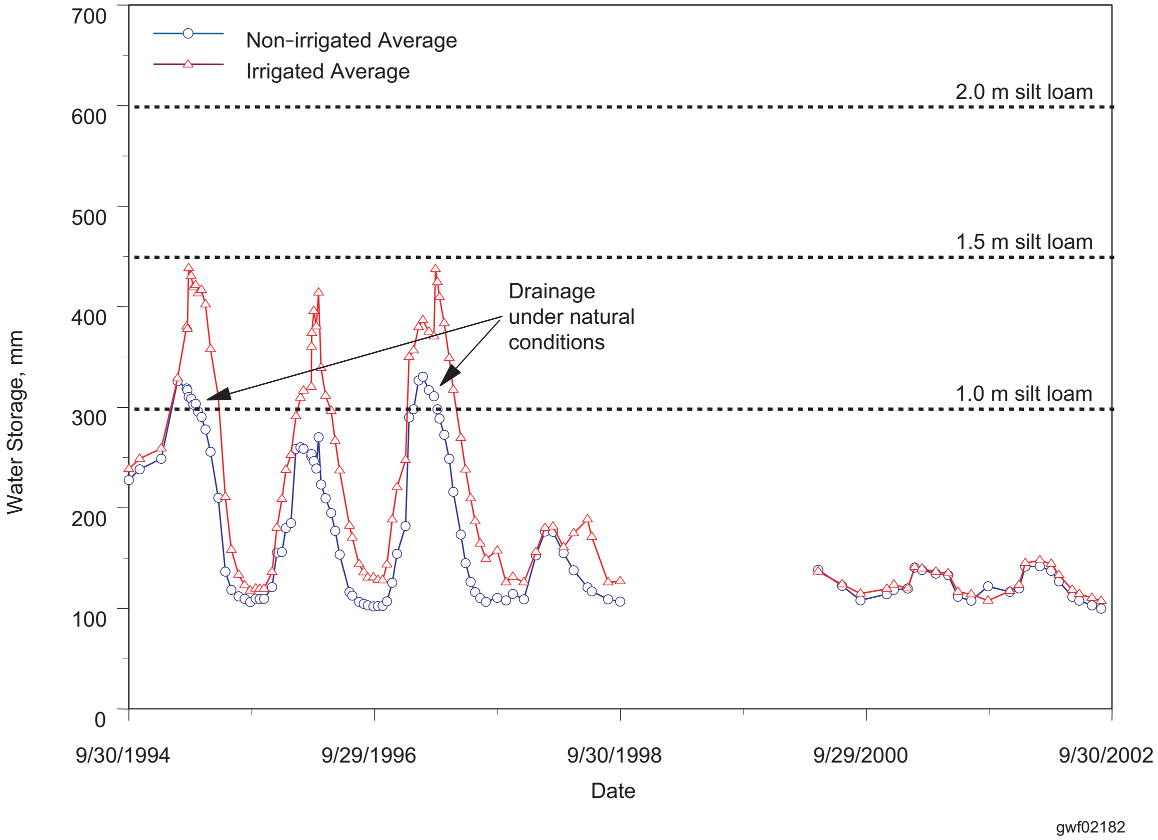

Figure 3.3-6. Temporal Variation in Mean Soil-Water Storage at the Hanford Site Prototype Surface Barrier Between September 1994 and September 2002. Monitoring after September 1998 was interrupted for more than a year and resumed in 2000. Horizontal dashed lines represent estimated storage limits for barriers with 2-, 1.5-, and 1.0-meter-thick silt-loam surfaces.

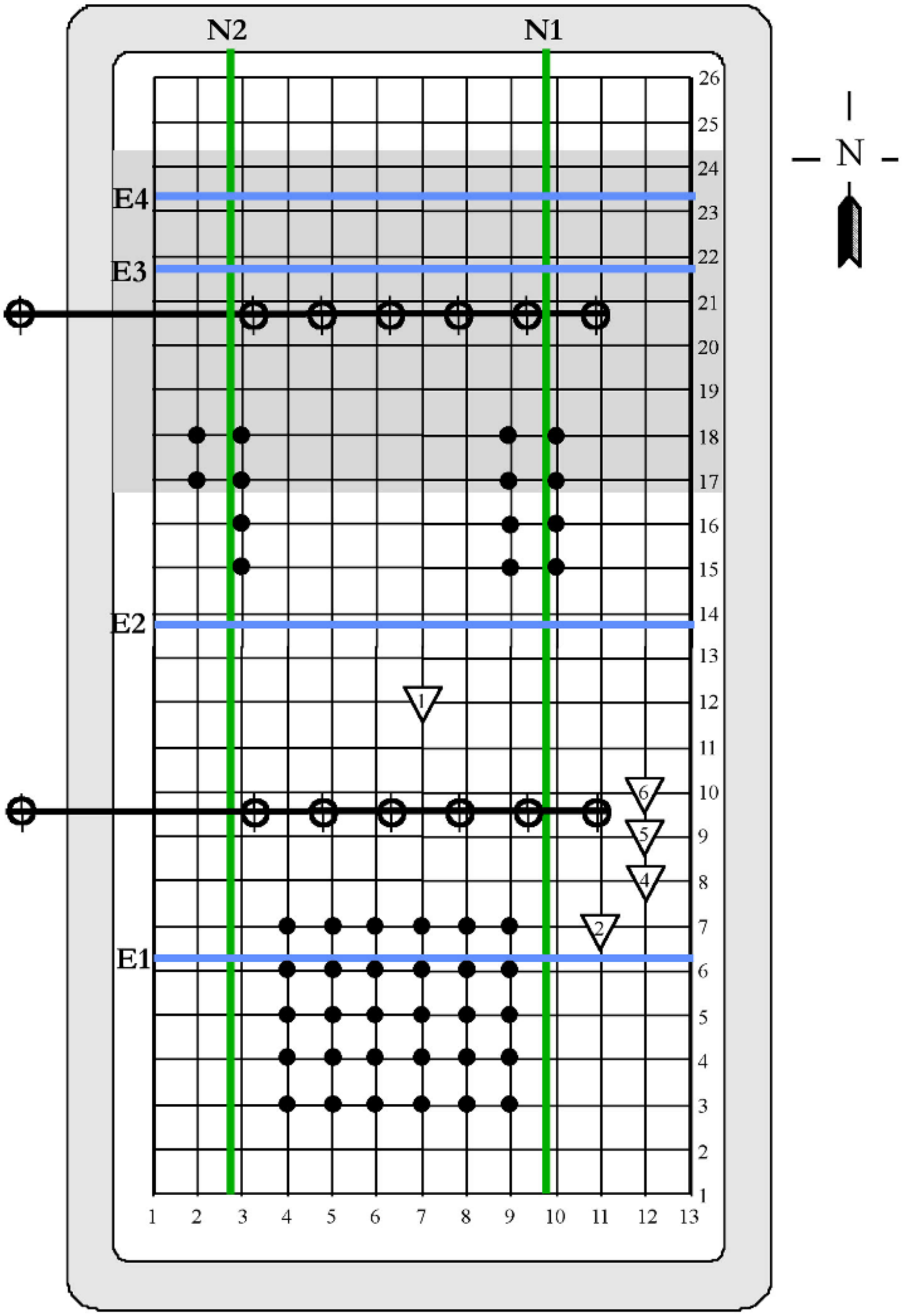

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Figure 3.3-7. Plan View of Barrier Surface Showing 3- by 3-Meter Grid on Which the Geophysical Surveys were Made. Electromagnetic induction measurements could be taken in only a few areas, identified by (•), without interference from buried instruments and cables.

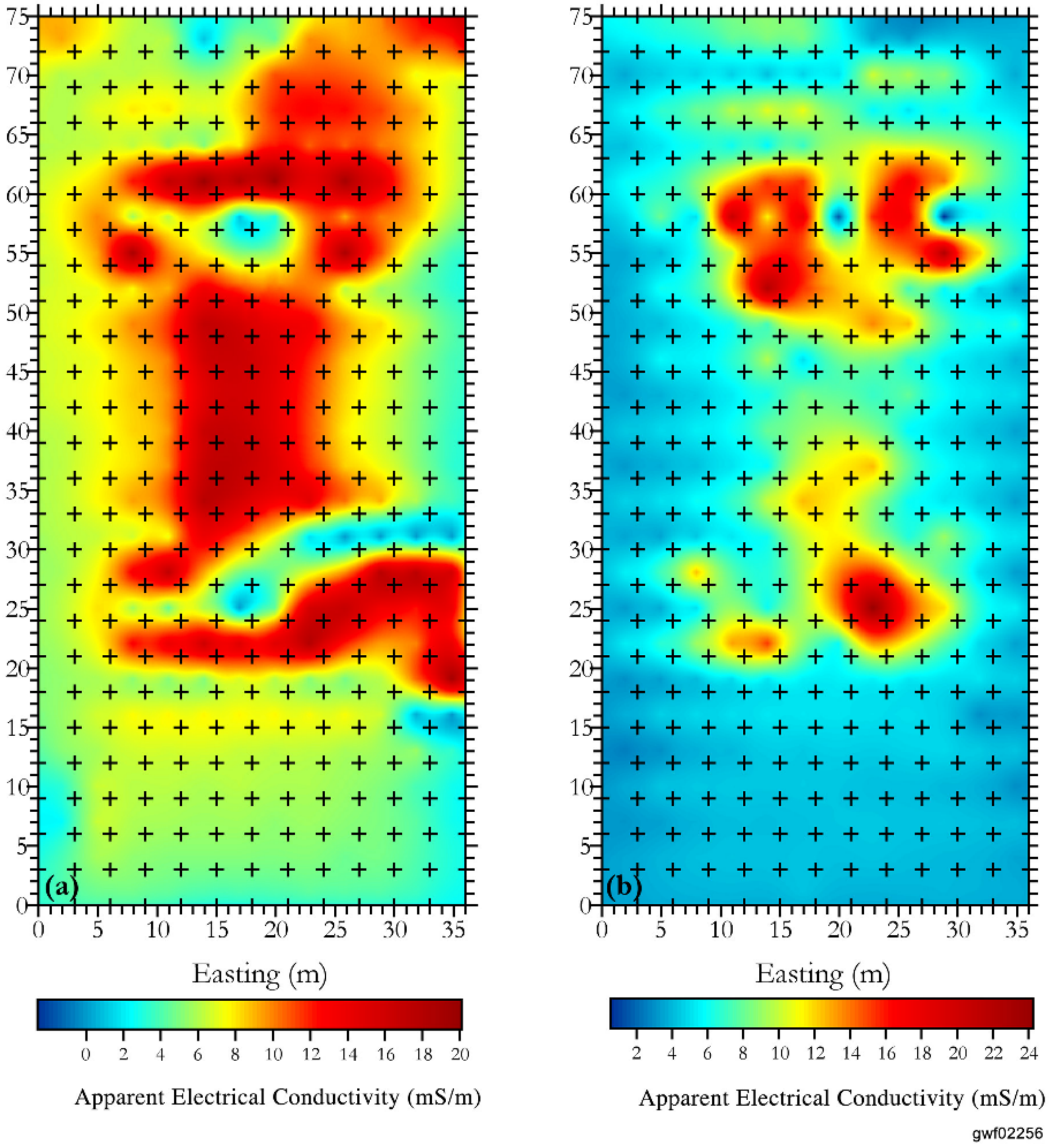

Figure 3.3-8. Comparison of EM-31 Surveys from (a) September 1994 and (b) September 2001

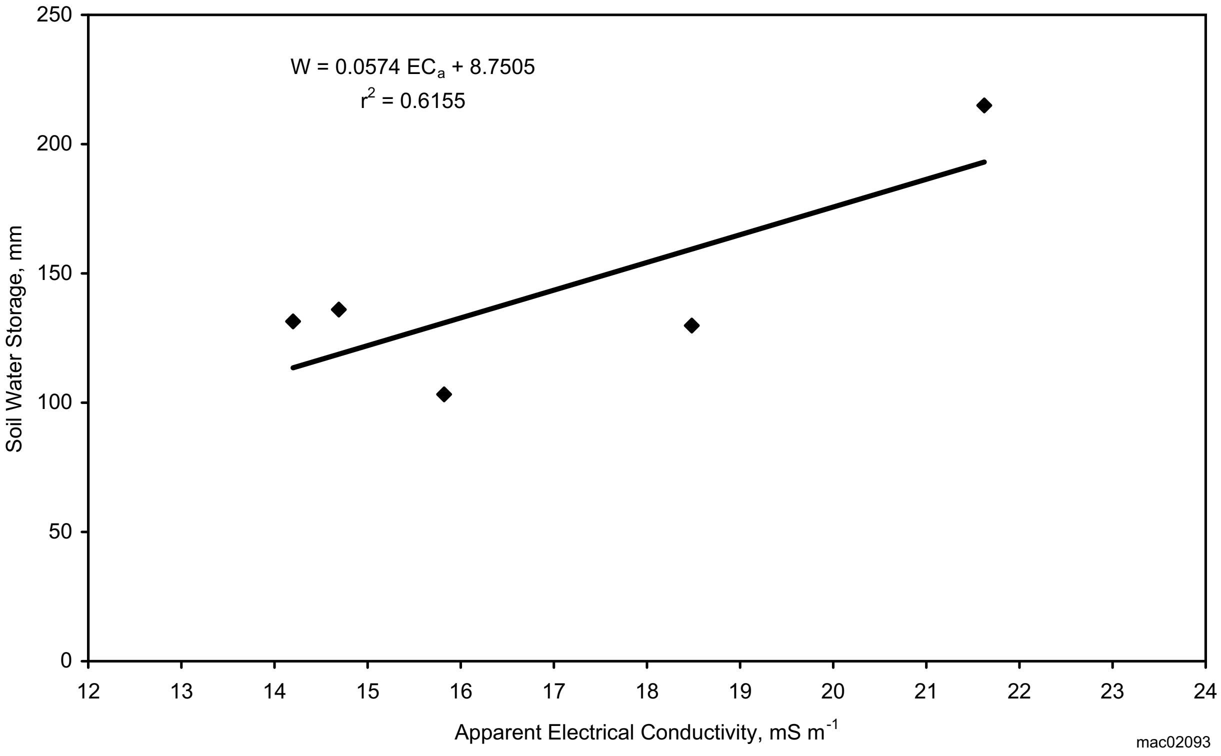

Figure 3.3-9. Relationship Between Soil-Water Storage and Apparent Electrical Conductivity for the South Non-Irrigated Part of the Hanford Surface Barrier

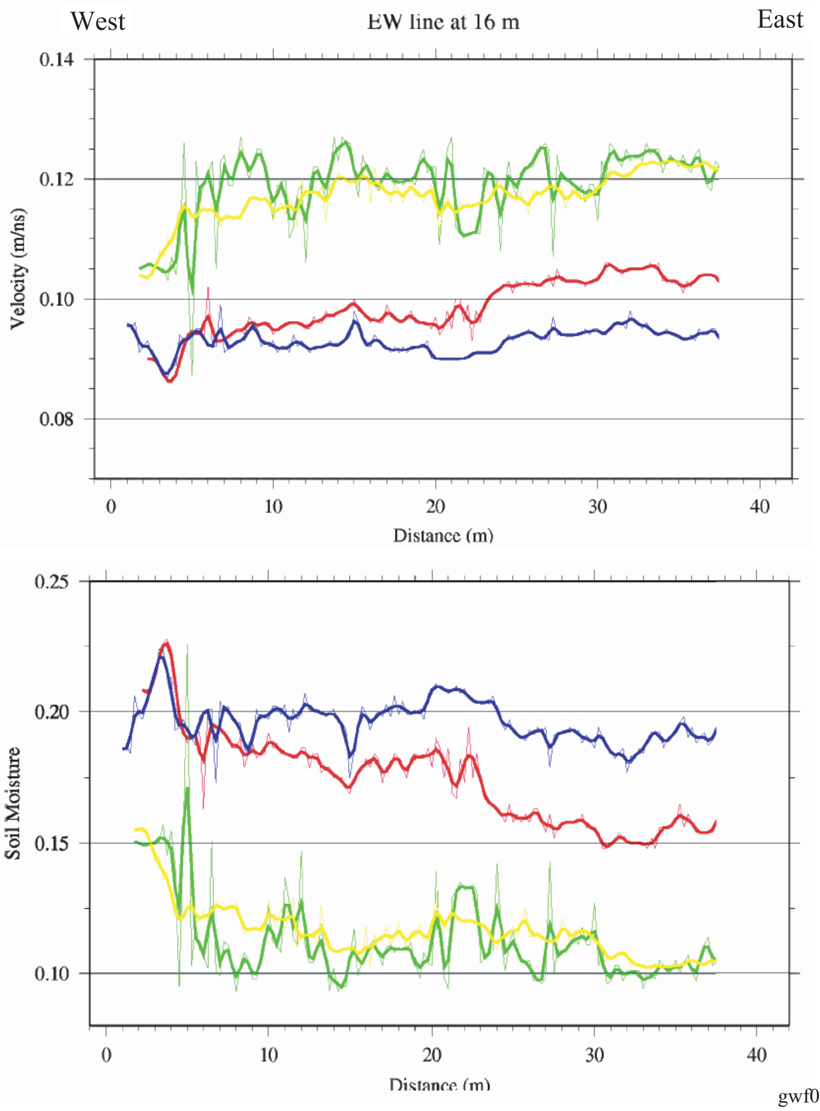

Figure 3.3-10. Electromagnetic Velocity and Soil Moisture Along Transect E1 (a) Velocity Versus Distance and (b) Soil Moisture Versus Distance (March 2001 – red; May 2001 – green; September 2001 – yellow; January 2002 – blue).

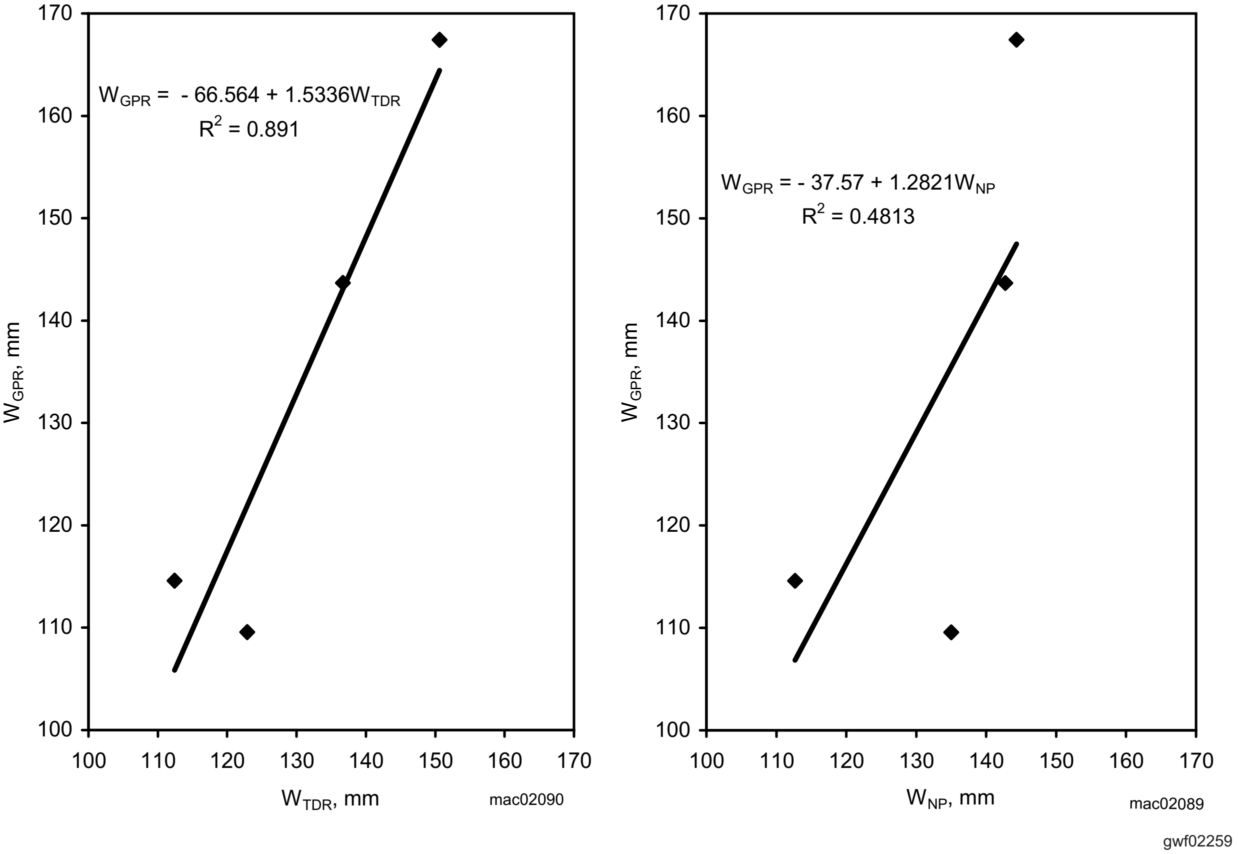

Figure 3.3-11. Relationship Between Water Storage Measured by Ground Penetrating Radar and (a) Time Domain Reflectometry and (b) Neutron Probe. W_{GPR} = Water storage from ground penetrating radar methods; W_{TDR} = water storage from time domain reflectometry methods; and W_{NP} = water storage from neutron probe data.

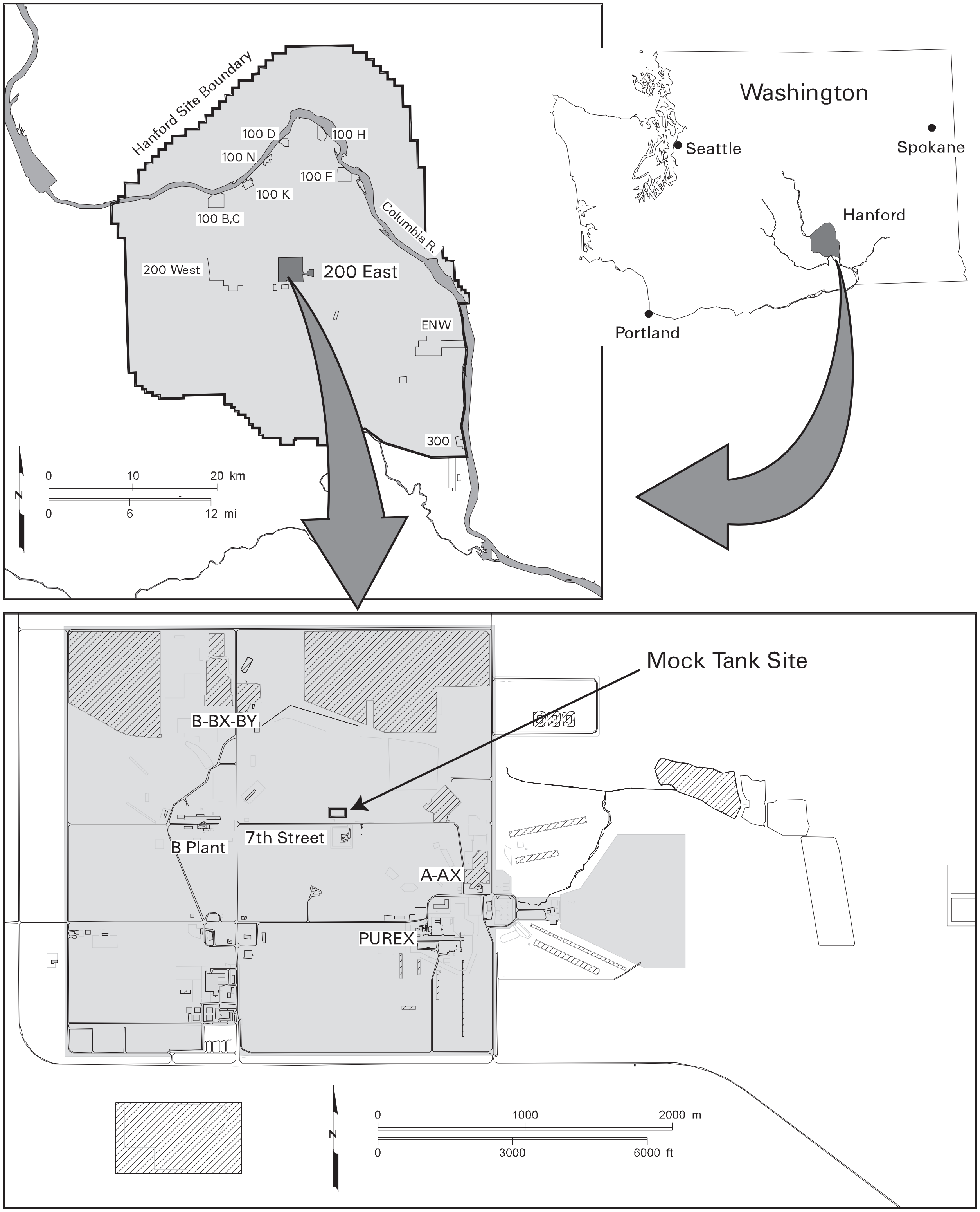

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Figure 3.3-12. Location of the Hanford Site Mock Tank Site

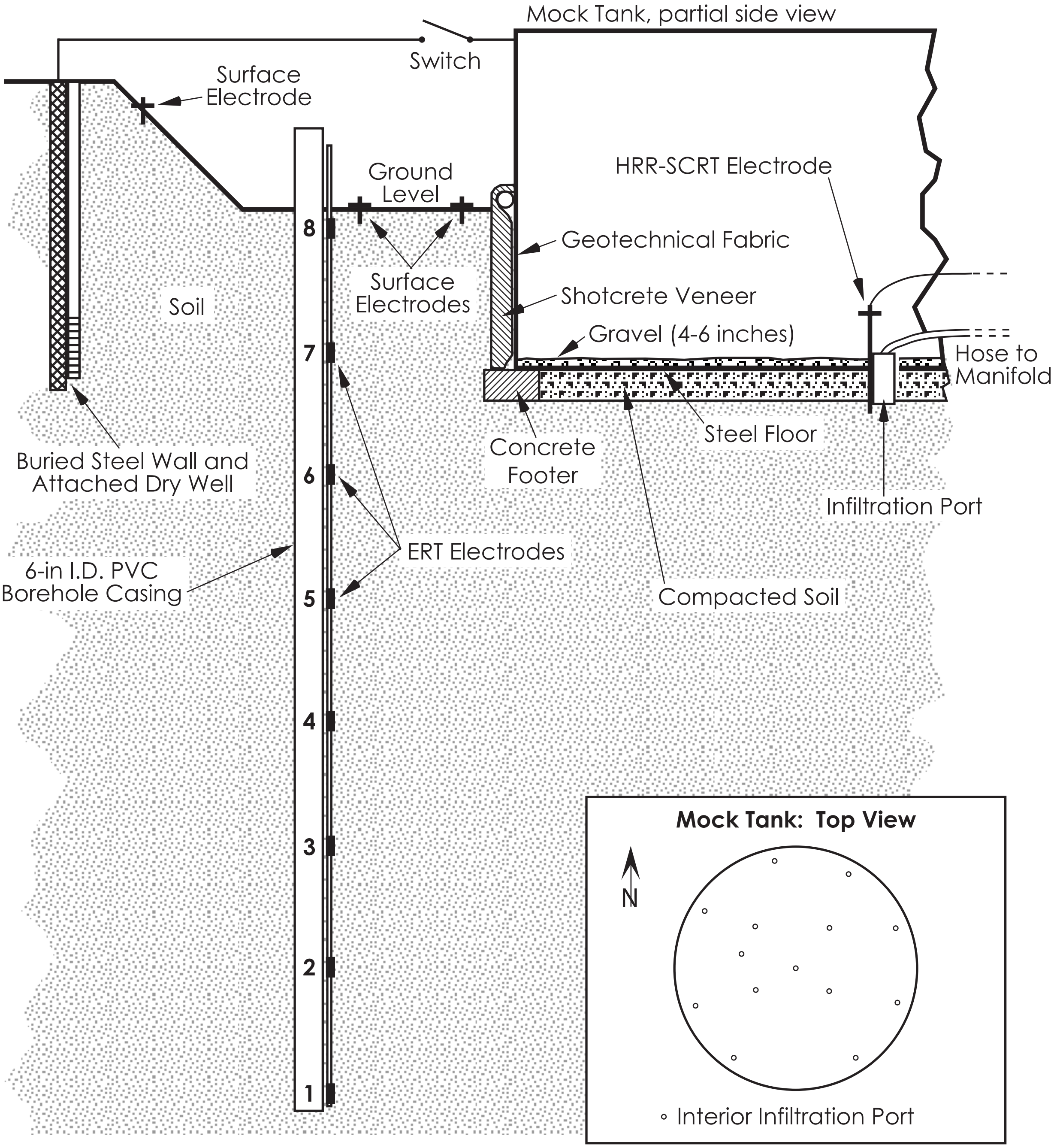

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Figure 3.3-13. Details of Mock Tank Construction in Relation to One of the 1995 Electrical Resistivity Tomography Installations. The mock tank is ~15.2 meters in diameter; the electrical resistivity tomography array extends to ~10.6 meters below ground surface with an electrode every 1.52 meters.

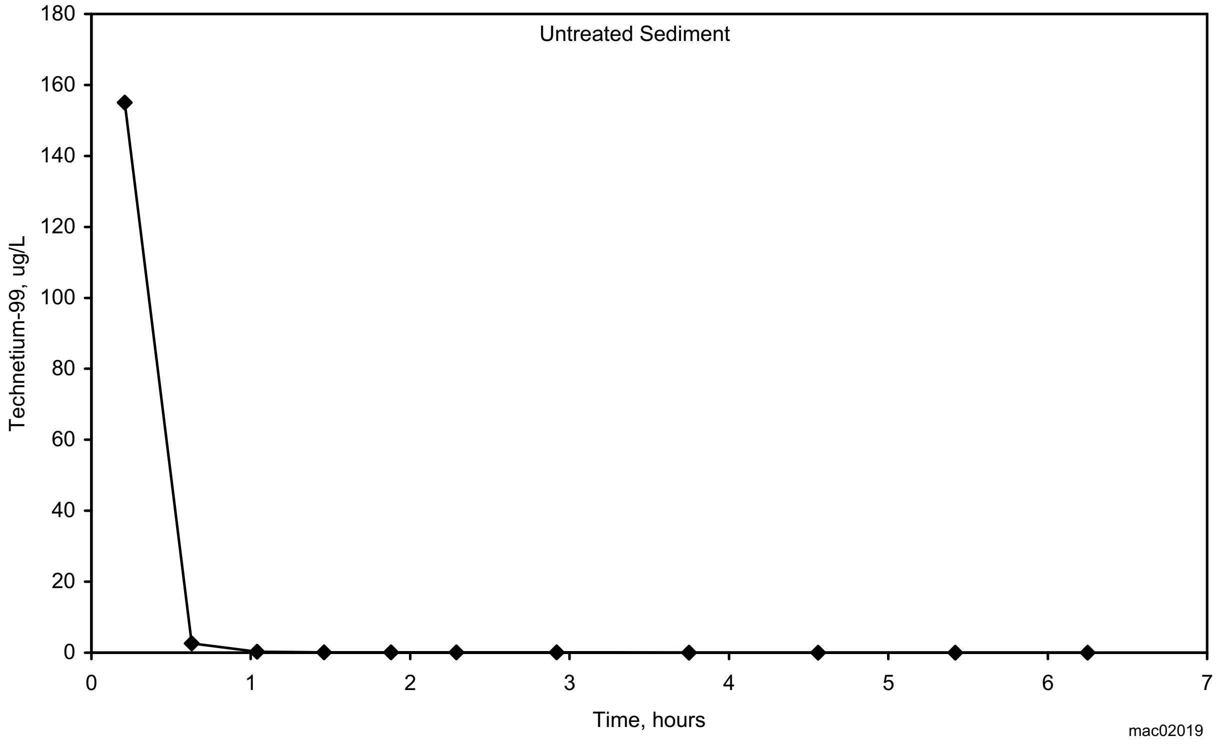

Figure 3.3-14. Release of Technetium-99 from the Untreated Sediment

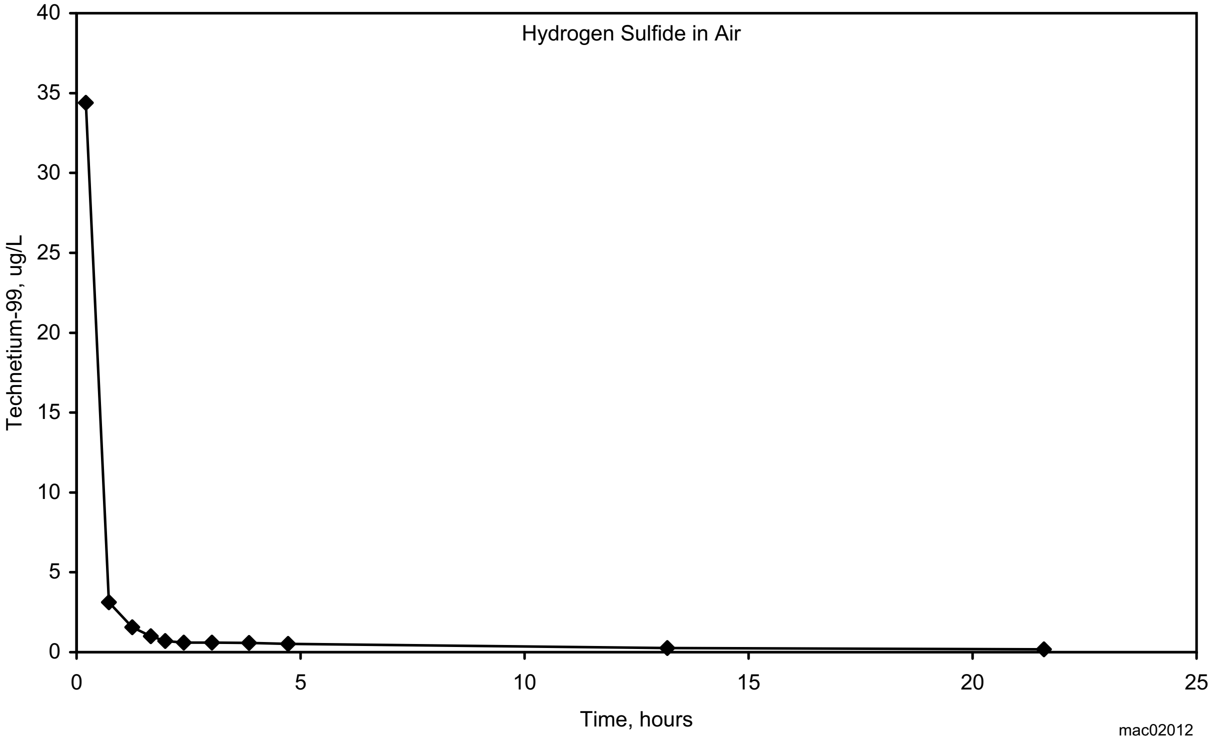

Figure 3.3-15. Release of Technetium-99 During Leaching of the Hydrogen Sulfide/Air Treated Sediment

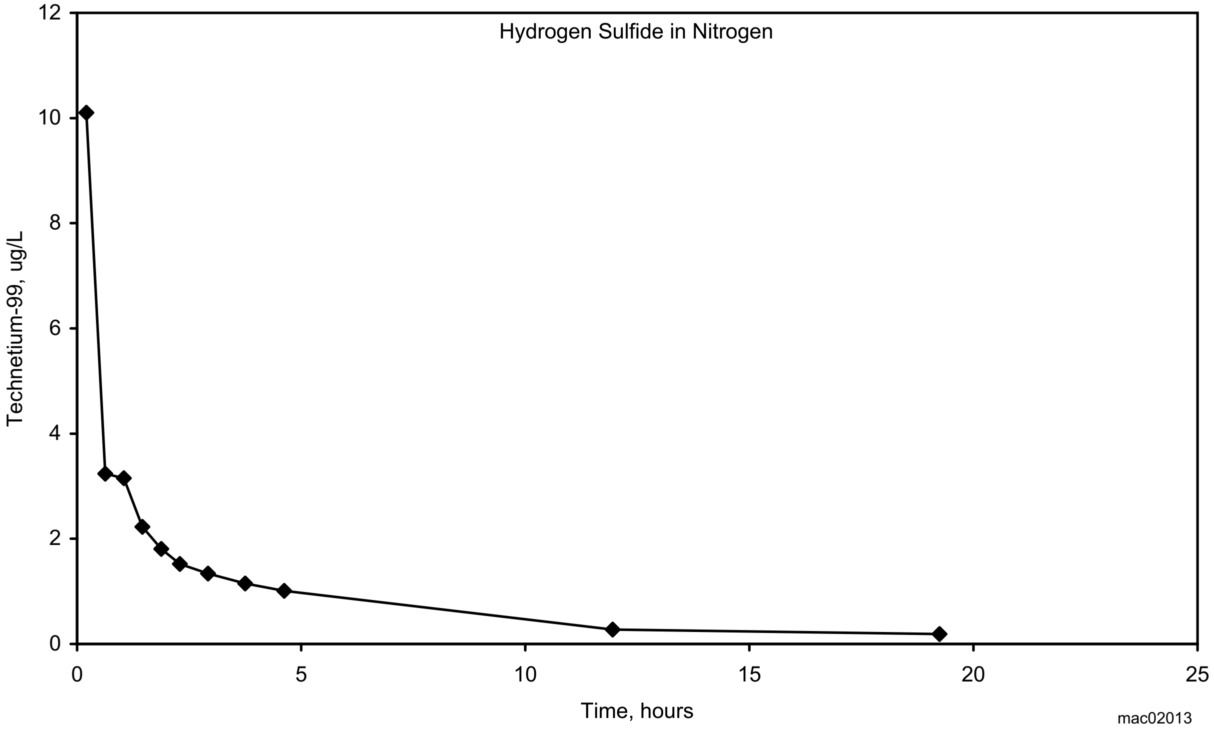

Figure 3.3-16. Release of Technetium-99 During Leaching of the Hydrogen Sulfide/Nitrogen Treated Sediment

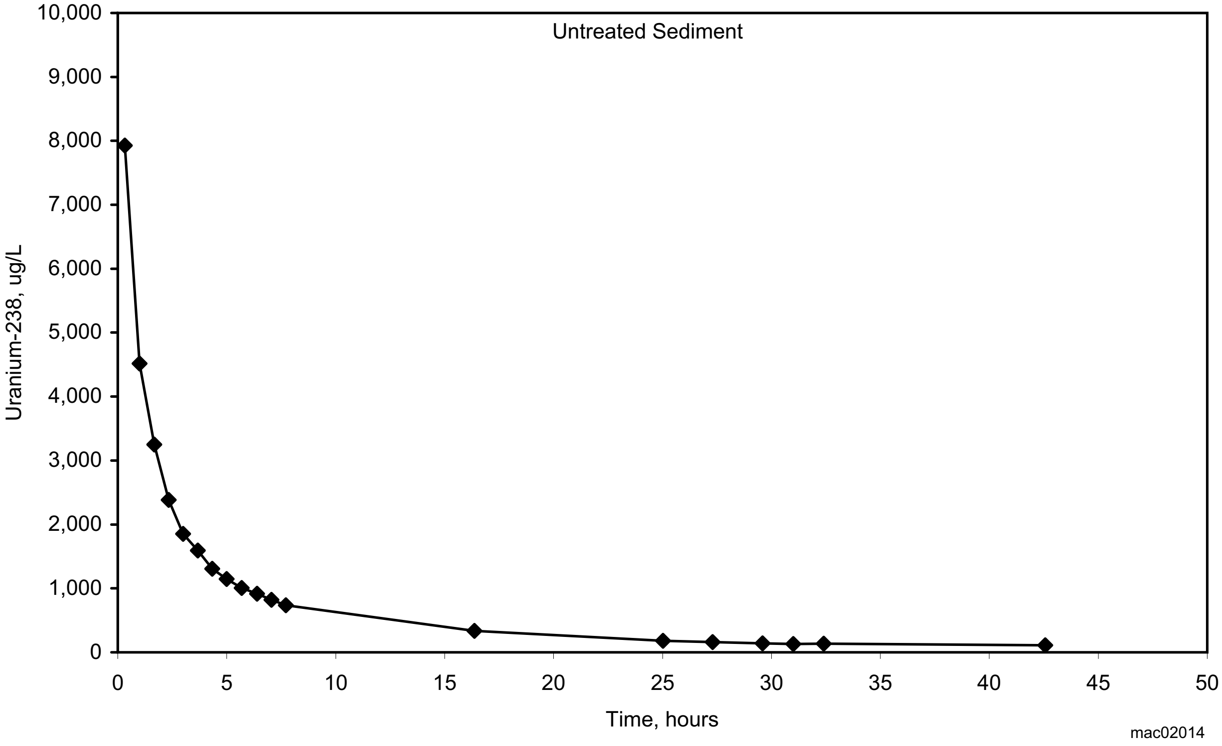

Figure 3.3-17. Release of Uranium-238 from the Untreated Sediment During Water Leaching

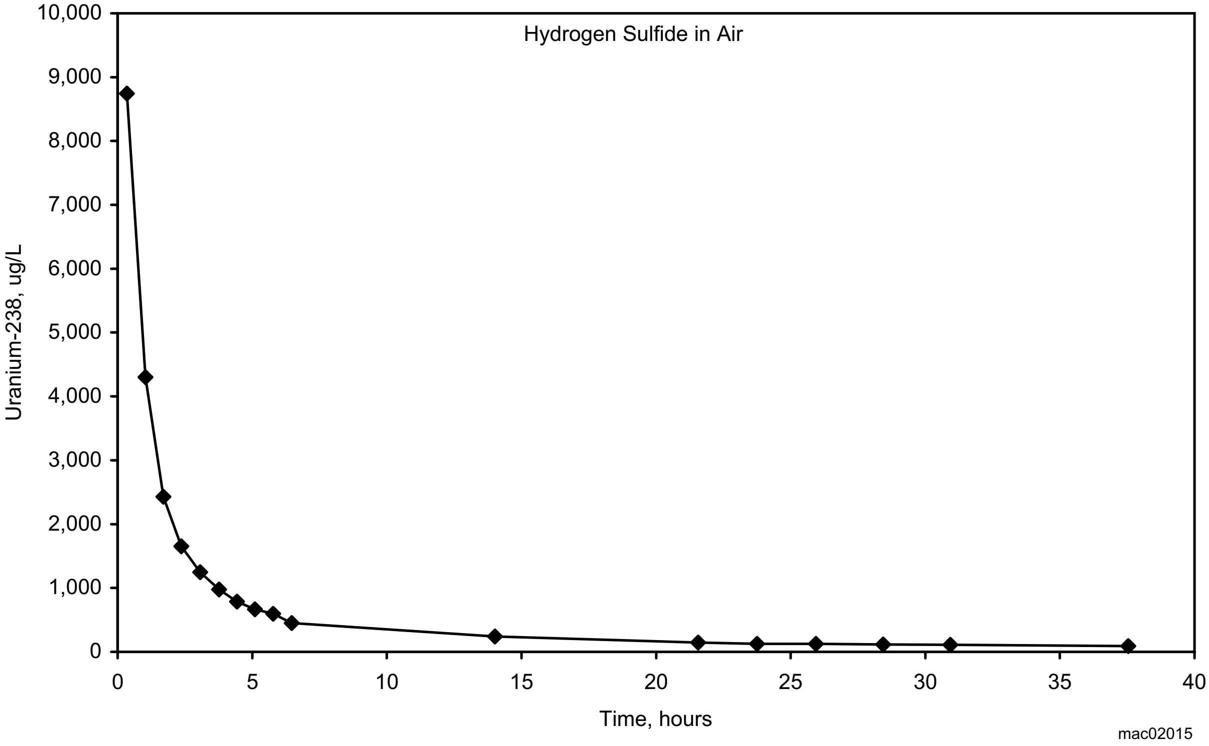

Figure 3.3-18. Release of Uranium-238 During Leaching of the Hydrogen Sulfide/Air Treated Sediment

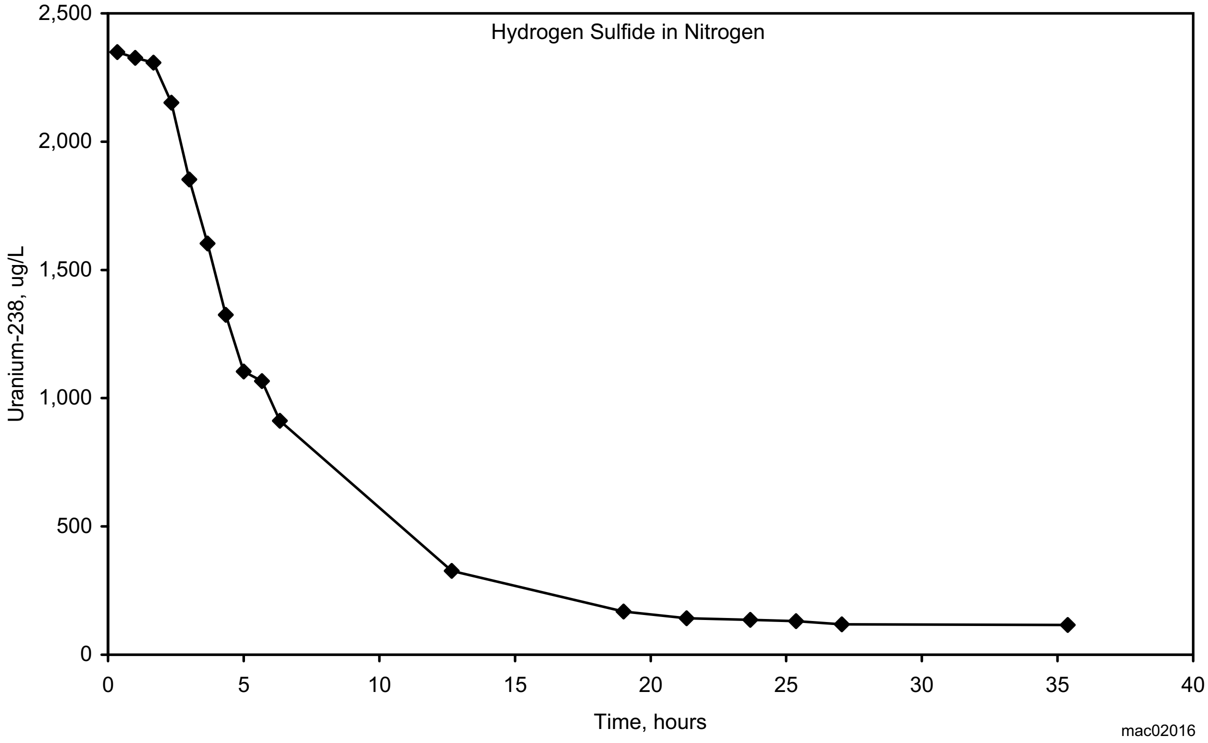

Figure 3.3-19. Release of Uranium-238 During Leaching of the Hydrogen Sulfide/Nitrogen Treated Sediment

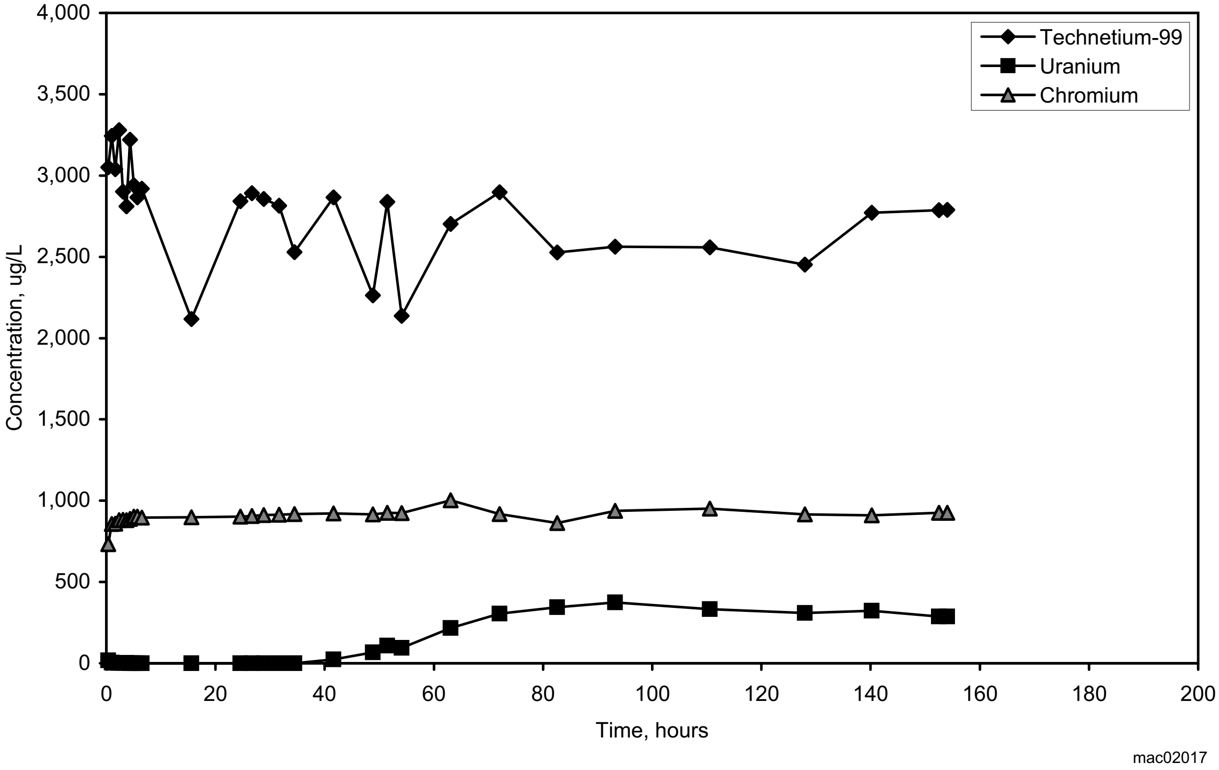

Figure 3.3-20. Concentration of Total Chromium, Technetium-99, and Uranium-238 in the Effluent of the Untreated Sediment Column

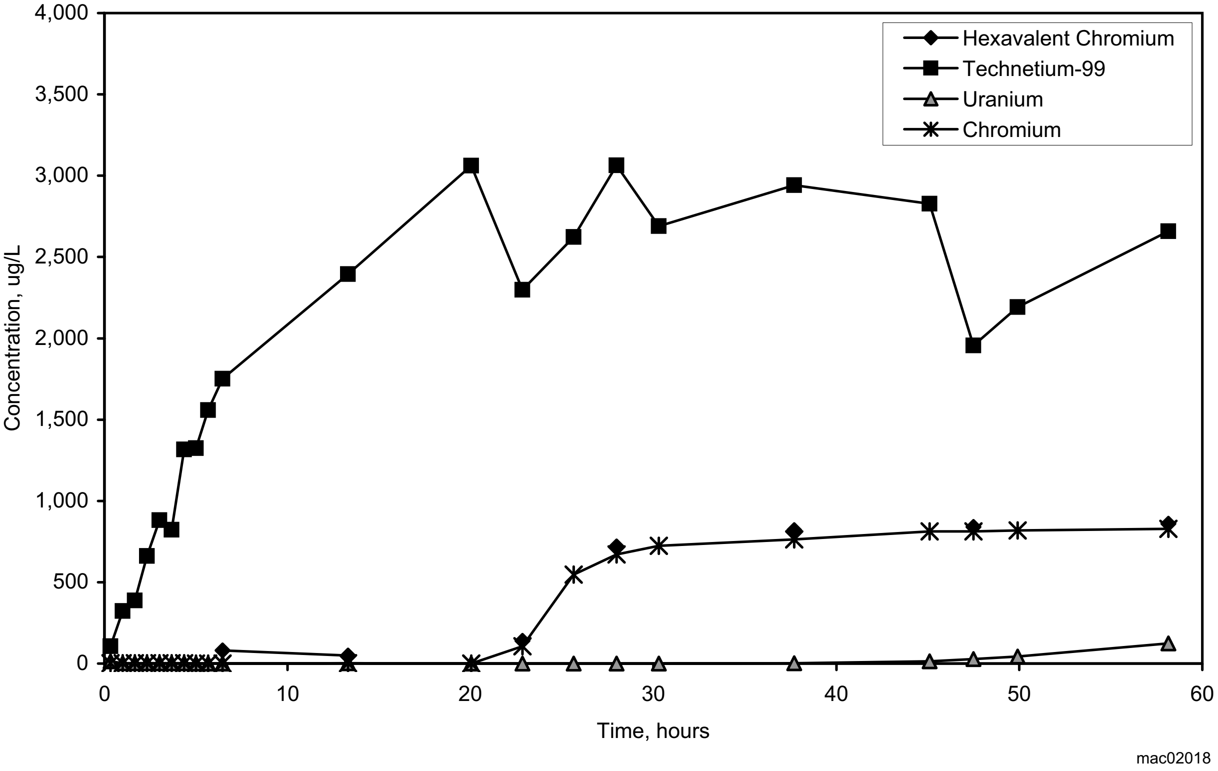

Figure 3.3-21. Concentrations of Chromium (VI), Total Chromium, Technetium-99, and Uranium-238 in the Effluent of the Treated Sediment Column

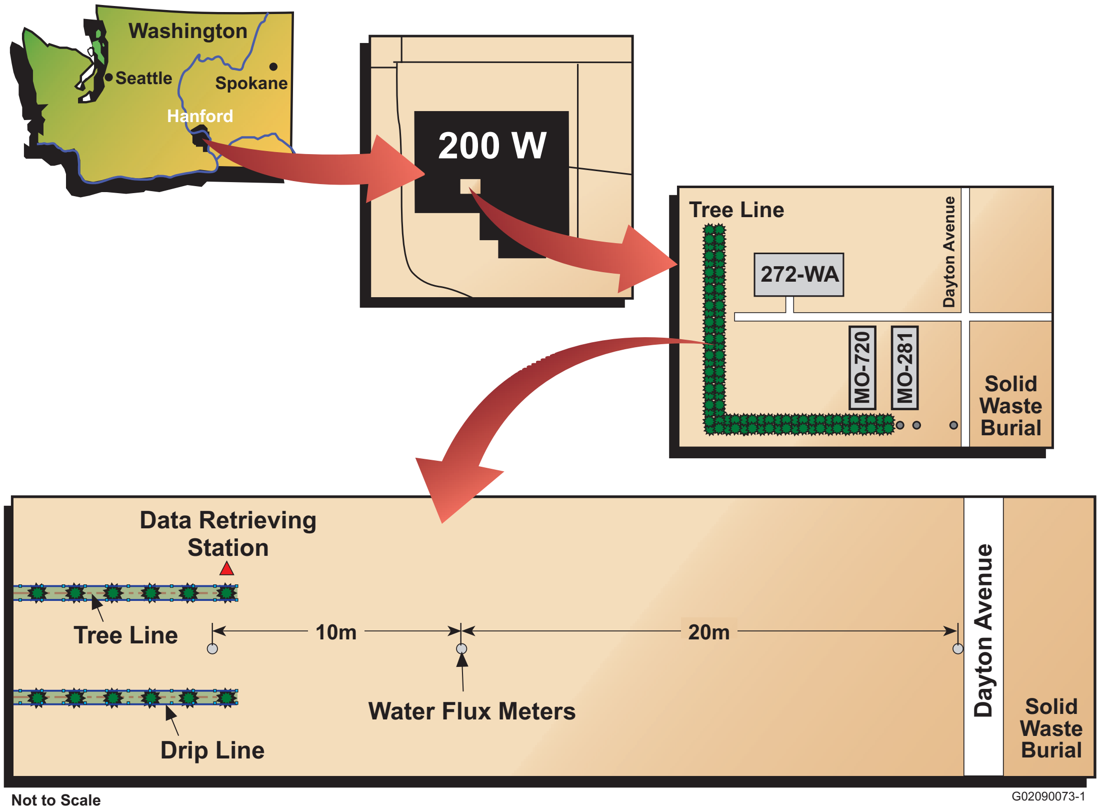

Figure 3.3-22. Location of Windbreak in 200 West Area

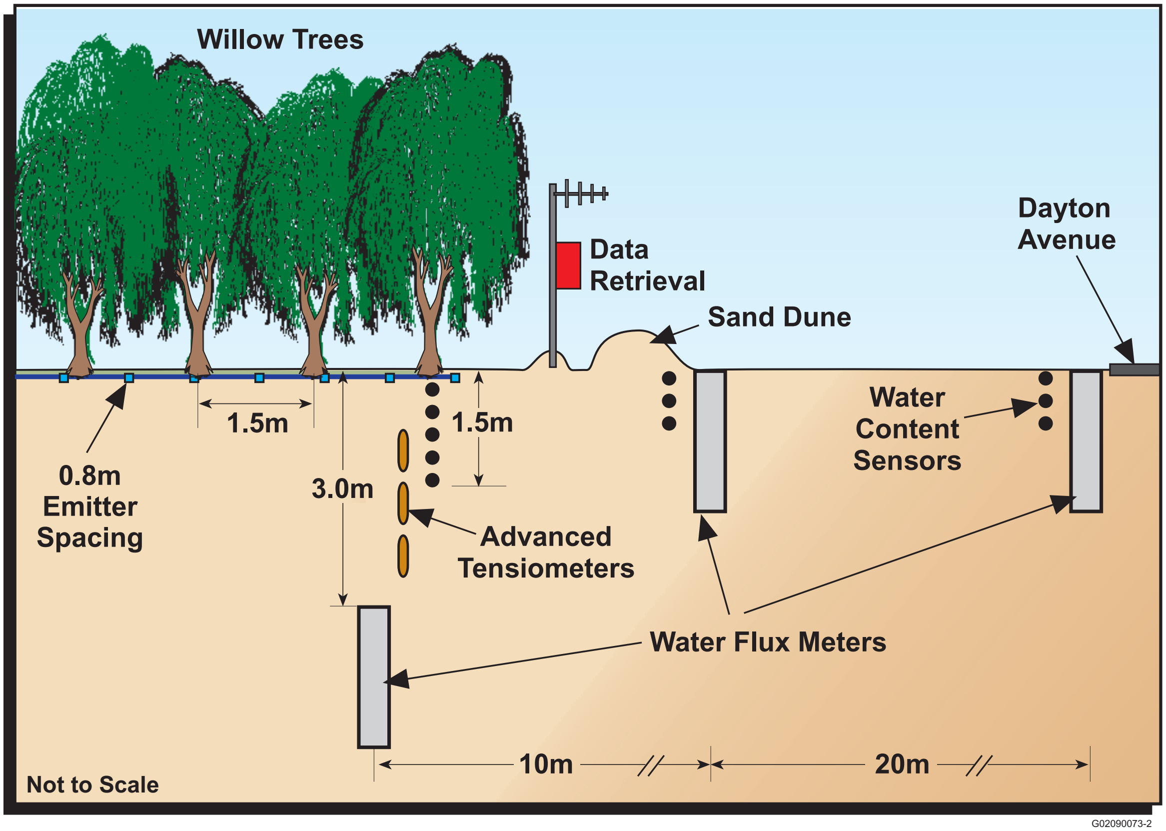

Figure 3.3-23. Cross Section Showing Placement of Sensors at the Tree Windbreak in 200 West Area

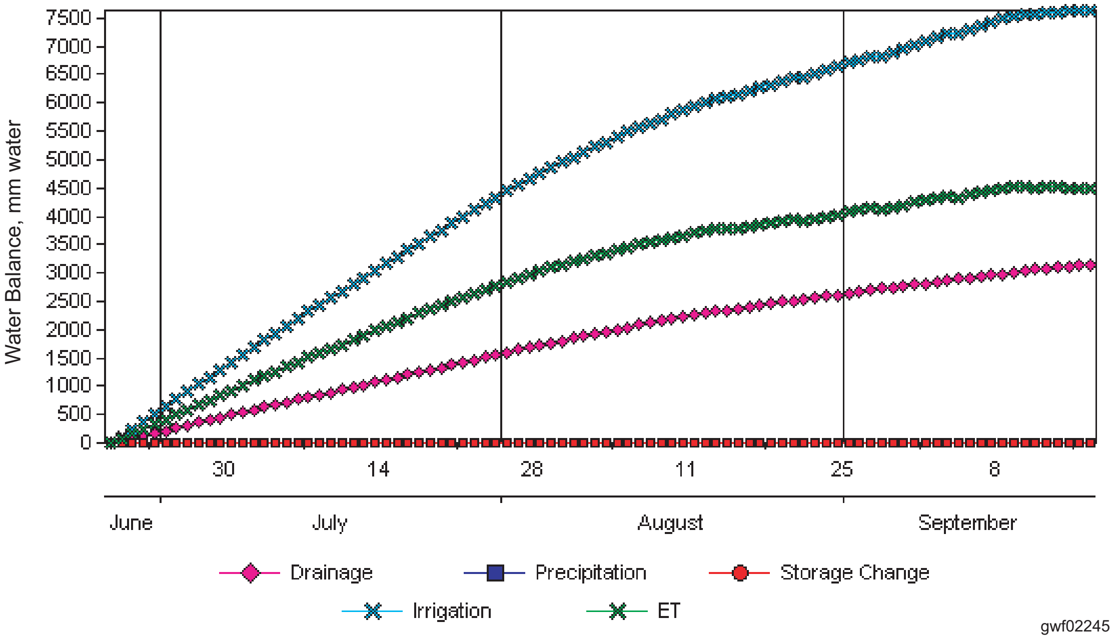

Figure 3.3-24. Water Balance (precipitation, irrigation, storage change, evapotranspiration, and drainage) at the Tree Windbreak in 200 West Area. Data show that 3,100 millimeters of drainage from apparent over-irrigation during the period June through September 2002.

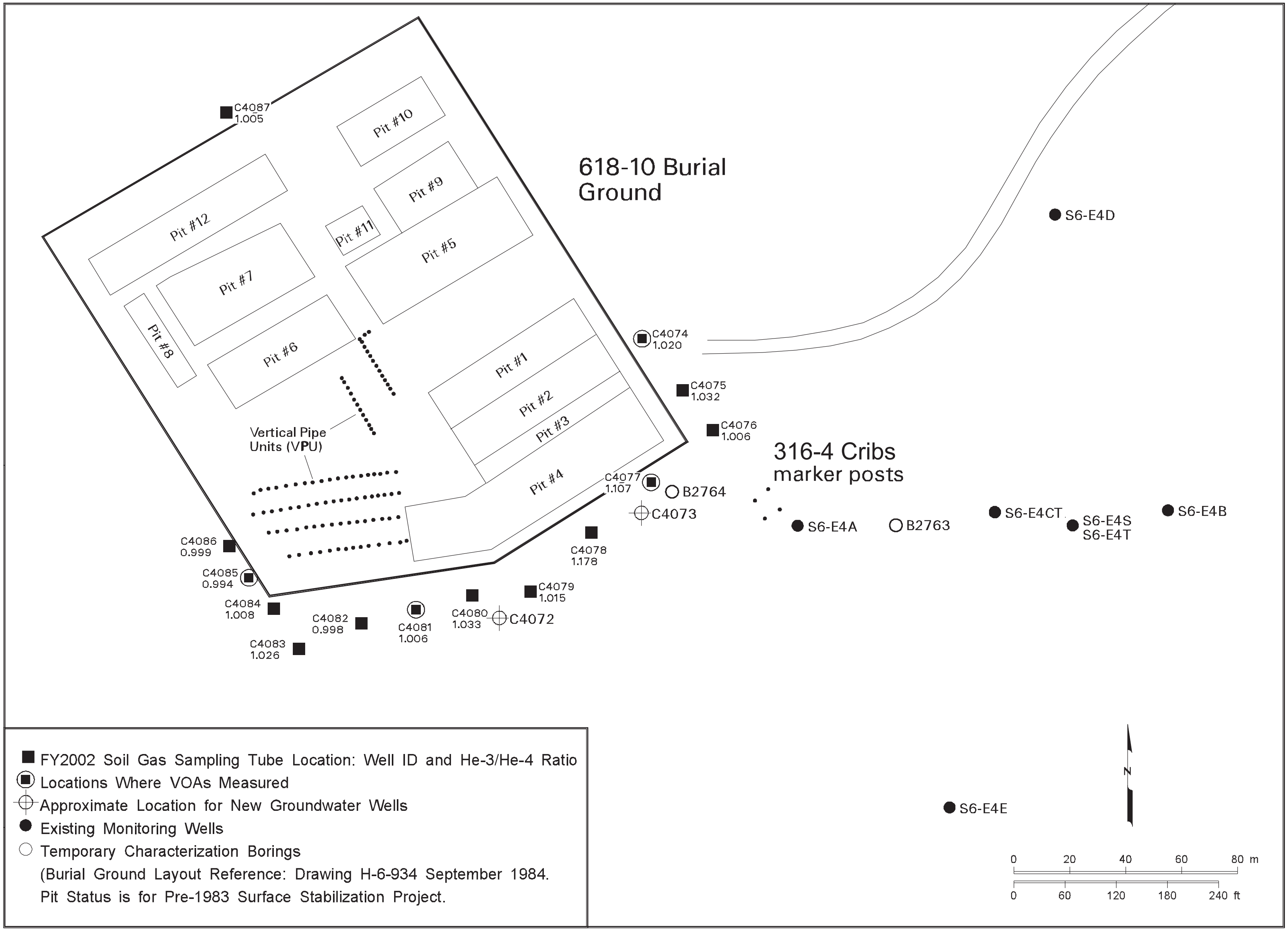

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Figure 3.3-25. Soil-Gas Sampling Points and Helium-3/Helium-4 Ratios Around 618-10 Burial Ground

	Informal, Local, Hanford Site Nomenclature	**DOE/RL-2002-39**	
Hanford formation	Touchet Beds (previously formalized)	Interbedded sand-and silt-dominated facies association (ISSD)	
	H1a Upper sandy sequence	Stratigraphically highest sand-dominated facies association (SD)	
	H1 Upper gravel sequence	Stratigraphically highest gravel-dominated facies association (GD)	
	H2 Sandy sequence	Sand-dominated facies association (SD)	
	H3 Lower gravel sequence	Stratigraphically lowest gravel-dominated facies association (GD)	
	H4 Lowest sand sequence	Stratigraphically lowest sand-dominated facies association (SD)	
	Pre-Missoula gravels	**Cold Creek unit**	Mainstream alluvium facies
	Early "Palouse" soil/silt		Fluvial overbank and/or eolian facies
	Plio-Pleistocene unit		Side-stream facies
	Ringold Formation	**Ringold Formation**	
	Columbia River Basalt Group	**Columbia River Basalt Group**	

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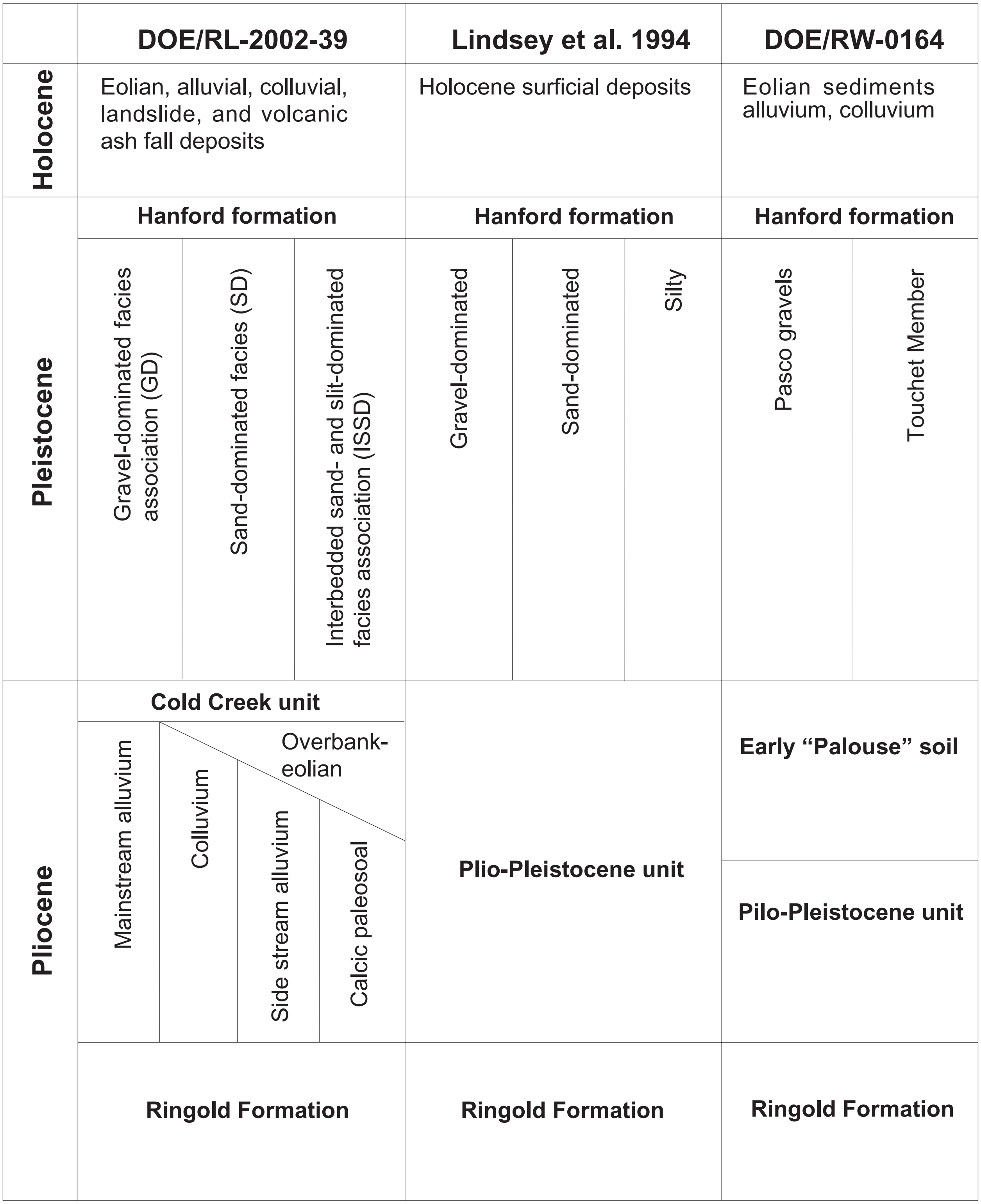
Figure 3.3-26. New Hanford Site Stratigraphic Nomenclature and Comparison to Previous Hanford Nomenclatures



	DOE/RL-2002-39	Lindsey et al. 1994	DOE/RW-0164
Holocene	Eolian, alluvial, colluvial, landslide, and volcanic ash fall deposits	Holocene surficial deposits	Eolian sediments alluvium, colluvium
Pleistocene	**Hanford formation** Gravel-dominated facies association (GD) Sand-dominated facies (SD) Interbedded sand- and slit-dominated facies association (ISSD)	**Hanford formation** Gravel-dominated Sand-dominated Silty	**Hanford formation** Pasco gravels Touchet Member
Pliocene	**Cold Creek unit** Mainstream alluvium Colluvium Overbank-eolian Side stream alluvium Calcic paleosol	**Plio-Pleistocene unit**	**Early “Palouse” soil** **Pilo-Pleistocene unit**
	Ringold Formation	**Ringold Formation**	**Ringold Formation**

ecs03001

Figure 3.3-27. Comparison Between New Hanford Site Nomenclature and Informal Hanford Nomenclature

4.0 Groundwater Modeling

P. D. Thorne

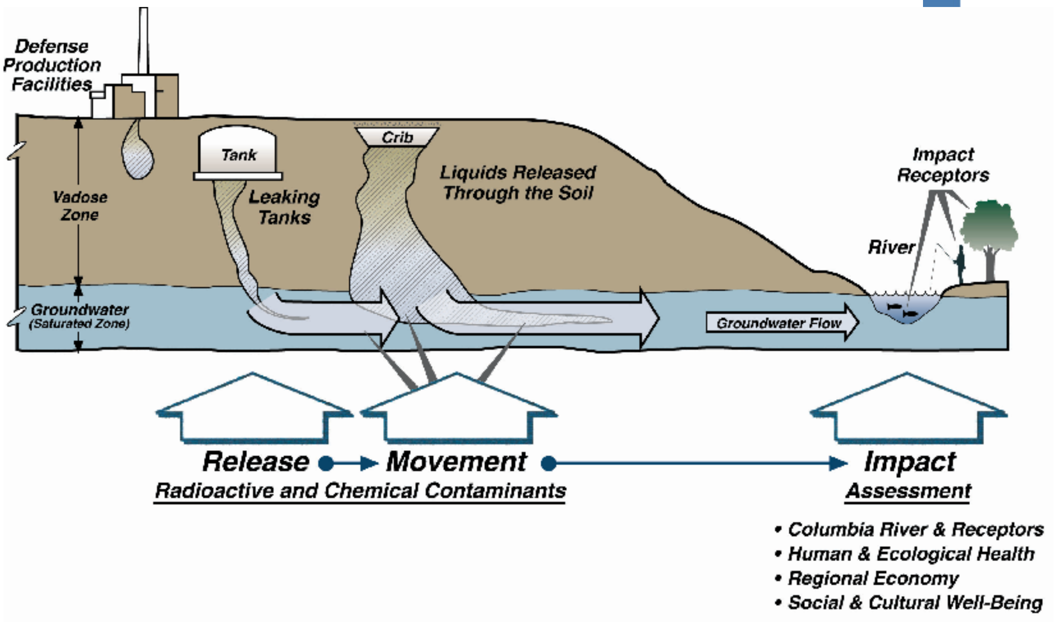
Predicting future groundwater conditions and the movement of contaminants in groundwater is important in planning waste management and cleanup activities for the Hanford Site. Such predictions are primarily made using computer models that simulate groundwater flow and contaminant transport. Groundwater modeling activities that address problems on a Hanford site-wide scale, such as contaminant movement from the Central Plateau to the Columbia River, have been consolidated under the Hanford Groundwater Monitoring Project. The consolidation of site-wide modeling eliminates redundancy and promotes consistency of groundwater models (DOE/RL-2000-11). Other groundwater models are used for problems at a local scale (i.e., <~10 kilometers). The major application of local-scale modeling during the past several years has been to design and evaluate pump-and-treat systems for groundwater.

Computer models of groundwater help predict future groundwater conditions and the movement of contaminants in groundwater. This information is important in planning waste management and cleanup activities at the Hanford Site.

This chapter summarizes Hanford Site groundwater modeling activities for fiscal year 2002. Section 4.1 reports progress on the continuing development of the consolidated site-wide groundwater model. Sections 4.2 through 4.4 describe specific applications of the consolidated model during the past year:

- completion of the System Assessment Capability initial assessment
- modeling to support the Hanford Site Solid Waste Environmental Impact Statement
- modeling of potential releases from each of the tank farm areas

Sections 4.5 and 4.6 briefly describe modeling activities that have been performed over the past several years to address problems on a local scale using models other than the consolidated site-wide groundwater model. These include



During fiscal year 2002, a three-dimensional groundwater model was applied as part of the System Assessment Capability to simulate groundwater flow and transport of contaminants in the unconfined aquifer. The System Assessment Capability is an integrated system of computer models and databases used to assess the impact of waste remaining on the Hanford Site. It will help decision makers and the public evaluate cleanup options.

modeling to support the design and operation of groundwater pump-and-treat systems and modeling of groundwater movement in the zone of interaction between the unconfined aquifer and the Columbia River.

4.1 Site-Wide Groundwater Flow and Transport Model

Objectives of Hanford Site Groundwater Model

A computer model of Hanford Site groundwater must be able to

- predict impact of Hanford activities on groundwater
- assess performance of waste-disposal facilities
- predict movement of contaminants
- evaluate remediation strategies

A conceptual model that provides the basis for the site-wide groundwater model was developed from information on the hydrogeologic structure of the aquifer, spatial distributions of hydraulic and transport properties, aquifer boundary conditions, and distribution and movement of contaminants. Development of the basic aspects of this three-dimensional model of the unconfined aquifer system is documented in PNL-8332, PNL-8971, PNL-10195, and PNNL-10886. The model consists of nine separate hydrogeologic units, eight of which exist below the water table. Figure 4.1-1 shows a cross section of the conceptual model layering from west to east across the central part of the Hanford Site. The groundwater flow system is bounded by the Columbia River on the north and east and by the Yakima River and basalt ridges on the south and west, respectively. Additional information on the site-wide groundwater model is presented in PNNL-11801 and PNNL-13641.

4.1.1 Status of the Consolidated Model

Quantifying uncertainty in model results is a major objective of the consolidated groundwater modeling task. Uncertainty is inherent in models because of assumptions about unknown aspects of the groundwater flow system and because the calculations used in groundwater models only approximate the processes of groundwater flow and transport. Understanding and quantifying the resulting uncertainty in model predictions will strengthen the technical defensibility of groundwater transport predictions and lead to a better basis for waste-management and cleanup decisions.

The effort to incorporate uncertainty in the site-wide model began in 1999 with recommendations from an external peer review panel to establish a new modeling framework that accepts the inherent uncertainty in model conceptual representations, inputs, and outputs (PNNL-13641). This framework will produce a range of predicted results for future groundwater conditions and contaminant transport based on differences in conceptual model assumptions.

While computer model predictions are never 100% correct, modelers are working to quantify the degree of uncertainty in model results. Understanding the uncertainty leads to a better basis for waste-management and cleanup decisions.

As described in PNNL-13641, uncertainty in the site-wide groundwater model is being quantified through sensitivity analysis (e.g., alternative conceptual models and future scenarios) for those aspects of the analysis related to vagueness, and uncertainty analysis for those situations where the uncertainty (e.g., for parameters) can be represented by probability density functions. Current activities involve developing alternative conceptual models that encompass identified uncertainties, then applying a transient inverse calibration to each model based on historical observations of water-level changes and contaminant movement. Results of the different calibrated alternative models will then span the range of results expected based on different assumptions. See PNNL-13641 for details about the Hanford Site groundwater conceptual model and a more detailed description of the strategy for quantifying uncertainty in model results.

Calibration of a base-case model and calibration of one alternative model were completed in fiscal year 2001 (PNNL-13447 and PNNL-13623). The alternative model included interaction between the unconfined aquifer system and the underlying basalt-confined aquifer. Previous site-wide modeling assumed the movement of water between these different systems was negligible. However, it is known that communication takes place, particularly along faults and in the area between Gable Mountain and Gable Butte, where erosion has removed the upper layers of confining basalt. Transient inverse calibration of these alternative models was completed with respect to historical observations of water-level changes. Calibration against historical patterns of contaminant movement is planned as a future activity. The calibration process utilized inverse-modeling procedures in UCODE, a universal inverse-modeling code developed jointly by the U.S. Geological Survey and the International Groundwater Modeling Center of the Colorado School of Mines (Poeter and Hill 1998).

During fiscal year 2002, development of the site-wide model focused on both improvements to the base-case, site-wide model and development of additional alternative conceptual models. The alternative models address uncertainty in the extent and distribution of major mud units within the unconfined aquifer and uncertainty in the distribution of hydraulic conductivity zones within the Hanford formation. The distribution of mud units within the aquifer affects vertical migration of contaminants and also affects lateral movement, particularly where mud units exist at the water table. The Hanford formation is critically important in the transport of groundwater contaminants to the Columbia River because of its relatively high hydraulic conductivity. Therefore, the distribution of Hanford formation zones that have unique values of hydraulic conductivity may have a large impact on contaminant movement from the Central Plateau to the Columbia River and the accessible environment.

During fiscal year 2002, scientists from Pacific Northwest National Laboratory and the Russian Academy of Sciences Institute for Nuclear Safety cooperated on a project to apply advanced geostatistical techniques to a groundwater model.

Advanced geostatistical techniques were applied to develop the new conceptual models, partially through a cooperative project between Pacific Northwest National Laboratory and the Russian Academy of Sciences Institute for Nuclear Safety (IBRAE). This allowed us to use the expertise of IBRAE staff in mathematical geology, and particularly, the application of advanced techniques for analyzing patterns in spatial data. Based on the available data, they applied several different spatial analysis techniques.

Some methods used a geostatistical approach, in which the phenomenon (e.g., existence of a mud unit) is considered as a random function and the data samples as a realization of that random function. This accounts for variability that is reflected by the structure of the spatial distribution of the phenomenon. Spatial correlation between the samples was analyzed and modeled using variograms (i.e., second-order moments of the distributions). The resulting model of spatial variability was then used in various stochastic simulation algorithms to create many different realizations.

In addition to the geostatistical methods, three “artificial intelligence” techniques were applied including:

- probabilistic neural network method
- artificial neural network – multilayer perceptron method
- support vector machine method

These techniques are also known as “machine learning algorithms” in which a mathematical construct is “trained” using known data points. The algorithm then creates estimates of unsampled values based on its “training,” which are informed by the spatial variability of the original data. Artificial intelligence methods are “model-free” estimators. They are not based on a theoretical or statistical model. The output results depend only on the input data, network architecture, and type of learning used. A principal advantage of the artificial intelligence techniques is the ability to discover patterns that are imperceptible to standard statistical methods.

Additional details of the geostatistical results and the development of alternative conceptual models are provided in Sections 4.1.3 and 4.1.4. Results from this research were presented at the International Containment and Remediation Technology Conference in Orlando, Florida (Thorne et al. 2001) and at the annual meeting of the International Association for Mathematical Geology in Berlin (Savelieva et al. 2002).

4.1.2 Improvements to the Base-Case Model

Transient inverse calibration of the base-case, site-wide groundwater model (PNNL-13447) significantly improved the ability of the model to simulate historically observed water-level changes over the entire Hanford Site, particularly near major discharge facilities in the 200 West Area. However, some hydraulic parameters took on unrealistic values indicating that changes in parameter zonation or other conceptual model improvements were needed. Most parameter estimates derived from the transient inverse calibration were consistent with prior knowledge. However, estimates for the specific yield of the Hanford formation (from 0.06 to 0.07) and the Ringold Formation (between 0.20 and 0.21) were not consistent with current understanding of these sediments. Calibration of the alternative model, including interaction with the basalt-confined aquifer system (PNNL-13623), resulted in a slight measurable improvement in overall model fit over the entire prediction period when compared to the baseline model. Estimates of specific yield, however, continued to take on unrealistic values for both the Hanford and Ringold Formations, indicating that additional conceptual model improvements were needed.

Based on these results, some adjustments were made during fiscal year 2002 to the base-case, site-wide model with the objective of producing realistic estimates of hydraulic parameters and better fits to historical water level data. The changes are summarized below:

- Account for delay of discharged wastewater caused by transit-time through the vadose zone.
- Create a separate hydrogeologic unit composed of gravels deposited on top of the Ringold Formation but prior to the Missoula floods. These gravels are found in the east-central portion of the site and were previously lumped with Hanford formation (Missoula flood) sediments to form model unit 1.
- Adjust hydrogeologic unit contacts southeast of 200 East Area, consistent with well data, to create a channel where saturated Hanford formation sediments exist below the water table.
- Adjust the extent of hydraulic parameter zones for the Hanford formation.

In fiscal year 2002, the site-wide conceptual model was modified to more accurately represent the groundwater flow system. The changes resulted in more realistic estimates of hydraulic parameters and helped the computer model fit historical water-level data more closely.

Preliminary calibration of the refined base-case model resulted in significant improvements to the parameter estimates. However, refinement of the base-case model is continuing, particularly with regard to the distribution of parameter zones within the Hanford formation (model unit 1).

4.1.3 Alternative Model — Mud Unit Extent and Distribution

One of the sets of alternative models under development during fiscal year 2002 addresses uncertainty in the extent and distribution of major mud units within the unconfined aquifer. Because of their low permeability, mud units within the aquifer system impede vertical movement of groundwater and migration of contaminants. Mud units also affect lateral movement, particularly where mud units exist at the water table; the three-dimensional distribution of mud units may cause contaminants to move deeper into the aquifer in some areas.

Three mud units are defined below the water table for the site-wide groundwater model (see Figure 4.1-1). Model unit 4 (upper Ringold mud) is composed of Lindsey's (BHI-00184) silt-dominated "facies association III" portion of the member of Taylor Flat. It does not include the sand-dominated "facies association II." In the model, sand-dominated upper-Ringold sediments generally occur beneath the silt-dominated sediments and are grouped with Lindsey's (BHI-00184) underlying gravel and sand-dominated units E and C to form model unit 5. The sand-dominated sediments are expected to have similar hydraulic properties. Model unit 6 corresponds to fine-grained over bank and paleosol deposits described by Lindsey (BHI-00184) that separate geologic unit B from overlying unit C in the east part of the Hanford Site. Model unit 8 is equivalent to Lindsey's (BHI-00184) lower mud unit and forms an aquitard across much of the Hanford Site. This unit is a combination of fine-grained paleosols and lacustrian deposits. The mud in this unit is often described as blue or green, sticky clay, and frequently includes a white ash.

Because of their low permeability, mud units within the aquifer system impede vertical movement of groundwater and migration of contaminants. An alternative model in fiscal year 2002 investigated uncertainty in the extent of major mud units.

Uncertainty in the distribution of mud units arises from both the possibility of misinterpretation and from actual spatial variability of the physical system. Uncertainty from misinterpretation can arise from the incorrect identification of a unit at a borehole or from a unit being missed in the borehole interpretation. Samples are often logged only every 1.5 to 3 meters, which may not be enough to intercept a relatively thin unit. Incomplete descriptions or errors in descriptions and field interpretations can also lead to misinterpretation of units at a borehole location. However, even if the interpretation of units at boreholes were 100% accurate, unit continuity between boreholes would be uncertain because of the variability of the aquifer system (i.e., the problem of interpolation and extrapolation under spatial variability). For example, an erosional hole may exist in a mud unit but is not represented in the model because no boreholes were in the area of the hole. On the other hand, a unit may be present in an area where no boreholes exist and not be represented in the model. The extent of mud units in the base-case model is based on data that are dense in a few areas and sparse over most of the site. The presence/absence of a particular mud unit is more uncertain in the areas of sparse data.

Several geophysical methods discussed in Section 4.1.1 were applied by researchers from IBRAE to explore the spatial variability of the presence/absence of each mud unit. The spatial analyses utilized data on the presence/absence of mud units at 405 wells, as well as the thickness of a unit if it was present. The first stage of the analysis focused on mapping the presence/absence of the mud, while the second stage focused on the variability of mud unit thickness. Maps showing probability of the mud unit presence/absence and thickness were then generated using several spatial methods. For example, Figures 4.1-2 through 4.1-4 are maps showing the probability of presence generated for each of the mud units using the "probabilistic neural network" method.

A stochastic simulation method was applied to create a set of 100 realizations that span the range of likely extent/distribution for each mud unit. These initial simulations were based of the probabilities of presence. The realizations were merged to create a final set of 10,000 different possible combinations of the realizations. Modelers then ranked the merged realizations according to the total area of mud present and the tortuosity (i.e., a measure of connectedness) for each mud unit. Ranking the merged realizations provides a range of cases that can be selected from for use in model calibration. Figure 4.1-5 shows cross sections of alternative conceptual models generated from the extreme (least mud and greatest mud) and median cases. These and other cases will be used in the inverse model calibration to create calibrated alternative conceptual models. The calibrated models will then produce a range of results for hydraulic head and contaminant transport that can then be compared to historical measurements.

4.1.4 Alternative Model — Parameter Zonation of Unit 1

Alternative models addressing uncertainty in the distribution of different Hanford formation sediments (with significantly different hydraulic properties) also were developed during fiscal year 2002. The Hanford formation (model unit 1) is especially important in transport of groundwater contaminants to the Columbia River because of its high hydraulic conductivity compared to Ringold sediments. Therefore, the distribution of Hanford formation zones that are given unique values of hydraulic parameters in the model may have a large impact on simulations of contaminant movement from the Central Plateau to the Columbia River. The uncertainty was evaluated using a two-dimensional approach to make the problem more manageable and because the most conductive sediment type will likely be dominant at any particular location. However, this approach does not account for water-table changes over time that can cause different sediments to be dominant at different times.

Alternative models addressing uncertainty in the distribution of different Hanford formation sediments also were developed during fiscal year 2002.

Uncertainty in the distribution of model unit 1 sediments comes from both the possibility of misinterpretation and from actual spatial variability. Uncertainty from misinterpretation can arise from the incorrect identification of a sediment facies type at a data location (well). Incomplete descriptions or errors in descriptions and field interpretations can also lead to misinterpretation. Uncertainty due to spatial variability arises because there are a limited number of data points and the sediment type in other locations is not known with certainty.

Five different sediment types were identified for unit 1 that were expected to have significantly different hydraulic properties. These were silt, sand, and three different gravel types (G1, G2, and G3). Data was available at 229 wells. Researchers from IBRAE used mathematical methods to study the spatial distribution of sediment types for unit 1. They developed methods that used not only the spatial distribution of sediment type data, but also “soft” information including a confidence level for each data point and sediment-type boundaries expected on the basis of geologic depositional environment. Both geostatistical and machine learning methods were used to generate interpolated maps of the unit 1 zonation.

A stochastic simulation method was used to create 100 different realizations that span the range of likely sediment-type distribution for model unit 1. The realizations were ranked according to overall hydraulic conductivity and tortuosity (a measure of connectedness). A hydraulic conductivity score was calculated for each realization by multiplying the area of each sediment type by the log of its mean hydraulic conductivity, as determined from historical aquifer tests. The conductivity score was given equal weight with the tortuosity in the ranking. Only the areas where unit 1 is within the model domain and below the water table were included in determining the rankings. Figures 4.1-6 through 4.1-8 show the distribution of different sediment types for the extreme (lowest and highest) and median conductivity realizations. These and other realizations will be calibrated to create alternative models. The calibrated models will then produce a range of results for hydraulic head and contaminant transport that can then be compared to historical measurements.

4.2 System Assessment Capability

An initial assessment performed using the System Assessment Capability was completed in fiscal year 2002. Results including those for the groundwater module are presented in PNNL-14027.

The System Assessment Capability is an integration of several linked computer models designed to simulate the movement of contaminants from waste sites through the vadose zone, groundwater, and Columbia River to receptors and to then assess the risk to human health, other living systems, the local economy, and cultures. The System Assessment Capability starts with waste inventory and simulates contaminant release from the various waste forms. It also incorporates linked modules to simulate transport through the vadose zone, groundwater, and Columbia River. Additional modules calculate the risks. The assessment uses a stochastic analysis, which means that selected parameters are represented by probability distributions from which values are selected.

The System Assessment Capability is an integrated system of computer models and databases used to assess the impact of waste remaining on the Hanford Site.

The initial System Assessment Capability met its primary objectives. The original scope of the effort was to develop and successfully test a site-wide assessment capability addressing composite risks from a suite of representative Hanford contaminants for subsurface and surface water pathways over a 1,000-year period. For the initial assessment, the transport of 10 different radionuclide and chemical contaminants released from 890 wastes sites from 1944 through 3050 was simulated. The stochastic capability involves a systems approach and Monte Carlo analysis of significant operational, physical, chemical, biological, and socioeconomic features of the Hanford Site and its environs. Completion of the initial assessment demonstrates that a site-wide analysis can be completed.

The groundwater module of the System Assessment Capability receives contaminant flux from the vadose zone module. It simulates contaminant movement through the uppermost aquifer system to the Columbia River and other potential exposure locations such as wells or seeps. The concentration of contaminants in groundwater is then used in the risk module calculations and contaminant flux is passed on to the Columbia River module.

The groundwater module of the initial assessment completed in fiscal year 2002 used the base-case model described in Section 4.1.1. A two-dimensional variable-thickness version of the site-wide groundwater model had been used in earlier simulations done with the System Assessment Capability. Improvements in computer hardware made it possible to apply the three-dimensional model and still generate results in a reasonable amount of time. Use of the three-dimensional model led to significant improvements in the groundwater transport simulations.

4.3 Modeling to Support the Receptor Risk Model for Tank Farms

The site-wide groundwater model was applied to determine the flow path and travel time for potential contaminant releases at each of the tank farms located in the 200 East or 200 West Areas to the Columbia River. Eighteen tank farms were assessed in this evaluation. Because of the model grid spacing (~375 meters) in the Central Plateau, releases from some tank farms were combined at single location, resulting in consolidation of the eighteen tank farms being considered to eight locations, five in the 200 East Area and three in the 200 West Area.

Computer models provide a site-wide context for cleanup decisions that must be made at individual waste sites.

The groundwater simulations were performed using the base-case model that had been calibrated to water level changes from 1944 to 1996 (PNNL-13641) (see Section 4.1.1). Because of the long-term nature of the simulations being made, the flow system was assumed to reflect natural steady state conditions after the effect of Hanford operational discharges have ceased. The applied Columbia River boundary conditions reflect long-term annual average flow and stage conditions.

The simulations were based on a unit release at each tank farm for five discrete sorption coefficient (K_d) classes at each location. The sorption coefficient classes applied were 0, 0.2, 0.5, 0.8, 1, and 3. The 0 K_d class represents a contaminant that moves with the groundwater flow. A K_d class of 3 represents an upper limit at which the contaminant is strongly absorbed to the sediment matrix in the flow path. All simulations assumed that the contaminant is conserved (i.e., there is no decay).

Simulated results showed that for all sites, the majority of the contaminant plumes move to the north, through the gap between Gable Mountain and Gable Butte toward the Columbia River. A lesser component of the plumes moves to the east toward the Columbia River south of Gable Mountain.

Earlier flow modeling results by Cole et al. (PNNL-11801) suggested that as the water table drops in the central part of the Hanford Site and the saturated thickness of the unconfined aquifer decreases, groundwater flow northward from the 200 Areas may be cut-off by relatively impermeable basalt in the area just north of the 200 East Area. The water table is within a few meters of the currently interpreted basalt surface and in the natural recharge and boundary fluxes that control predictions of future water-table elevation. Therefore, the potential for movement of contaminants northward through the gap is also uncertain. These issues are currently being investigated as part of the site-wide groundwater modeling task.

4.4 Modeling for the Solid Waste Environmental Impact Statement

A version of the site-wide model described in PNNL-11801 was applied to predict transport from low-level burial grounds located in the 200 West and 200 East Areas. This version of the model utilizes a distribution of hydraulic conductivity based on a steady-state calibration of the model. The contaminant source term for the modeling included both low-level waste that has been previously placed in the burial grounds and waste that is forecast to be placed in the burial grounds before 2046. The long-term assessment required estimating the cumulative dose using a suite of models that estimated source-term release, vadose zone flow and transport, and groundwater flow and transport. Results are presented in DOE/EIS-0286D.

4.5 Local-Scale Modeling of Pump-and-Treat Systems

The Hanford environmental restoration contractor has performed local-scale modeling during the past several years to design and evaluate pump-and-treat systems for groundwater. The Micro-FEM© code was used to model capture and injection zones of extraction and injection wells, respectively, and to estimate the area affected by the pump-and-treat systems over time. The model was used to evaluate the hydraulic effects of the remedial action sites in several different operational areas. The operational areas and the contaminants of concern being treated at each are listed below:

- 100-KR-4 Operable Unit (100-K Area) – hexavalent chromium
- 100-NR-2 Operable Unit (100-N Area) – strontium-90
- 100-HR-3 Operable Unit (includes both 100-D and 100-H Areas) – hexavalent chromium
- 200-UP-1 Operable Unit (200 West Area) – technetium-99 and uranium
- 200-ZP-1 Operable Unit (200 West Area) – carbon tetrachloride

During fiscal year 2002, computer models that can evaluate the hydraulic effects of remedial action sites were updated to reflect the changing water-table elevation and changes in pumping rates at the pump-and-treat locations.

During fiscal year 2002, these models were only updated to reflect the changing water-table elevation in the aquifer and changes in pumping rates. Additional information on these models is provided in DOE/RL-99-79 and DOE/RL-2000-01.

4.6 Local-Scale Modeling of Groundwater — River Interaction

Local-scale modeling of water movement in the zone of interaction between the unconfined aquifer and the Columbia River also has been conducted over the past few years to support the Groundwater/Vadose Zone Integration Project. The results of this modeling effort were published in PNNL-13674. Groundwater path lines were calculated to illustrate the direction and rate-of-flow within the zone of interaction, using Pacific Northwest National Laboratory's Subsurface Transport Over Multiple Phases (STOMP) code (PNNL-11218). Graphics software was then used to animate water movement and show how the flow field responds to the fluctuating river stage over one complete seasonal cycle of the river. The model was developed for the zone of interaction at the 100-H Area. This two-dimensional simulation of water movement in the near-river unconfined aquifer clearly demonstrated the strong influence exerted by fluctuations in the Columbia River stage. The rise and fall of the river cause the direction and rate of groundwater flow to constantly change, with complete reversals in direction of flow and pore-water velocities varying from no motion up to 10 meters per day. The dynamic nature of this flow field has implications for monitoring strategies, environmental restoration remedial actions, and river impact assessments (PNNL-11218).

Computer models show how groundwater flow responds to fluctuating river stage.

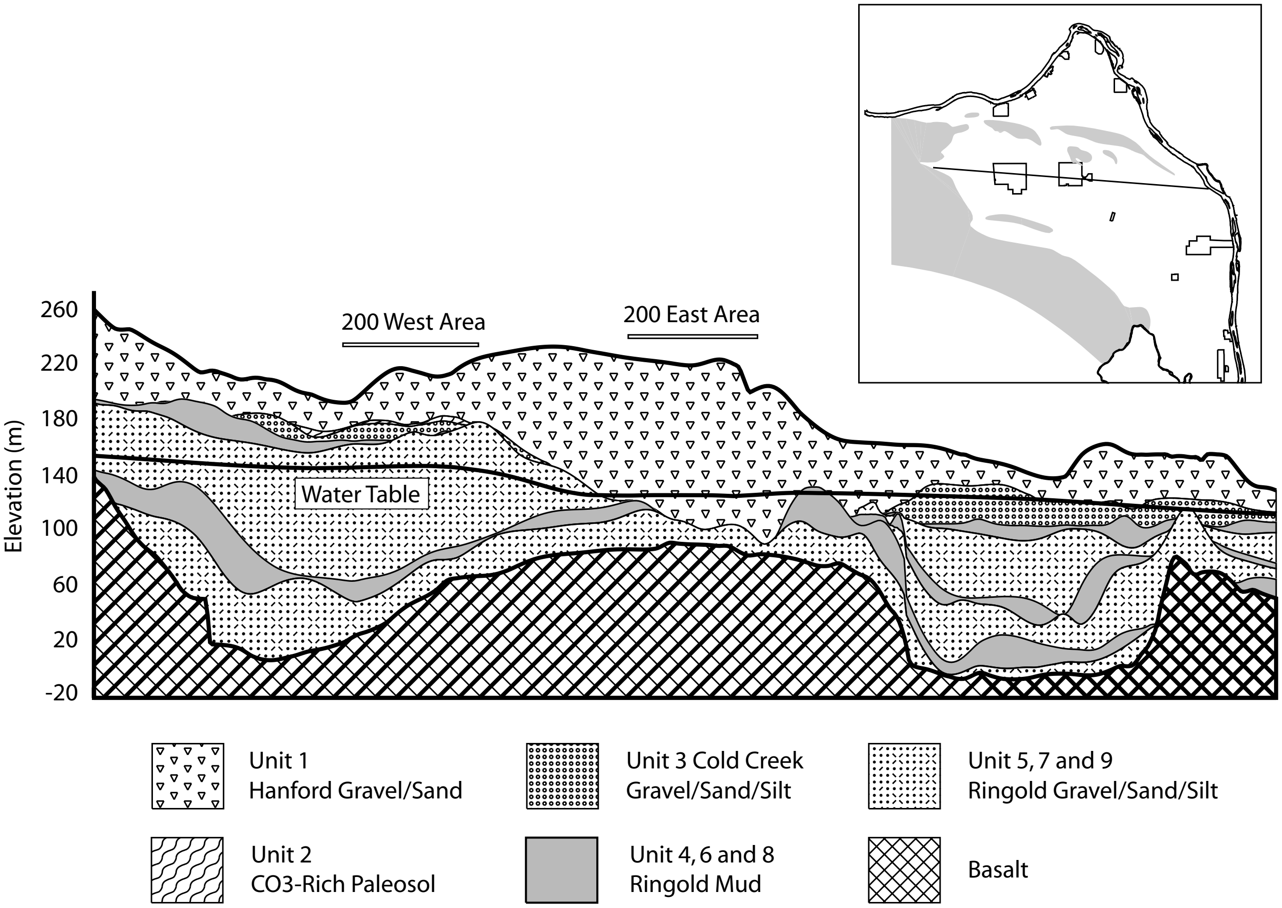


Figure 4.1-1. Cross Section of the Conceptual Model from West to East Across the Hanford Site

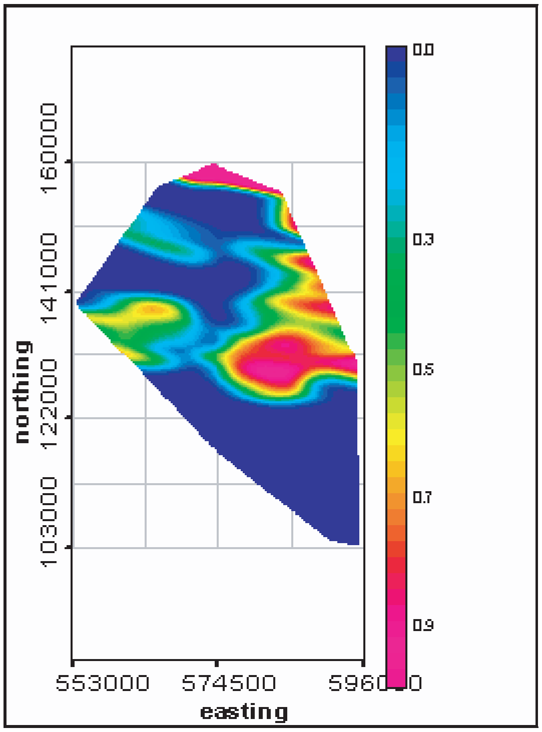


Figure 4.1-2. Map Showing Probability of Unit 4 Mud Presence Generated Using the "Probabilistic Neural Network" Method

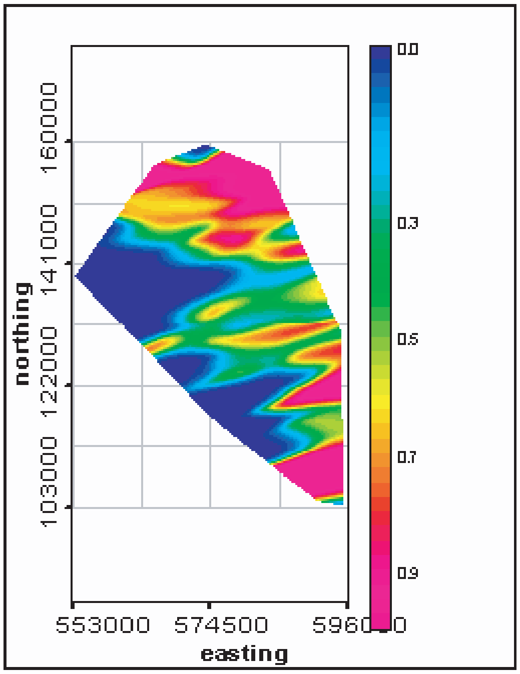


Figure 4.1-3. Map Showing Probability of Unit 6 Mud Presence Generated Using the "Probabilistic Neural Network" Method

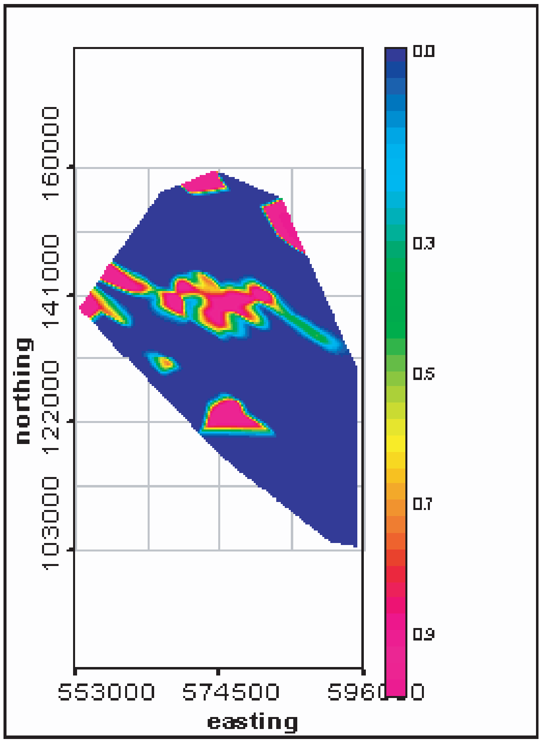


Figure 4.1-4. Map Showing Probability of Unit 8 Mud Presence Generated Using the "Probabilistic Neural Network" Method

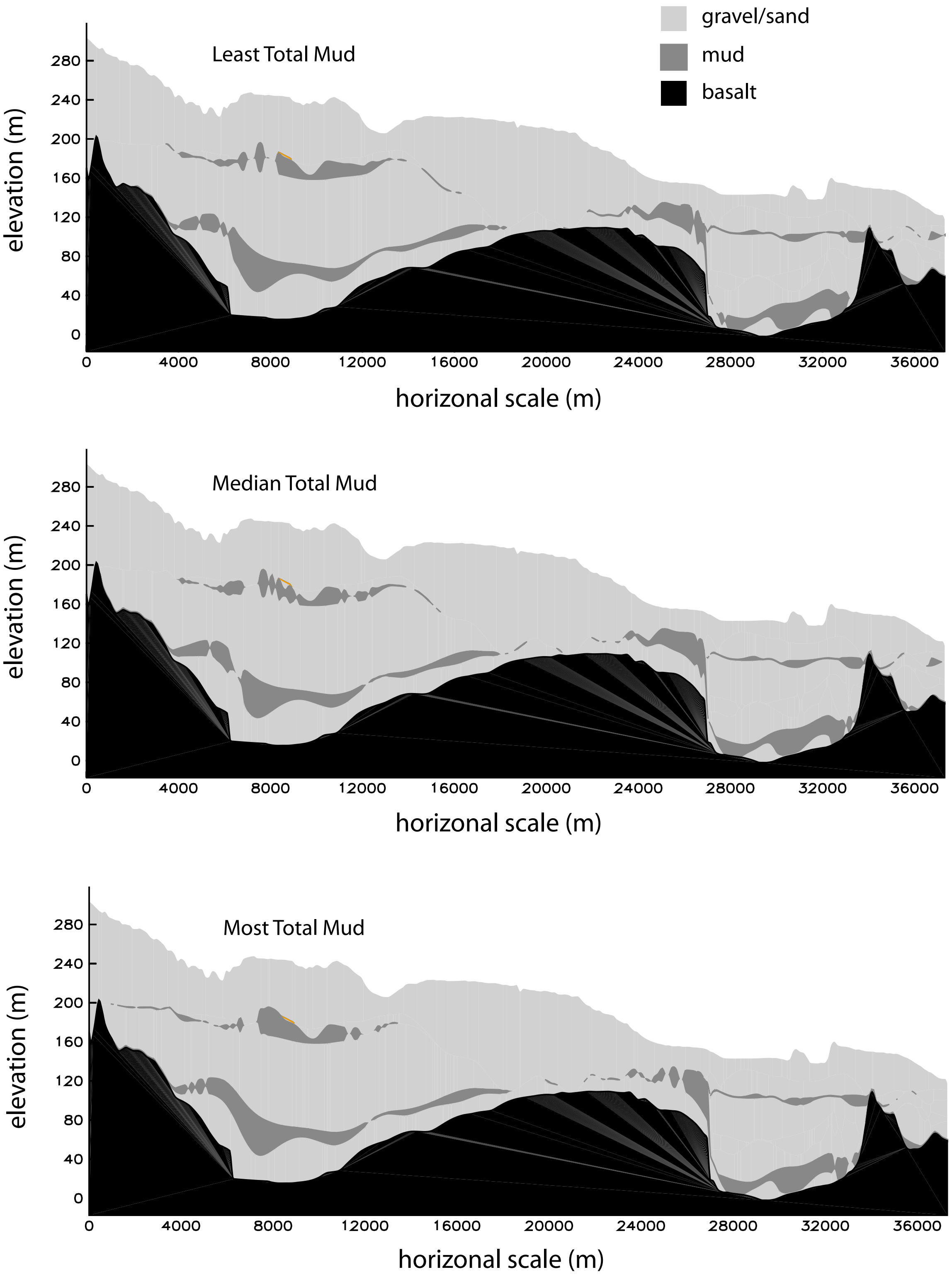


Figure 4.1-5. Cross Sections of Alternative Conceptual Models with the Least Total Mud Extent, Median Total Mud Extent, and Greatest Total Mud Extent

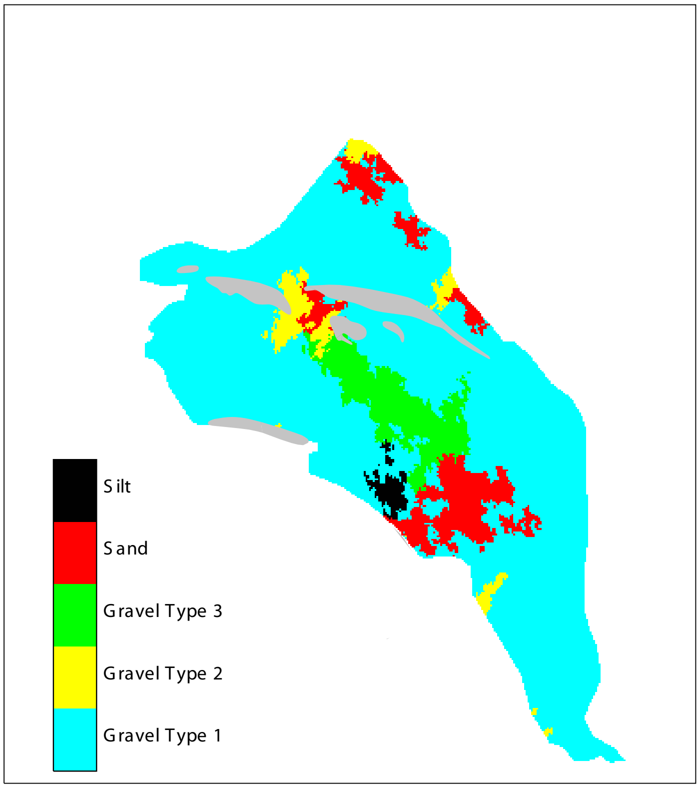


Figure 4.1-6. Alternative Distribution of Hanford Formation Sediment Types with the Lowest Overall Hydraulic Conductivity

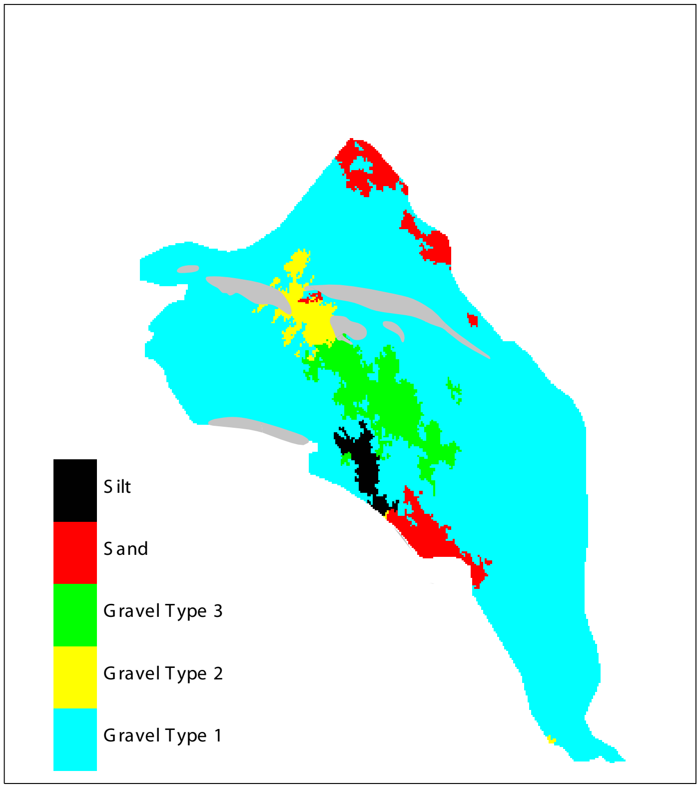


Figure 4.1-7. Alternative Distribution of Hanford Formation Sediment Types with the Median Overall Hydraulic Conductivity

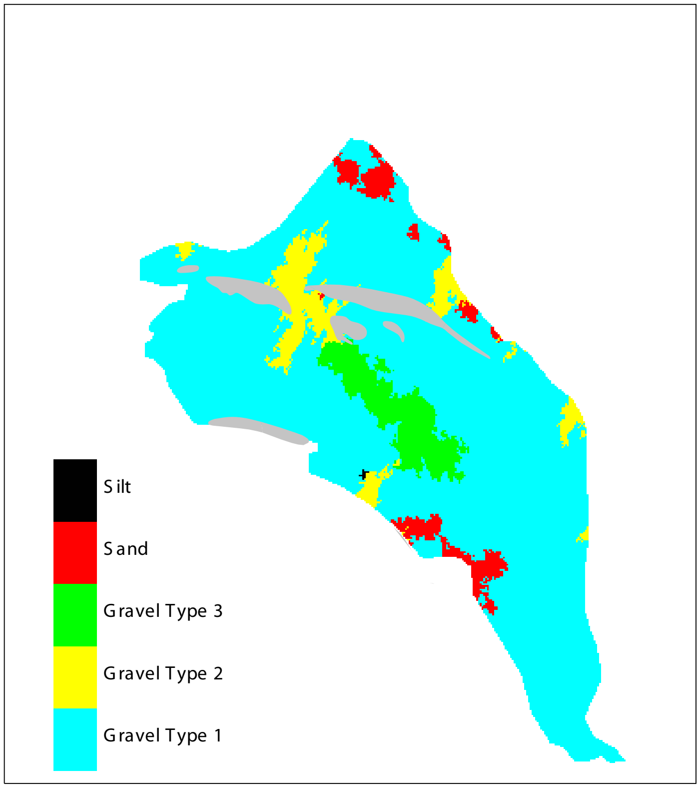


Figure 4.1-8. Alternative Distribution of Hanford Formation Sediment Types with the Highest Overall Hydraulic Conductivity

5.0 Well Installation, Maintenance, and Decommissioning

B. A. Williams and J. E. Auten

This section describes well installation, maintenance, and decommissioning activities conducted on the Hanford Site during fiscal year 2002.

5.1 Well Installation

The Hanford Groundwater Monitoring Project along with the Groundwater Protection Program define needs for new wells at Hanford. Each year, the groundwater project identifies new wells to maintain compliance with the *Resource Conservation and Recovery Act* (RCRA) detection and assessment groundwater monitoring requirements and U.S. Department of Energy (DOE) orders (i.e., long-term regional plume monitoring). These compliance issues include ongoing RCRA

Each year, the Hanford Groundwater Monitoring Project and DOE's Groundwater Protection Program identify the need for new wells at the Hanford Site that will maintain compliance with requirements in the Resource Conservation and Recovery Act, DOE orders, and the Comprehensive Environmental Response, Compensation, and Liability Act. The above photo shows well drilling at the Central Plateau during 2002.

facility groundwater assessments, replacement of monitoring wells that go dry because of the declining water table, replacement of wells that pose contamination risks to the environment, improvement of spatial coverage of the monitoring networks, and vertical characterization of groundwater contamination. The Groundwater Protection Program, operated by Fluor Hanford, Inc., determines the need for new remediation (i.e., pump-and-treat systems) and performance assessment monitoring wells annually to fulfill obligations of the *Comprehensive, Environmental Response, Compensation, and Liability Act* (CERCLA).

Each year, DOE and the Washington State Department of Ecology approve the total number of new RCRA wells to be installed via the Tri-Party Agreement Milestone M-24-00 (Ecology et al. 1998) using an integrated data quality objectives process. This process integrates the borehole and well data needs of various Hanford Site projects in the proposed wells (i.e., CERCLA, RCRA, and the River Protection Project). DOE, and the lead regulator (U.S. Environmental Protection Agency or Washington State Department of Ecology) approve new CERCLA wells needed to support groundwater protection and restoration projects (i.e., pump-and-treat operations and performance assessment wells), using this process.

Well Installation

Twenty-eight new wells were installed on the Hanford Site in calendar year 2002:

- 2 for RCRA monitoring
- 23 for CERCLA investigations or remediation
- 3 for the River Protection Project

New in 2002, the Cleanup, Constraints, and Challenges Team was asked to assess and define the total number of groundwater monitoring wells required to complete all the monitoring networks on the Central Plateau of the Hanford Site. Negotiations have begun and approval among Washington State Department of Ecology, U.S. Environmental Protection Agency, and DOE (the Tri-Parties) is pending an integrated CERLCA/RCRA data quality objective document (HNF-12236) that defines all of the 200 West and 200 East groundwater wells required to fulfill CERCLA long-term plume monitoring and RCRA monitoring requirements. If the document is approved, these wells will be prioritized by the Tri-Parties and scheduled for installation over the next 4 years (2003 to 2006). The wells, to be installed annually, will continue to be approved via the Tri-Party Agreement Milestone M-24-00 (Ecology et al. 1998).

During fiscal year 2002, DOE transitioned the Central Plateau and the Groundwater Protection Program work to Fluor Hanford, Inc. from the environmental restoration contractor (Bechtel Hanford, Inc.); the scope of this work also includes oversight and contracting responsibilities for all Hanford drilling projects outside of the tank farms. Due to the transition, DOE and Washington State Department of Ecology negotiations during the year resulted in a late agreement to install four wells, two RCRA and two CERCLA, during the fourth quarter of calendar year 2002. Tri-Party Agreement Milestone M-24-00 (Ecology et al. 1998) required the installation of two new RCRA groundwater monitoring wells by December 31, 2002. In addition, the agreement required one new CERCLA well to be installed at the 200-ZP-1 Operable Unit and one new well installed at the 200-UP-1 Operable Unit. Table 5.1-1 lists all new wells completed in calendar year 2002 (Figure 5.1-1). Well data packages will be published in fiscal year 2003 with more detailed information about these new wells, including the detailed geologic and geophysical descriptions and a complete set of soil and/or groundwater sampling data results.

Twenty-one new wells were also installed in the 100-D Area during 2002. One new well was installed for activities related to environmental restoration (see Table 5.1-1) and 20 wells were completed for the In Situ Redox Manipulation Project at 100-D Area. Four boreholes were drilled and ultimately three wells were completed for the Immobilized Low-Activity Waste Site in the 200 East Area (PNNL-14029).

During 2002, two characterization boreholes, C3961 and C3962, were drilled to support the 384 Power House Fuel Bunker Tank Removal Project. A total of 66 GeoProbe boreholes were drilled at different areas for vadose characterization.

One of these GeoProbe boreholes were drilled outside the VZFS300 N lysimeter facility in the 300/400 Area and immediately decommissioned after sample retrieval (Table 5.1-2). Fourteen GeoProbe boreholes were installed around the 618-10 burial ground as part of a tritium investigation. The boreholes were for soil-gas sampling in the vadose zone (see Section 3.3.8) and will be decommissioned as soon as the investigations are completed in fiscal year 2003. Fifty-one other GeoProbe boreholes were drilled in the 200 West Area as part of the carbon tetrachloride investigation.

5.2 Well Maintenance

Maintenance of groundwater wells is performed to meet regulatory requirements as part of a scheduled preventive maintenance cycle (routine) or in response to problems identified in the field (non-routine). Non-routine maintenance includes both surface and subsurface tasks. Surface tasks include conducting field inspections, well labeling, maintenance and replacement of locking well caps, casing repairs, and diagnosis and repair of surface electrical and pump-discharge deficiencies. Subsurface tasks include repairing and replacing sampling pumps; performing camera surveys; brushing casing perforations or screens; developing wells to improve yield, recovery, and sample quality; or removing sediment accumulation. Routine maintenance is performed on a 5-year cycle to support groundwater sampling and to minimize non-routine maintenance activities. At a minimum, routine maintenance includes the following tasks:

- removing groundwater sampling pump systems or aquifer-testing equipment
- inspecting and repairing or replacing sampling pump systems or aquifer-testing equipment
- brushing or cleaning of well casing perforations or well screens
- removing debris and fill material
- developing the well
- performing borehole video camera survey
- reinstalling sampling or aquifer-testing instrumentation/equipment
- documenting well conditions and maintenance activities

Four hundred and fifty-six wells received non-routine maintenance in fiscal year 2002.

Non-routine tasks are performed in response to a problem identified in the field or requests. Non-routine maintenance tasks are varied and depend on the specific problem encountered at a well. These activities also include the installation or removal of pumps or monitoring equipment. A summary of maintenance activities by regulatory program is presented in Table 5.2-1. No routine well maintenance was performed during fiscal year 2002.

5.3 Well Decommissioning

Decommissioning activities result in the permanent removal of a well, borehole, or piezometer from service and from the Hanford Site well inventory. Decommissioning is performed in accordance with Washington State Department of Ecology standards (WAC 173-160) and involves backfilling a well with impermeable material to prevent vertical movement of water or contaminants. Typically, well decommissioning is done by placing sand across the screened interval, perforating the casing across any confining layers, and pressure grouting. The casing is removed if possible. If not, the casing is cut ~1 meter below ground surface. A brass plate is set in the grout below land surface and the hole is backfilled. A well becomes a candidate for decommissioning if its use has been permanently discontinued; if its condition is so poor that its continued use is impractical; or it poses an environmental, safety, or public health hazard.

Wells that present the risk of being immediate hazards to the public health or safety are categorized into basic risk groups (high, medium, and low). These categories identify wells that have the potential to provide preferential pathways that allow movement of contaminants deeper into the subsurface strata. At this time, decommissioning is generally driven by the long-range environmental restoration schedule (DOE/RL-96-105) and available funding. No Hanford Site wells were decommissioned during fiscal year 2002.

Table 5.1-1. Well Installations for Calendar Year 2002

Well Number	Well ID	Program	Project
199-D4-68	C3298	CERCLA	100 D ISRM
199-D4-69	C3299	CERCLA	100 D ISRM
199-D4-70	C3300	CERCLA	100 D ISRM
199-D4-71	C3301	CERCLA	100 D ISRM
199-D4-72	C3302	CERCLA	100 D ISRM
199-D4-73	C3303	CERCLA	100 D ISRM
199-D4-74	C3304	CERCLA	100 D ISRM
199-D4-75	C3305	CERCLA	100 D ISRM
199-D4-76	C3306	CERCLA	100 D ISRM
199-D4-77	C3307	CERCLA	100 D ISRM
199-D4-78	C3308	CERCLA	100 D ISRM
199-D4-79	C3309	CERCLA	100 D ISRM
199-D4-80	C3310	CERCLA	100 D ISRM
199-D4-81	C3311	CERCLA	100 D ISRM
199-D3-3	C3312	CERCLA	100 D ISRM
199-D4-82	C3313	CERCLA	100 D ISRM
199-D3-4	C3314	CERCLA	100 D ISRM
199-D4-87	C3799	CERCLA	100 D ISRM
199-D4-88	C3800	CERCLA	100 D ISRM
199-D4-89	C3801	CERCLA	100 D ISRM
199-D8-72	C3829	CERCLA	100-HR-3(D)
299-E17-22	C3826	ORP	ILAW
299-E17-23	C3827	ORP	ILAW
Decommissioned	C3828	ORP	ILAW
299-E17-24	C3926	ORP	ILAW
299-W14-19	C3957	RCRA	SST TX-TY
299-W15-43	C3955	CERCLA	200-ZP-1
299-W15-44	C3956	RCRA	SST TX-TY
299-W19-46	C3958	CERCLA	200-UP-1

CERCLA = *Comprehensive Environmental Response, Compensation, and Liability Act.*
ILAW = Immobilized low-activity waste.
ISRM = In situ redox manipulation.
ORP = Office of River Protection.
RCRA = *Resource Conservation and Recovery Act.*
SST = Single-shell tank.

Table 5.1-2. Characterization Boreholes for Fiscal Year 2002

Well ID	Program	Project	Facility	Location
C3961	CERCLA		384 power house fuel bunker	300 Area
C3962	CERCLA		384 power house fuel bunker	300 Area
C4074	CERCLA	300-FF-5	618-10 burial ground	300 Area
C4075	CERCLA	300-FF-5	618-10 burial ground	300 Area
C4076	CERCLA	300-FF-5	618-10 burial ground	300 Area
C4077	CERCLA	300-FF-5	618-10 burial ground	300 Area
C4078	CERCLA	300-FF-5	618-10 burial ground	300 Area
C4079	CERCLA	300-FF-5	618-10 burial ground	300 Area
C4080	CERCLA	300-FF-5	618-10 burial ground	300 Area
C4081	CERCLA	300-FF-5	618-10 burial ground	300 Area
C4082	CERCLA	300-FF-5	618-10 burial ground	300 Area
C4083	CERCLA	300-FF-5	618-10 burial ground	300 Area
C4084	CERCLA	300-FF-5	618-10 burial ground	300 Area
C4085	CERCLA	300-FF-5	618-10 burial ground	300 Area
C4086	CERCLA	300-FF-5	618-10 burial ground	300 Area
C4087	CERCLA	300-FF-5	618-10 burial ground	300 Area
C4091			VZFS300 N lysimeter facility	300/400 Area
C4106	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C4107	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C4108	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C4109	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C4110	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C4111	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C4112	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C4113	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C4114	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C4115	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C4116	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3840	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3841	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3842	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3843	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3844	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3845	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3846	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3847	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3848	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3849	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3850	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3851	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3852	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3853	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3854	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3855	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3856	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3857	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3858	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3859	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3860	CERCLA	200-PW-1	Carbon tetrachloride	200 West

Table 5.1-2. (contd)

Well ID	Program	Project	Facility	Location
C3860	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3861	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3862	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3863	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3864	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3865	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3866	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3867	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3868	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3869	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3870	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3871	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3872	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3873	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3874	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3875	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3876	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3877	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3878	CERCLA	200-PW-1	Carbon tetrachloride	200 West
C3879	CERCLA	200-PW-1	Carbon tetrachloride	200 West

CERCLA = *Comprehensive Environmental Response, Compensation, and Liability Act.*

Table 5.2-1. Well Maintenance Summary for Fiscal Year 2002

Program	Routine	Non-Routine
CERCLA	0	246
LTMC	0	1
RCRA	0	179
Surveillance	0	13
Geophysical Logging Support	0	17
Total	0	456

CERCLA = *Comprehensive Environmental Response, Compensation, and Liability Act.*
LTMC = Long-term monitoring - CERCLA.
RCRA = *Resource Conservation and Recovery Act.*

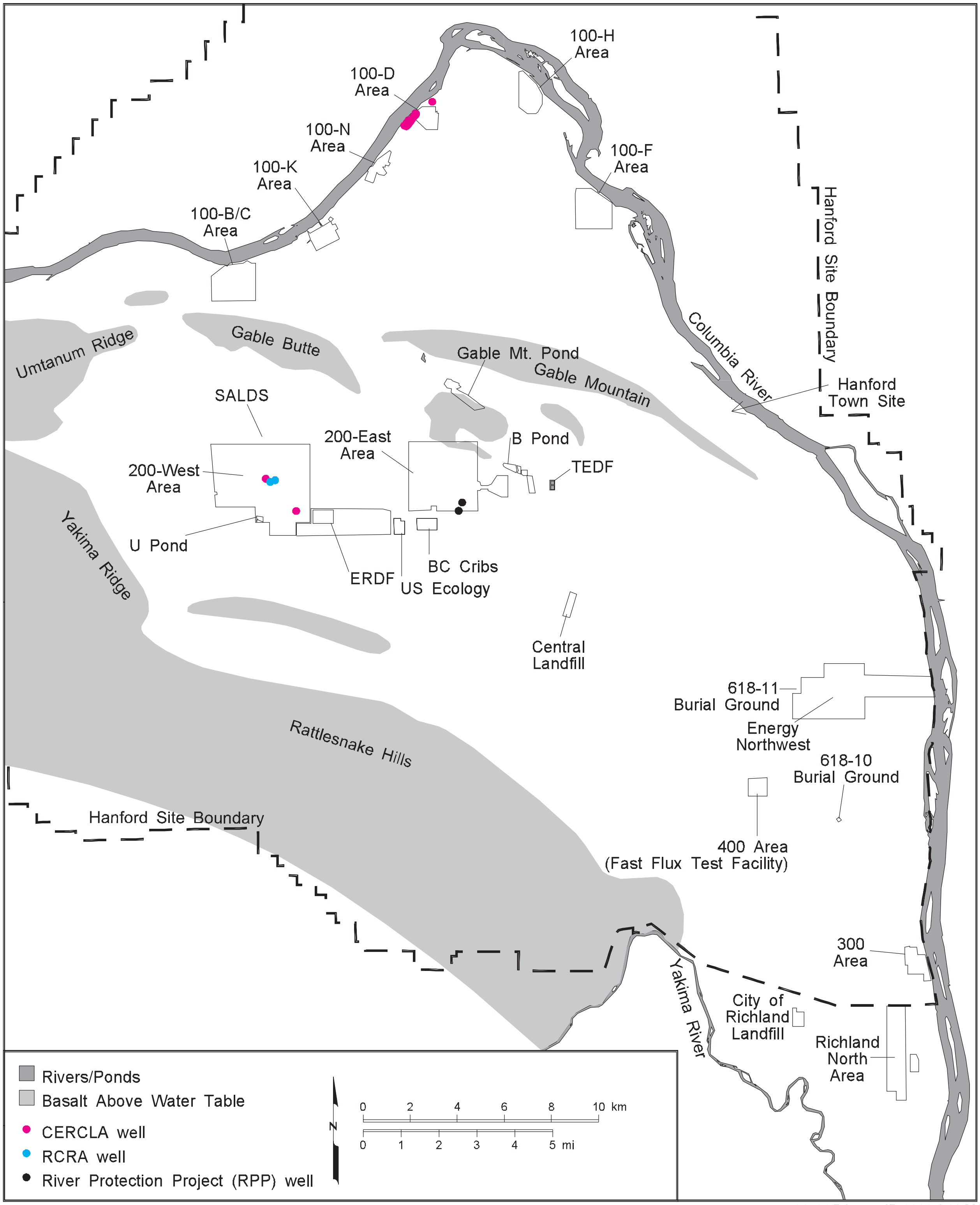


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Figure 5.1-1. Groundwater Monitoring Wells Installed in Calendar Year 2002

6.0 References

Public Laws

Atomic Energy Act of 1954. As amended, Ch. 1073, 68 Stat. 919, 42 USC 2011 et seq.

Comprehensive Environmental Response, Compensation, and Liability Act. 1980. Public Law 96-510, as amended, 94 Stat. 2767, 42 USC 9601 et seq.

Resource Conservation and Recovery Act. 1976. Public Law 94-580, as amended, 90 Stat. 2795, 42 USC 6901 et seq.

Code of Federal Regulations

40 CFR 264. U.S. Environmental Protection Agency. "Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities." *Code of Federal Regulations*.

40 CFR 265. U.S. Environmental Protection Agency. "Interim Status Standards for Owners of Hazardous Waste Treatment, Storage, and Disposal Facilities." *U.S. Code of Federal Regulations*.

40 CFR 265, Subpart F. U.S. Environmental Protection Agency. "Ground-Water Monitoring." *U.S. Code of Federal Regulations*.

Washington Administrative Code

WAC 173-160. *Minimum Standards for Construction and Maintenance of Wells*. Washington Administrative Code, Olympia, Washington.

WAC 173-200. *Water Quality Standards for Ground Waters of the State of Washington*. Washington Administrative Code, Olympia, Washington.

WAC 173-200-40. *Criteria*. Washington Administrative Code, Olympia, Washington.

WAC 173-216. *State Waste Discharge Program*. Washington Administrative Code, Olympia, Washington.

WAC 173-303-645. *Release from Regulated Units*. Washington Administrative Code, Olympia, Washington.

WAC 173-304. *Minimum Functional Standards for Solid Waste Handling*. Washington Administrative Code, Olympia, Washington.

WAC 173-340. *Model Toxics Control Act – Cleanup*. Washington Administrative Code, Olympia, Washington.

WAC 246-290. *Public Water Supplies*. Washington Administrative Code, Olympia, Washington.

WAC 246-290-310. *Maximum Contaminant Levels (MCLs)*. Washington Administrative Code, Olympia, Washington.

ARH-2035. 1971. *Investigation and Evaluation of 102-BX Tank Leak*. J. C. Womack and D. J. Larkin, Atlantic Richfield Hanford Company, Richland, Washington.

ARH-ST-156. 1977. *Evaluation of Scintillation Probe Profiles from 200 Area Crib Monitoring Wells*. K. R. Fecht, G. V. Last, and K. R. Price, Atlantic Richfield Hanford Company, Richland, Washington.

BHI-00012, Rev. 00. 1994. *300-FF-2 Operable Unit Technical Baseline Report*. D. H. Deford, R. W. Carpenter, and M. W. Einan, Bechtel Hanford, Inc., Richland, Washington.

BHI-00127. 1995. *100-H Area Technical Baseline Report*. D. Deford and M. W. Einan, Bechtel Hanford, Inc., Richland, Washington.

BHI-00184, Rev. 0. 1995. *Miocene- to Pliocene-Aged Suprabasalt Sediments of the Hanford Site, South-Central Washington*. K. A. Lindsey, Bechtel Hanford, Inc., Richland, Washington.

BHI-00212, Rev. 00. 1995. *Geophysical Investigations of the 316-4 (300 North Crib), the 618-8 Burial Ground, the 618-13 (Mound), the Undocumented Solid Waste Burial Ground, the Solid Waste Burial Ground (Early Burial Ground), and the Burial Trench West of the Process Trenches, 300-FF-2 Operable Unit*. K. A. Bergstrom, T. H. Mitchell, and B. J. Bolin, prepared by CH2M HILL Hanford, Inc. for Bechtel Hanford, Inc., Richland, Washington.

BHI-00291, Rev. 1. 1997. *Geophysical Investigation of the 618-10 and 618-11 Burial Grounds, 300-FF-2 Operable Unit*. K. A. Bergstrom, D. J. Brolin, and T. H. Mitchell, Bechtel Hanford, Inc., Richland, Washington.

BHI-00720, Rev. 6. 2002. *Performance Evaluation Report for Soil Vapor Extraction Operations at the Carbon Tetrachloride Site, February 1992 - September 2001/June 2002*. V. J. Rohay, Bechtel Hanford, Inc., Richland, Washington.

BHI-00917. 1996. *Conceptual Site Models for Groundwater Contamination at 100-BC-5, 100-KR-4, 100-HR-3, and 100-FR-3 Operable Units*. R. E. Peterson, R. F. Raidl, and C. W. Denslow, Bechtel Hanford, Inc., Richland, Washington.

BHI-01153. 1998. *Aquifer Sampling Tube Completion Report: 100 Area and Hanford Townsite Shorelines*. R. E. Peterson, J. V. Borghese, and D. B. Erb, CH2M HILL Hanford, Inc. for Bechtel Hanford, Inc., Richland, Washington.

BHI-01367, Rev. 0. 2000. *200-CW-1 Operable Unit Borehole/Test Pit Summary Report*. C. S. Clearlock, K. M. Singleton, M. E. Todd, and D. B. Barnett, Bechtel Hanford, Inc., Richland, Washington.

BHI-01531. 2001. *Borehole Summary Report for the 2001 ILAW Site Characterization Well*. L. D. Walker, Bechtel Hanford, Inc., Richland, Washington.

BHI-01551, Rev. 0. 2002. *Alternative Fine-Grained Soil Borrow Source Study Final Report*. M. J. Galgoul and C. Sump, Bechtel Hanford, Inc., Richland, Washington.

BHI-01606. 2002. *Borehole Summary Report for Borehole C3102 in the 216-T-26, 200-TW-1 Scavenged Waste Group Operable Unit*. M. E. Todd and C. A. Kahler-Royer, Bechtel Hanford, Inc., Richland, Washington.

BHI-01607. 2002. *Borehole Summary Report for Boreholes C3103 and C3104, and Drive Casings C3340, C3341, C3342, C3343, and C3344, in the 216-B-38 Trench and 216-B-7A Crib, 200-TW-2 Tank Waste Group Operable Unit*. M. E. Todd and C. Trice, Bechtel Hanford Inc., Richland, Washington.

BHI-01613. 2002. *116-F-14 Characterization Test Pit Results*. S. W. Clark, Bechtel Hanford Inc., Richland, Washington.

BHI-01624. 2002. *Aquifer Sampling Tubes Data Summary, Fall 2001*. R. F. Raidl, Bechtel Hanford, Inc., Richland, Washington.

BHI-01631, Rev. 0. 2002. *Carbon Tetrachloride Field Investigation Report for Drilling in the Vicinity of the PFP and the 216-Z-9 Trench*. V. J. Rohay, J. M. Faurote, and C. W. Miller, CH2M HILL Hanford, Inc., Richland, Washington.

BHI-01641, Rev. 0. 2002. *Groundwater Monitoring and Sampling at the Environmental Restoration Disposal Facility, Calendar Year 2001*. C. W. Miller, C. S. Wright, and R. S. Edrington, Bechtel Hanford Inc., Richland, Washington.

BHI-01651, Rev. 0. 2002. *200-CS-1 Operable Unit Test Pit Summary Report for Fiscal Year 2002*. C. S. Cearlock and D. L. Bowers, Bechtel Hanford, Inc., Richland, Washington.

BHI-01667, Rev. 0. 2002. *Protection of 300 Area Groundwater from Uranium Contaminated Soils at Remediated Sites*. S. W. Callison and S. W. Clark, prepared by CH2M HILL Hanford, Inc. for Bechtel Hanford, Inc., Richland, Washington.

BHI-100381. 2002. *200-BP-1 Prototype Hanford Barrier Annual Monitoring Report for Fiscal Year 2001*. A. L. Ward, J. K. Linveille, G. W. Gee, and C. D. Wittreich, Bechtel Hanford, Inc., Richland, Washington.

Brodzinski, R. L. and H. L. Nielson. 1980. "A Well-Logging Technique for the In-Situ Determination of Sr-90." *Nuclear Instruments and Methods* 173:299-301.

City of Richland. 2002a. *Horn Rapids Landfill Environmental Monitoring Report – Calendar Year 2001*. City of Richland, Public Works Department, Richland, Washington.

City of Richland. 2002b. *Horn Rapids Landfill Environmental Monitoring Report – First Quarter 2002*. City of Richland, Public Works Department, Richland, Washington.

City of Richland. 2002c. *Horn Rapids Landfill Environmental Monitoring Report – Second Quarter 2002*. City of Richland, Public Works Department, Richland, Washington.

City of Richland. 2002d. *Horn Rapids Landfill Environmental Monitoring Report – Third Quarter 2002*. City of Richland, Public Works Department, Richland, Washington.

Clark, I. D. and P. Fritz. 1997. *Environmental Isotopes in Hydrogeology*. Lewis Publishers, Boca Raton, Florida.

CP-13514, Rev. 0. 2003. *200-PW-1 Operable Unit Report on Step I Sampling and Analysis of the Dispersed Carbon Tetrachloride Vadose Zone Plume*. V. J. Rohay and D. C. Weekes, Fluor Hanford, Inc., Richland, Washington.

Dauble, D. D. and D. G. Watson. 1997. "Status of Fall Chinook Salmon Populations in the Mid-Columbia River, 1948-1992." *North American Journal of Fisheries Management*, Vol. 17, No. 2.

DOE/EIS-0286D. 2002. Draft *Hanford Site Solid (Radioactive and Hazardous) Waste Program Environmental Impact Statement Richland, Washington*. U.S. Deptartment of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-88-20. 1989. *Low-Level Burial Grounds Dangerous Waste Permit Application*. U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-88-21. 1988. *Hanford Facility Dangerous Waste Part A Permit Application* (3 vols.). U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-89-28, Rev. 2. 1994. *216-B-3 Pond System Closure/Post-Closure Plan*. U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-91-03. 1991. *Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities for 1990*. Prepared by Geosciences Group, Westinghouse Hanford Company, Environmental Division for U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-91-32, Draft B. 1991. *Expedited Response Action Proposal (EE/CA & EA) for 200 West Area Carbon Tetrachloride Plume, Appendix B*. V. J. Rohay and V. G. Johnson for the U.S. Department of Energy, Richland Field Office, Richland, Washington.

DOE/RL-91-61. 1991. *T Plant Source Aggregate Area Management Study*. U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-92-23, Rev. 0. 1992. *Hanford Site Groundwater Background*. U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-92-24, Rev. 3. 1995. *Hanford Site Background: Part 1, Soil Background for Inorganics*. U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-92-67, Draft B. 1992. *Final Remedial Investigation Study-Environmental Assessment Report for the 1100-EM-1 Operable Unit, Hanford*. U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-93-43, Rev. 0. 1994. *Limited Field Investigation Report for the 100-HR-3 Operable Unit*. Prepared by IT Corporation for Westinghouse Hanford Company, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-93-73, Rev. 2. 1997. *300 Area Process Trenches Modified Closure/Postclosure Plan.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-93-79, Rev. 0. 1994. *Limited Field Investigation Report for the 100-KR-4 Operable Unit.* Prepared by IT Corporation for Westinghouse Hanford Company, U.S. Department of Energy, Richland, Washington.

DOE/RL-93-88. 1994. *Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities for 1993.* Prepared by Geosciences Group, Westinghouse Hanford Company, Environmental Division for U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-94-95, Rev. 1. 1995. *Hanford Site Groundwater Remediation Strategy.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-95-02, Rev. 0. 1995. *Treatability Report for the 200-UP-1 Operable Unit - Hanford Site.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-95-30. 1995. 200-ZP-1 *Operable Unit Treatability Test Report.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-95-54, Draft B. 1995. *Proposed Plan for Interim Remedial Measures at the 100-FR-1 Operable Unit.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-95-73. 1996. *Operation and Maintenance Plan for the 300-FF-5 Operable Unit.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-95-83. 1995. *The Pilot-Scale Treatability Test Summary for the 100-HR-3 Operable Unit.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-95-92, Decisional Draft. 1995. *Proposed Plan for Interim Remedial Measures at the 100-FR-2 Operable Unit.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-95-110. 1996. *The N-Springs Expedited Response Action Performance Evaluation Report.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-95-111. 1997. *Corrective Measures Study for the 100-NR-1 and 100-NR-2 Operable Units.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-96-12, Rev. 0. 1996. *Hanford Site Background: Part 2, Soil Background for Radionuclides.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-96-39. 1998. *100-NR-1 Treatment, Storage, and Disposal Units Corrective Measure Study/Closure Plan.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-96-42. 1997. *Limited Field Investigation Report for the 300-FF-2 Operable Unit.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-96-61. 1997. *Hanford Site Background: Part 3, Groundwater Background.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-96-105, Rev. 1. 1997. *Richland Environmental Restoration Project Baseline, Multi-Year Work Plan.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-97-48, Rev. 0. 1997. *183-H Postclosure Plan.* J. W. Baden and R. E. Peterson, CH2M HILL Hanford, Inc. for Bechtel Hanford, Inc., U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-98-38, Rev. 0. 1998. *Fiscal Year 1997 Annual Report for the 100-NR-2, 200-UP-1, and 200-ZP-1 Pump and Treat Operations and Operable Units.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-98-66, Rev. 0. 1999. *Focused Feasibility Study for the K-Basins Interim Remedial Action.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-99-11. 1999. *200-BP-1 Prototype Barrier Treatability Test Report.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-99-13. 1999. *Annual Summary Report, February to December 1998, for the 100-HR-3 and 100-KR-4 Pump-and-Treat Operations and Operable Units.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-99-79. 2000. *Fiscal Year 1999 Annual Summary Report for the 200-UP-1, 200-ZP-1, and 100-NR-2 Pump-and-Treat Operations and Operable Units.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2000-01, Rev. 0. 2000. *Annual Summary Report Calendar Year 1999 for the 100-HR-3 and 100-KR-4 Pump-and-Treat Operations and Operable Units.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2000-11, Rev. 1. 2000. *Recommendations for Selection of a Site-Wide Groundwater Flow and Transport Model.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2000-71. 2001. *Fiscal Year 2000 Annual Summary Report for Three 200-UP-1 and 200-ZP-1 Pump-and-Treat Operations.* L. C. Swanson, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2000-72, Rev. 0. 2000. *Performance Assessment Monitoring Plan for the Hanford Site Low-Level Burial Grounds.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2001-53. 2002. *Fiscal Year 2001 Annual Summary Report for the 200-UP-1 and 200-ZP-1 Pump-and-Treat Operations.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2001-67, Rev. 1. 2002. *200-PW-1 Operable Unit Dispersed Carbon Tetrachloride Vadose Zone Plume Sampling and Analysis Plan – Step I.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2002-01, Rev. 0. 2001. *Fiscal Year 2001 Annual Summary Report for the In-Situ REDOX Manipulation Operations.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2002-05. 2001. *Calendar Year 2001 Annual Summary Report for the 100-HR-3, 100-KR-4, and 100-NR-2 Operable Units and Pump-and-Treat Operations.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2002-10. 2002. *Sampling and Analysis Plan for the 200-UP-1 Groundwater Monitoring Well Network.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2002-11. 2002. *300-FF-5 Operable Unit Sampling and Analysis Plan.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2002-39, Rev. 0. 2002. *Standardized Stratigraphic Nomenclature for Post-Ringold-Formation Sediments Within the Central Pasco Basin.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2003-04, Decisional Draft. 2003. *Sampling and Analysis Plan for the 200-PO-1 Groundwater Operable Unit.* M. J. Hartman and J. W. Lindberg, Pacific Northwest National Laboratory, Richland, Washington.

DOE/RW-0164, Vol. 1. 1988. *Site Characterization Plan: Reference Repository Location, Hanford Site, Washington.* U.S. Department of Energy, Office of Civilian Radioactive Waste Management, Washington, D.C.

Ecology - Washington State Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy. 1998. *Hanford Federal Facility Agreement and Consent Order.* Document No. 89-10, Rev. 5 (The Tri-Party Agreement), Olympia, Washington.

Ecology. 2000. *State Waste Discharge Permit ST 4500*. Washington State Department of Ecology, Kennewick, Washington.

Ecology and EPA - Washington State Department of Ecology and U.S. Environmental Protection Agency. 1994. *Action Memorandum: N-Springs Expedited Response Action Cleanup Plan, U.S. Department of Energy Hanford Site, Washington.* Olympia, Washington.

EMF-1865, Addenda 27. 2002. *Quarterly Groundwater Monitoring Summary – Fourth Quarter 2001*. Framatome ANP Richland, Inc., Richland, Washington.

EMF-1865, Addenda 30. 2002. *Quarterly Groundwater Monitoring Summary – Third Quarter 2002*. Framatome ANP Richland, Inc., Richland, Washington.

EMO-1026. 1991. *Addendum to Data Compilation Task Report for the Source Investigation of the 300-FF-1 Operable Unit Phase 1 Remedial Investigations*. J. S. Young and J. S. Fruchter, Pacific Northwest National Laboratory, Richland, Washington.

EPA. 2000. "Explanation of Significant Difference for the 300-FF-5 Record of Decision" (see ROD 1996a). Issued by U.S. Environmental Protection Agency, Region 10, and U.S. Department of Energy, Richland Operations Office, Richland, Washington.

EPA. 2001. *USDOE Hanford Site First Five Year Review Report.* U.S. Environmental Protection Agency, Region 10, Hanford Project Office, Seattle, Washington.

Gee, G. W., M. J. Fayer, M. L. Rockhold, and M. D. Campbell. 1992. "Variations in recharge at the Hanford Site." *Northwest Sci.* 66:237-250.

GJO-96-13-TAR, GJO-HAN-7. 1997. *Spectrum Shape-Analysis Techniques Applied to the Hanford Tank Farms Spectra Gamma Logs*. Prepared by R. D. Wilson, MACTEC-ERS, for the U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJO-97-25-TAR, GJO-HAN-15. 1998. *Enhancements, Validations and Applications of Spectrum Shape-Analysis Techniques Applied to Hanford Tank Farms Spectral Gamma Logs*. Prepared by R. D. Wilson, MACTEC-ERS, for the U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJO-99-113-TAR, GJO-HAN-28. 2000. *Hanford Tank Farms Vadose Zone, B Tank Farm Report*. Prepared by MACTEC-ERS for the U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJO-2001-250-TAR. 2001. *Hanford Geophysical Logging Project Recalibration of a High-Rate Logging System for Characterization of Intense Radiation Zones at the Hanford Site*. Prepared by MACTEC-ERS for the U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJO-2002-322. 2002. *Hanford 200 Areas Spectral Gamma Baseline Characterization Project, Waste Site Summary Report: 216-B-35 to -42 Trenches*. Prepared by MACTEC-ERS for the U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJO-2002-328-TAR. 2002. *Hanford Geophysical Logging Project 2001 Recalibration of Logging Systems for Characterization of Subsurface Contamination at the Hanford Site*. Prepared by MACTEC-ERS for the U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJO-2002-343. 2002. *Hanford 200 Areas Spectral Gamma Baseline Characterization Project, Waste Site Summary Report: 216-B-8 Crib and Adjacent Sites*. Prepared by S. M. Stoller Corporation for the U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJO-2002-358-TAC. 2002. *Hanford 200 Area Spectral Gamma Baseline Characterization Project: 216-B-5 Injection Well and 216-B-9 Crib and Tile Field Waste Site Summary Report*. Prepared by S. M. Stoller Corporation for the U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJO-HAN-11. 1997. *Hanford Tank Farms Vadose Zone, TX Tank Farm Report.* U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJO-HAN-89. 1997. *Hanford Tank Farms Vadose Zone: Tank Summary Data Report for Tank BX-102.* U.S. Department of Energy, Grand Junction Project Office, Grand Junction, Colorado.

GJO-HGLP 1.6.3, Rev. 0. 2002. *Hanford Geophysical Logging Project Data Analysis Manual.* Prepared by MACTEC-ERS for the U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

Grim, R. E. 1968. *Clay Mineralogy.* 2nd edition. McGraw-Hill Book Company, New York, New York.

Hausenbuiller, R. L. 1972. *Soil Science: Principles and Practices.* Wm. C. Brown Company Publishers, Dubuque, Iowa.

Hewitt, A. D. 1994. "Dynamic Study of Common Well Screen Materials." *Ground Water Monitoring and Remediation,* 14(1):87-94.

HNF-5507, Rev. 0. 2000. *Subsurface Conditions Description of the B-BX-BY Waste Management Area.* M. I. Wood, T. E. Jones, R. Schalla, B. N. Bjornstad, and S. M. Narbutovskih, CH2M HILL Hanford Group, Inc., Richland, Washington.

HNF-12236, Rev. 0, Draft. 2002. *Data Quality Objective Summary Report for Establishing a RCRA/CERCLA/AEA Integrated 200-UP-1 and 200-ZP-1 Groundwater Monitoring Network.* M. E. Byrnes and B. A. Williams, Fluor Hanford, Inc., Richland, Washington.

HNF-SD-SNF-TI-009. 1998. *105-K Basin Material Design Basis Feed Description for Spent Nuclear Fuel Project Facilities, Vol. 1, Spent Nuclear Fuel.* A. N. Praga, Duke Engineering & Services Hanford, Richland, Washington.

HNF-SD-WM-TI-740, Rev. 0. 1990. *Standard Inventories of Chemicals and Radionuclides in Hanford Site Tank Wastes.* Prepared by M. J. Kupfer, A. L. Boldt, B. A. Higley, K. M. Hodgson, L. W. Shelton, B. C. Simpson, R. A. Watrous, M. D. LeClair, G. L. Borsheim, R. T. Winward, R. M. Orme, N. G. Colton, S. L. Lambert, D. E. Place, and W. W. Schulz for Lockheed Martin Hanford Corporation, Richland, Washington.

HW-74095. 1963. "Volume 3—Description of the 100-KE and the 100-KW Production Reactor Plants." In: *Hazards Summary Report.* Hanford Atomic Products Operation, General Electric Company, Richland, Washington.

HW-77170. 1963. *Status of the Groundwater Beneath Hanford Reactor Areas: January 1962 to January 1963.* D. J. Brown, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Jenkins, O. P. 1922. *Underground Water Supply of the Region About White Bluffs and Hanford.* Bulletin No. 26, State of Washington Department of Conservation and Development, Division of Geology, Olympia, Washington.

Kearl, P. M. 1997. "Observations of Particle Movement in a Monitoring Well Using the Colloidal Borescope." *Journal of Hydrology* 200:323-344.

LA-UR-96-3860. 1997. *Hanford Tank Chemical and Radionuclide Inventories: HOW Model Rev. 4.* S. F. Agnew, Los Alamos National Laboratory, Los Alamos, New Mexico.

Lindsey K. A., S. P. Reidel, K. R. Fecht, J. L. Slate, A. G. Law, and A. M. Tallman. 1994. "Geohydrologic Setting of the Hanford Site, South-Central Washington" in *Field Trips in the Pacific Northwest: 1994 Geologic Society of America Meeting,* Chapter 1C, D. A. Swanson and R. A. Hagerud (eds.), pp. 1C-1 to 1C-16, Geological Society of America, Boulder, Colorado.

Link, S. O., N. R. Wing, and G. W. Gee. 1995. "The Development of Permanent Isolation Barriers for Buried Wastes in Cool Deserts: Hanford Washington." *J. Arid Land Studies* 4:215-224.

MAC-HGLP 1.6.2, Rev. 0. 2001. *Hanford Geophysical Logging Project, Project Management Plan.* U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

MAC-HGLP 1.6.5, Rev. 0. 2001. *Hanford Geophysical Logging Project, Logging Operation Procedures*. U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

MAC-HGLP 1.8.1, Rev. 0. 2001. *Hanford Tank Farms Vadose Zone Monitoring Project Baseline Monitoring Plan*. U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

Morrison, R. D. 1998. "Determining Surface Release Sources from Soil and Groundwater Contamination." In *Environmental Forensics, Determining Liability Through Applied Science, International Business Communications Executive Forum*, Houston, Texas, September 24-25, 1998.

NAVD88. 1988. North American Vertical Datum of 1988.

NGVD29. 1929. National Geodetic Vertical Datum of 1929.

Narbutovskih, S. M., J. P. McDonald, R. Schalla, and M. D. Sweeney. 2002. "Application of the Colloidal Borescope to Determine a Complex Groundwater Flow Pattern." *Evaluation and Remediation of Low Permeability and Dual Porosity Environments*, ASTM STP1415, M. N. Sara and L. G. Everett (eds.), ASTM International, West Conshohocken, Pennsylvania.

PNL-6716. 1988. *Interim Characterization Report for the 300 Area Process Trenches*. R. Schalla, R. W. Wallace, R. L. Aaberg, S. P. Airhart, D. J. Bates, J.V.M. Carlile, C. S. Cline, D. I. Dennison, M. D. Freshley, P. R. Heller, E. J. Jensen, K. B. Olsen, R. G. Parkhurst, J. T. Rieger, and E. J. Westergard, Pacific Northwest Laboratory, Richland, Washington.

PNL-7147. 1989. *Final Report: Soil Gas Survey at the Solid Waste Landfill*. J. C. Evans, R. M. Freeland, D. W. Glover, and C. Veverka, Pacific Northwest Laboratory, Richland, Washington.

PNL-8167. 1992. *Hydrogeologic Controls on Ground-Water and Contaminant Discharge to the Columbia River Near the Hanford Townsite*. S. P. Luttrell, D. R. Newcomer, S. S. Teel, and V. R. Vermeul, Pacific Northwest Laboratory, Richland, Washington.

PNL-8332. 1992. *Status Report on the Development of a Three-Dimensional Conceptual Model for the Hanford Site Unconfined Aquifer System*. P. D. Thorne and M. A. Chamness, Pacific Northwest Laboratory, Richland, Washington.

PNL-8391. 1993. *Testing and Monitoring Plan for the Permanent Isolation Surface Barrier Prototype*. G. W. Gee, L. L. Cadwell, H. D. Freeman, M. W. Ligotke, S. O. Link, R. A. Romine, and W. H. Walters, Jr., Pacific Northwest Laboratory, Richland, Washington.

PNL-8580. 1993. *Water Level Measurements for Modeling Hydraulic Properties in the 300-FF-5 and 100 Aggregate Area Operable Units*. M. D. Campbell, W. J. McMahon, and K. R. Simpson, Pacific Northwest Laboratory, Richland, Washington.

PNL-8869. 1993. *Preliminary Potentiometric Map and Flow Dynamic Characteristics for the Upper-Basalt Confined Aquifer System*. F. A. Spane, Jr. and R. G. Raymond, Pacific Northwest Laboratory, Richland, Washington.

PNL-8971. 1993. *Three-Dimensional Conceptual Model for the Hanford Site Unconfined Aquifer System, FY 1993 Status Report*. P. D. Thorne, M. A. Chamness, F. A. Spane, Jr., V. R. Vermeul, and W. D. Webber, Pacific Northwest Laboratory, Richland, Washington.

PNL-10094. 1994. *Hydrogeology Along the Southern Boundary of the Hanford Site Between the Yakima and Columbia Rivers, Washington*. T. L. Liikala, Pacific Northwest Laboratory, Richland, Washington.

PNL-10195. 1994. *Three-Dimensional Conceptual Model for the Hanford Site Unconfined Aquifer System, FY 1994 Status Report*. P. D. Thorne, M. A. Chamness, V. R. Vermeul, Q. C. MacDonald, and S. E. Schubert, Pacific Northwest Laboratory, Richland, Washington.

PNL-10817. 1995. *Hydrochemistry and Hydrogeologic Conditions Within the Hanford Upper Basalt Confined Aquifer System*. F. A. Spane, Jr. and W. D. Webber, Pacific Northwest Laboratory, Richland, Washington.

PNNL-10886. 1995. *Development of a Three-Dimensional Ground-Water Model of the Hanford Site Unconfined Aquifer System: FY 1995 Status Report*. S. K. Wurstner, P. D. Thorne, M. A. Chamness, M. D. Freshley, and M. D. Williams, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11218. 1997. *STOMP: Subsurface Transport Over Multiple Phase-Users Guide*. M. D. White and M. Oostrom, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11573. 1997. *Groundwater Monitoring Plan for the 183-H Solar Evaporation Basins*. M. J. Hartman, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11574. 1997. *Results of RCRA Groundwater Quality Assessment Program at the 216-U-12 Crib*. B. A. Williams and C. J. Chou, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11604. 1997. *Results of RCRA Groundwater Quality Assessment at the 216-B-3 Pond Facility*. D. B. Barnett and S. S. Teel, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11633. 1997. *Origin of Increased Sulfate in Groundwater at the ETF Disposal Site*. E. C. Thornton, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11665. 1997. *Tritium Monitoring in Groundwater and Evaluation of Model Predictions for the Hanford Site 200 Area Effluent Treatment Facility*. D. B. Barnett, M. P. Bergeron, C. R. Cole, M. D. Freshley, and S. K. Wurstner, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11800. 1998. *Composite Analysis for Low-Level Waste Disposal in the 200-Area Plateau of the Hanford Site*. C. T. Kincaid, M. P. Bergeron, C. R. Cole, M. D. Freshley, N. Hassig, V. G. Johnson, D. I. Kaplan, R. J. Serne, G. P. Steile, D. L. Strenge, P. D. Thorne, L. W. Vail, G. A. Whyatt, and S. K. Wurstner, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11801. 1997. *Three-Dimensional Analysis of Future Groundwater Flow Conditions and Contaminant Plume Transport in the Hanford Site Unconfined Aquifer System: FY 1996 and 1997 Status Report*. C. R. Cole, S. K. Wurstner, M. P. Bergeron, M. D. Williams, and P. D. Thorne, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11809. 1998. *Results of Phase I Groundwater Quality Assessment for Single-Shell Tank Waste Management Areas T and TX-TY at the Hanford Site*. F. N. Hodges, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11810. 1998. *Results of Phase I Groundwater Quality Assessment for Single-Shell Tank Waste Management Area S-SX at the Hanford Site*. V. G. Johnson and C. J. Chou, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11826. 1998. *Results of Phase I Groundwater Quality Assessment for Single-Shell Tank Waste Management Areas B-BX-BY at the Hanford Site*. S. M. Narbutovskih, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11966. 1998. *Radionuclide Distribution Coefficients for Sediments Collected from Borehole 299-E17-21: Final Report for Subtask 1a*. D. I. Kaplan, K. E. Parker, and I. V. Kutynakov, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11986. 1998. *Evaluation of Groundwater Monitoring Results at the Hanford Site 200 Area Treated Effluent Disposal Facility*. D. B. Barnett, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-12023. 1998. *Groundwater Monitoring for the 100-K Area Fuel-Storage Basins: July 1996 through April 1998*. V. G. Johnson, C. J. Chou, M. J. Hartman, and W. D. Webber, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-12086. 1999. *Hanford Site Groundwater Monitoring for Fiscal Year 1998*. M. J. Hartman (ed.), Pacific Northwest National Laboratory, Richland, Washington.

PNNL-12114. 1999. *RCRA Assessment Plan for Single-Shell Tank Waste Management Area S-SX at the Hanford Site*. V. G. Johnson and C. J. Chou, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-12261. 2000. *Revised Hydrogeology for the Suprabasalt Upper Aquifer System, 200 East Area and Vicinity, Hanford Site Washington*. B. A. Williams, B. N. Bjornstad, R. Schalla, and W. D. Webber, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13021. 1999. *Water-Level Monitoring Plan for the Hanford Groundwater Monitoring Project*. J. P. McDonald, M. A. Chamness, and D. R. Newcomer, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13022. 2000. *Groundwater Quality Assessment Plan for Single-Shell Waste Management Area B-BX-BY at the Hanford Site*. S. M. Narbutovskih, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13023. 2001. *RCRA Groundwater Monitoring Plan for Single-Shell Tank Waste Management Area A-AX at the Hanford Site*. S. M. Narbutovskih, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13024. 2001. *RCRA Groundwater Monitoring Plan for Single-Shell Tank Waste Management Area C at the Hanford Site*. D. G. Horton and S. M. Narbutovskih, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13024-ICN-1. 2002. *Interim Change Notice for RCRA Groundwater Monitoring Plan for Single-Shell Tank Waste Management Area C*. S. M. Narbutovskih and D. G. Horton, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13032. 2000. *Groundwater Monitoring Plan for the Hanford Site 200 Area Treated Effluent Disposal Facility*. D. B. Barnett, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13078. 1999. *Effects of Barometric Fluctuations on Well Water-Level Measurements and Aquifer Test Data*. F. A. Spane, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13080. 1999. *Hanford Site Groundwater: Settings, Sources, and Methods*. M. J. Hartman (ed.), Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13107. 2000. *Identification of a Hanford Waste Site for Initial Deployment of the In Situ Gaseous Reduction Approach*, E. C. Thornton, K. J. Cantrell, J. M. Faurote, T. J Gilmore, K. B. Olsen, and R. Schalla, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13116. 2000. *Hanford Site Groundwater Monitoring for Fiscal Year 1999*. M. J. Hartman, L. F. Morasch, and W. D. Webber (eds.), Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13121. 2000. *Groundwater Monitoring and Tritium-Tracking Plan for the 200 Area State-Approved Land Disposal Site*. D. B. Barnett, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13185. 2000. *Groundwater Quality Assessment Plan for Single-Shell Tank Waste Management Area U at the Hanford Site*. F. N. Hodges and C. J. Chou, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13217. 2000. *Measurement of Tritium in Gas Phase Soil Moisture and Helium-3 in Soil Gas at the Hanford Townsite and 100 K Area*. K. B. Olsen, G. W. Patton, R. Poreda, P. E. Dresel, and J. C. Evans, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13228. 2000. *Evaluation of Elevated Tritium Levels in Groundwater Downgradient from the 618-11 Burial Ground Phase I Investigations*. P. E. Dresel, B. A. Williams, J. C. Evans, R. M. Smith, C. J. Thompson, and L. C. Hulstrom, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13230. 2000. *Hanford Site Environmental Report for Calendar Year 1999*. R. L. Dirkes, R. W. Hanf, and T. M. Poston (eds.), Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13282. 2000. *Groundwater Quality Assessment for Waste Management Area U; First Determination*. F. N. Hodges and C. J. Chou, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13342. 2000. *Analysis of the Hydrologic Response Associated with Shutdown and Restart of the 200-ZP-1 Pump-and-Treat System*. F. A. Spane, Jr., Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13367-ICN-1. 2002. *Interim Change Notice for Groundwater Monitoring Plan for the Hanford Site 216-B-3 Pond RCRA Facility*. D. B. Barnett, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13378. 2001. *Results of Detailed Hydrologic Characterization Tests - Fiscal Year 1999*. F. A. Spane, Jr., P. D. Thorne, and D. R. Newcomer, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13404. 2001. *Hanford Site Groundwater Monitoring for Fiscal Year 2000*. M. J. Hartman, L. F. Morasch, and W. D. Webber (eds.), Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13441. 2000. *RCRA Groundwater Quality Assessment Report for Waste Management Area S-SX (November 1997 through April 2000)*. V. G. Johnson and C. J. Chou, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13447. 2001. *Hanford Site-Wide Groundwater Model Calibration Using Inverse Methodology*. C. R. Cole, M. P. Bergeron, S. K. Wurstner, P. D. Thorne, S. Orr, and M. I. McKinley, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13486. 2001. *Characterization Activities Conducted at the 183-DR Site in Support of an In Situ Gaseous Reduction Demonstration*. E. C. Thornton, T. J Gilmore, K. B. Olsen, R. Schalla, and K. J. Cantrell, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13514. 2001. *Results of Detailed Hydrologic Characterization Tests – Fiscal Year 2000*. F. A. Spane, Jr., P. D. Thorne, and D. R. Newcomer, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13612. 2001. *Groundwater Quality Assessment Plan for Single-Shell Tank Waste Management Area U*. R. M. Smith, F. N. Hodges, and B. A Williams, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13623. 2001. *Transient Inverse Calibration of Site-Wide Groundwater Model to Hanford Operational Impacts from 1943 to 1996 – Alternative Conceptual Model Considering Interaction with Uppermost Basalt Confined Aquifer*. V. R. Vermeul, C. R. Cole, M. P. Bergeron, P. D. Thorne, and S. K. Wurstner, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13641. 2001. *Uncertainty Analysis Framework – Hanford Site-Wide Groundwater Flow and Transport Model*. C. R. Cole, M. P. Bergeron, C. J. Murray, P. D. Thorne, S. K. Wurstner, and P. Rogers, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13652, Rev. 1. 2001. *Geologic and Wireline Borehole Summary from the Second ILAW Borehole (299-E24-21)*. S. P. Reidel, D. G. Horton, and M. M. Valenta, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13674. 2001. *Zone of Interaction Between Hanford Site Groundwater and Adjacent Columbia River*. R. E. Peterson and M. P. Connelly, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13675. 2001. *Measurement of Helium-3/Helium-4 Ratios in Soil Gas at the 618-11 Burial Ground*. K. B. Olsen, P. E. Dresel, and J. C. Evans, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13692. 2002. *Survey of Radiological and Chemical Contaminants in the Near-Shore Environment at the Hanford Site 300 Area*. A Cooperative Environmental Monitoring Project involving the Hanford Site Public Safety and Resource Protection Program (PSRPP) and Washington State Department of Health. G. W. Patton, B. L. Tiller, E. J. Antonio, T. M. Poston, and S. P. Van Verst, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13757-1. 2002. *Characterization of Vadose Zone Sediment: Uncontaminated RCRA Borehole Core Samples and Composite Samples*. R. J. Serne, H. T. Schaef, B. N. Bjornstad, B. A. Williams, D. C. Lanigan, D. G. Horton, R. E. Clayton, V. L. LeGore, M. J. O'Hara, C. F. Brown, K. E. Parker, I. V. Kutnyakov, J. N. Serne, A. V. Mitroshkov, G. V. Last, S. C. Smith, C. W. Lindenmeier, J. M. Zachara, and D. S. Burke, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13757-2. 2002. *Characterization of Vadose Zone Sediment: Borehole 299-W23-19 [SX-115] in the S-SX Waste Management Area*. R. J. Serne, H. T. Schaef, B. N. Bjornstad, D. C. Lanigan, G. W. Gee, C. W. Lindenmeier, R. E. Clayton, V. L. LeGore, M. J. O'Hara, C. F. Brown, R. D. Orr, G. V. Last, I. V. Kutnyakov, D. S. Burke, T. C. Wilson, and B. A. Williams, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13788. 2002. *Hanford Site Groundwater Monitoring for Fiscal Year 2001*. M. J. Hartman, L. F. Morasch, and W. D. Webber (eds.), Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13801. 2002. *Groundwater Quality Assessment Report for Waste Management Area S-SX: (April 2000 through December 2001)*. V. G. Johnson and C. J. Chou, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13818. 2002. *Results of Tank Leak Detection Demonstration Using Geophysical Techniques at the Hanford Mock Tank Site—Fiscal Year 2001*. D. B. Barnett, G. W. Gee, and M. D. Sweeney, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13910. 2002. *Hanford Site Environmental Report for Calendar Year 2001*. T. M. Poston, R. W. Hanf, R. L. Dirkes, and L. F. Morasch (eds.), Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13910, APP. 1. 2002. *Hanford Site Environmental Surveillance Data Report for Calendar Year 2001*. L. E. Bisping, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13910, Appendix 2. 2002. *Hanford Site Near-Facility Environmental Monitoring Data Report for Calendar Year 2001*. C. J. Perkins, B. M. Markes, S. M. McKinney, R. M. Mitchell, and R. C. Roos, Duratek Federal Services, Inc., Northwest Operations, Richland, Washington.

PNNL-13929. 2002. *RCRA Groundwater Quality Assessment Report for Single-Shell Tank Waste Management Area T (January 1998 through December 2001)*. D. G. Horton, F. N. Hodges, V. G. Johnson, and C. J. Chou, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-14022. 2002. *300 Area Uranium Leach and Adsorption Project*. R. J. Serne, C. F. Brown, H. T. Schaef, E. M. Price, M. J. Lindberg, Z. Wang, P. L. Gassman, and J. G. Catalano, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-14027. 2002. *An Initial Assessment of Hanford Impact Performed with the System Assessment Capability*. R. W. Bryce, C. T. Kincaid, P. W. Eslinger, and L. F. Morasch (eds.), Pacific Northwest National Laboratory, Richland, Washington.

PNNL-14029. 2002. *Geologic and Wireline Summaries from Fiscal Year 2002 ILAW Boreholes*. S. P. Reidel and A. M. Ho, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-14031. 2002. *Evaluation of Potential Sources for Tritium Detected in Groundwater at Well 199-K-111A, 100-K Area*. R. E. Peterson, F. A. Spane, K. B. Olsen, and M. D. Williams, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-14033. 2002. *Groundwater Monitoring and Assessment Plan for the 100-K Area Fuel Storage Basins*. R. E. Peterson, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-14038. 2002. *Results of Tritium Tracking and Groundwater Monitoring at the Hanford Site 200 Area State-Approved Land Disposal Site – Fiscal Year 2002*. D. B. Barnett and J. T. Rieger, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-14049. 2002. *Data Quality Objectives Summary Report – Designing a Groundwater Monitoring Network for the 200-BP-5 and 200-PO-1 Operable Units*. E. C. Thornton and J. W. Lindberg, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-14070. 2002. *Groundwater Monitoring Plan for the 216-S-10 Pond and Ditch*. B. A. Williams and C. J. Chou, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-14099. 2002. *Groundwater Conditions at Single-Shell Tank Waste Management Area TX-TY (January 1998 through December 2001)*. D. G. Horton, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-14107. 2002. *Groundwater Chemistry and Hydrogeology of the Upper Saddle Mountains Basalt-Confined Aquifer South and Southeast of the Hanford Site*. D. R. Newcomer, E. C. Thornton, and T. L. Liikala, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-14111. 2002. *Fiscal Year 2003 Integrated Monitoring Plan for the Hanford Groundwater Monitoring Project*. M. J. Hartman, P. E. Dresel, J. W. Lindberg, J. P. McDonald, D. R. Newcomer, and E. C. Thornton, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-14113. 2002. *Results of Detailed Hydrologic Characterization Tests – Fiscal Year 2001*. F. A. Spane, Jr., P. D. Thorne, and D. R. Newcomer, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-14115. 2002. *Hydrologic Characterization Using Vadose Zone Monitoring Tools: Status Report*. G. W. Gee, A. L. Ward, J. B. Sisson, J. M. Hubbell, D. A. Myers, and H. A. Sydnor, Pacific Northwest National Laboratory, Richland, Washington.

Poeter, E. P. and M. C. Hill. 1998. *Documentation of UCODE, A Computer Code for Universal Inverse Modeling*. Water Resources Investigations Report 98-4080, U.S. Geological Survey, Reston, Virginia.

Record of Decision (ROD). 1993. *Record of Decision, USDOE Hanford 1100 Area, Hanford Site, Richland, Washington (1100-EM-1, 1100-EM-2, 1100-EM-3, and 1100-IU-1 Operable Units)*. State of Washington Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Record of Decision (ROD). 1995. *Declaration of the Record of Decision for the 200-ZP-1 Operable Unit*. State of Washington Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Record of Decision (ROD). 1996a. *Declaration of the Record of Decision for the 100-HR-3 and 100-KR-4 Operable Units*. State of Washington Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Record of Decision (ROD). 1996b. *Record of Decision for the 300-FF-1 and 300-FF-5 Operable Units*. State of Washington Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Record of Decision (ROD). 1997. *Declaration of the Record of Decision for the 200-UP-1 Operable Unit*. State of Washington State Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Record of Decision (ROD). 1999a. *Record of Decision for the USDOE Hanford 100-KR-2 Operable Unit K Basins Interim Remedial Action*. (EPA 541-R99-059). Agreement between the U.S. Department of Energy and the U.S. Environmental Protection Agency, with concurrence by the Washington State Department of Ecology, Olympia, Washington.

Record of Decision (ROD). 1999b. *Interim Remedial Action Record of Decision for the 100-NR-1 and -NR-2 Operable Units of the Hanford 100-N Area*. Washington State Department of Ecology, Olympia, Washington.

Record of Decision (ROD). 1999c. *Amended Record of Decision, Decision Summary and Responsiveness Summary for the 100-HR-3 Operable Unit*. U.S. Environmental Protection Agency, Region X, Seattle, Washington.

RHO-BWI-LD-5. 1978. *Geology of Gable Mountain - Gable Butte Area*. K. R. Fecht, Rockwell Hanford Operations, Richland, Washington.

RHO-BWI-ST-5. 1979. "Pasco Basin Hydrology." In *Hydrologic Studies Within the Columbia Plateau, Washington: An Integration of Current Knowledge*. R. E. Gephart, F. A. Spane, Jr., L. S. Leonhart, D. A. Palombo, and S. R. Strait, Rockwell Hanford Operations, Richland, Washington.

RHO-CD-1142. 1981. *Long-Term In Situ Disposal Engineering Study*. M. R. Adams, R. A. Carlson, and P. K. Brockman, Rockwell Hanford Operations, Richland, Washington.

RHO-RE-ST-12 P. 1984. *An Assessment of Aquifer Intercommunication in the B Pond-Gable Mountain Pond Area of the Hanford Site*. M. J. Graham, G. V. Last, and K. R. Fecht, Rockwell Hanford Operations, Richland, Washington.

RPP-7389, Rev. 0. 2001. *Preliminary Inventory Estimates for Single Shell Tank Leaks in B-BX-BY Tank Farms*. T. E. Jones, B. C. Simpson, M. I. Wood, and R. A. Corbin, CH2M HILL Hanford Group, Inc., Richland, Washington.

RPP-7578, Rev. 2. 2002. *Site-Specific SST Phase 1 RFI/CMS Work Plan Addendum for WMAs T and TX-TY*. J. D. Crumpler, CH2M HILL Hanford Group, Inc., Richland Washington.

RPP-10098, Rev. 0. 2003. *Field Investigation Report for Waste Management Area B-BX-BY*. A. J. Knepp, CH2M HILL Hanford Group, Inc., Richland, Washington.

Savelieva, E., M. Kanevski, V. Timonin, A. Pozdnukhov, C. Murray, T. Scheibe, Y. Xie, P. Thorne, and C. Cole. 2002. "Uncertainty in the Hydrogeologic Structure Modeling." *In Proceedings of the Annual Conference of the International Association for Mathematical Geology*, Berlin, Germany, September 15-20, 2002.

Thorne, P. D., C. J. Murray, C. R. Cole, M. P. Bergeron, and S. K. Wurstner. 2001. "Capturing Hydrogeologic Uncertainty in Transport Predictions at the Hanford Site, Washington." *In Proceedings of the 2001 International Containment and Remediation Technology Conference*, Orlando, Florida, June 10-13, 2001.

UCRL-JC-122180. 1995. *Detection of Leaks in Underground Storage Tanks Using Electrical Resistance Methods*. A. Ramirez, W. Daily, A. Binley, D. LaBrecque, and D. Roelant, Lawrence Livermore National Laboratory, Livermore, California.

UCRL-JC-122875. 1996. "Tank Leak Detection Using Electrical Resistance Methods." A. Ramirez, W. Daily, A. Binley, and D. LaBrecque, prepared for the *Symposium on the Application of Geophysics to Engineering and Environment*, Keystone, Colorado, Lawrence Livermore National Laboratory, Livermore, California.

Ward, A. L. and G. W. Gee. 1997. "Performance Evaluation of a Field-Scale Surface Barrier." *J. Environ. Qual.* 26:694-705.

Ward, A. L. and G. W. Gee. 2000. "Hanford Site Surface Barrier Technology." In *Vadose Zone Science and Technology Solutions*, pp. 1415-1423, B. B. Looney and R. W. Falta (Eds.), Battelle Press, Columbus, Ohio.

WHC-EP-0133. 1988. *U1/U2 Uranium Plume Characterization, Remedial Action Review and Recommendation for Future Action*. S. M. Baker, J. L. Devary, R. P. Elmore, R. L. Lorang, A. J. Rossi, and M. D. Freshley, Westinghouse Hanford Company, Richland, Washington.

WHC-EP-0587. 1992. *Groundwater Impact Assessment Report for the 400 Area Ponds*. D. K. Tyler, Westinghouse Hanford Company, Richland, Washington.

WHC-EP-0595. 1993. *Westinghouse Hanford Company Operational Groundwater Status Report 1990-1992*. V. G. Johnson, Westinghouse Hanford Company, Richland, Washington.

WHC-EP-0675. 1993. *Groundwater Impact Assessment Report for the 1325-N Liquid Waste Disposal Facility*. D. J. Alexander and V. G. Johnson, Westinghouse Hanford Company, Richland, Washington.

WHC-MR-0415. 1993. *Miscellaneous Information Regarding Operation and Inventory of 618-10 Burial Ground*. C. R. Webb, Westinghouse Hanford Company, Richland, Washington.

WHC-SA-1674-VA. 1992. *Characterization of a Chromium Plume in Groundwater Along the Columbia River Shoreline, Hanford Site, Washington*. R. E. Peterson and M. P. Connelly, Westinghouse Hanford Company, Richland, Washington. (Presented at 1992 Fall Meeting, American Geophysical Union, San Francisco, December 7-11, 1992.)

WHC-SA-3035-VA. 1996. *Electrical Resistivity Tomography at the DOE Hanford Site*. S. M. Narbutovskih, T. D. Halter, M. D. Sweeney, W. Daily, and A. L. Ramirez, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-EN-AP-015, Rev. 0. 1989. *Revised Ground-Water Monitoring Plan for the 200 Areas Low-Level Burial Grounds*. G. V. Last and B. N. Bjornstad, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-EN-AP-108. 1993. *Interim-Status Groundwater Quality Assessment Plan for the 216-U-12 Crib*. C. J. Chou and B. A. Williams, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-EN-AP-132, Rev. 0. 1993. *Interim-Status Groundwater Quality Assessment Plan for the Single-Shell Tank Waste Management Areas T and TX-TY*. J. A. Caggiano and C. J. Chou, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-EN-AP-174. 1995. *Groundwater Monitoring and Assessment Plan for the 100-K Area Fuel Storage Basins*. V. G. Johnson, C. J. Chou, and J. W. Lindberg, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-EN-AP-191, Rev. 0. 1996. *Assessment Groundwater Monitoring Plan for Single Shell Tank Waste Management Area S-SX*. J. A. Caggiano, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-EN-TA-004, Rev. 0. 1996. *Feasibility of CPT-Deployed Vertical Electrode Array in Single-Shell Tank Farms*. S. M. Narbutovskih, D. F. Iwatate, M. D. Sweeney, A. L. Ramirez, W. Daily, R. M. Morey, and L. Christensen, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-EN-TI-101. 1993. *Carbon Tetrachloride Evaporative Losses and Residual Inventory Beneath 200 West Area at the Hanford Site*. Prepared by Ebasco Services for Westinghouse Hanford Company, Richland, Washington.

WHC-SD-EN-TI-181. 1993. *100-D Technical Baseline Report*. R. W. Carpenter, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-EN-TI-199. 1993. *Nonradioactive Dangerous Waste Landfill Soil-Gas Survey: Final Data Report*. I. D. Jacques, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-EN-TI-221, Rev. 0. 1994. *Geology of the 100-FR-3 Operable Unit, Hanford Site, South-Central Washington*. R. F. Raidl, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-EN-TI-239. 1994. *100-K Area Technical Baseline Report*. R. W. Carpenter and S. L. Cotè, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-EN-TI-248, Rev 0. 1994. *1994 Conceptual Model of the Carbon Tetrachloride Contamination in the 200 West Area at the Hanford Site*. V. J. Rohay, K. J. Swett, and G. V. Last, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-EN-TI-280, Rev. 2. 1995. *Groundwater Monitoring Results for the 100-K Area Fuel Storage Basins: January to June, 1995*. V. G. Johnson and S. D. Evelo, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-SNF-TI-013, Rev. 0. 1995. *K-Basins Environmental Impact Statement Technical Input*. K. E. Bergsman, T. B. Bergman, D. W. Bergmann, G. E. Costley, M. T. Jansky, D. S. Leach, R. L. McCormick, M. J. Monthey, A. N. Praga, I. K. Ullah, W. L. Willis, and A. G. Hosler, Westinghouse Hanford Company, Richland, Washington.

Wilson, R. D., C. J. Koizumi, J. E. Meisner, and D. C. Stromswold. 1997. *Spectral Shape Analysis for Contaminant Logging at the Hanford Site*. 1997 IEEE Nuclear Science Symposium, Albuquerque, November 1997.

Wing, N. R. and G. W. Gee. 1994. "Quest for the Perfect Cap." *Civil Engr.* 64(10):38-41.

Appendix A

Supporting Information for RCRA Units, Regulated Units, CERCLA Operable Units, and *Atomic Energy Act of 1954* Monitoring

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Appendix A

Supporting Information for RCRA Units, Regulated Units, CERCLA Operable Units, and *Atomic Energy Act of 1954* Monitoring

M. J. Hartman

This appendix contains supplemental information for waste disposal facilities or groundwater operable units on the Hanford Site that require groundwater monitoring. Most of these are regulated under the *Resource Conservation and Recovery Act* (RCRA) (WAC 173-303), on which this appendix is focused (Figure A.1). Text and tables include information required by RCRA regulations (e.g., assessing the adequacy of the monitoring networks). The appendix also covers three treated effluent disposal facilities (WAC 173-216), one solid waste landfill (WAC 173-304), the 100-K Fuel Storage Basins, and various groundwater operable units (*Comprehensive Environmental Response, Compensation, and Liability Act* [CERCLA]). This appendix also summarizes exceedance of drinking water standards and U.S. Department of Energy (DOE) derived concentration guides.

A.1 RCRA Sites

RCRA groundwater monitoring continued during fiscal year 2002 at 24 waste management areas. Table A.1 lists the monitoring status for RCRA facilities at the end of fiscal year 2002. Estimates of groundwater velocity, and supporting data, are shown for RCRA sites in Table A.2. Table A.3 lists wells exceeding maximum contaminant levels for each RCRA unit during fiscal year 2002. RCRA units are discussed below in alphanumeric order.

A.1.1 116-N-1 (1301-N) Liquid Waste Disposal Facility

The 116-N-1 liquid waste disposal facility is monitored in accordance with a RCRA interim status indicator evaluation program (40 CFR 265, as referenced by WAC 173-303-400). The closure plan for this facility was incorporated into a modification of the Hanford Site RCRA Permit in 1999 (Ecology 1994). Remedial actions will be integrated with the 100-NR-1 and 100-NR-2 Operable Units. The closure plan (DOE/RL-96-39) states that RCRA monitoring during closure activities will continue according to BHI-00725. That plan is supplemented by PNNL-13914, which includes additional information on sampling and analysis, quality control, and statistical evaluation methods.

With one exception, upgradient and downgradient wells were sampled twice in fiscal year 2002 for contamination indicator parameters (pH, specific conductance, total organic carbon, and total organic halides) and once for groundwater quality and site-specific parameters (Table A.4 and Figure A.2). Upgradient well 199-N-57 was not sampled as scheduled in September 2002 because of problems with the pump. The pump was repaired, and the well was sampled in November 2002. Upgradient/downgradient comparison values for indicator parameters have been revised based on recent data for use in fiscal year 2003 comparisons (Table A.5).

Downgradient well 199-N-3 had pH values below the critical range in March and September 2002. DOE submitted an assessment report[a] to the Washington State Department of Ecology concluding that the below-background pH is part of the overall distribution of pH in the area, and does not appear to indicate contamination from the facility (see Section 2.4.10 of main text). Detection monitoring will continue.

The groundwater flow direction is not expected to change in the near future, and there are no plans to modify the network in fiscal year 2003. Table A.3 lists constituents that exceeded maximum contaminant levels in fiscal year 2002.

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[a] Letter report 02-GWVZ-0029 from J. G. Morse (U.S. Department of Energy, Richland, Washington) to J. Hedges (Washington State Department of Ecology, Kennewick, Washington), *Notification of Exceedance of Critical Range for pH in 1301-N Facility*, dated July 8, 2002.

A.1.2 120-N-1 and 120-N-2 (1324-N/NA) Facilities

The 120-N-2 (1324-N) surface impoundment and 120-N-1 (1324-NA) percolation pond are monitored in accordance with RCRA interim status indicator evaluation programs (40 CFR 265, as referenced by WAC 173-303-400). The closure plan for these facilities were incorporated into a modification of the Hanford Site RCRA Permit in 1999 (Ecology 1994). Remedial actions will be integrated with the 100-NR-1 and 100-NR-2 Operable Units. The closure plan (DOE/RL-96-39) states that RCRA monitoring during closure activities will continue according to BHI-00725. That plan is supplemented by PNNL-13914, which includes additional information on sampling and analysis, quality control, and statistical evaluation methods.

In fiscal year 2002, all but one of the monitoring wells for this site were sampled twice for contamination indicator parameters and groundwater quality and site-specific parameters (see Table A.4 and Figure A.2). Downgradient well 199-N-59 contained too little water to sample in March 2002, but was sampled in September 2002.

Average specific conductance values in wells downgradient of the facilities continued to exceed the critical mean value in fiscal year 2002. A previous groundwater quality assessment indicated that the high specific conductance is caused by the non-hazardous constituents sulfate and sodium (WHC-SD-EN-EV-003). Because an assessment has already been completed and non-hazardous constituents caused the high conductance, detection monitoring will continue.

The groundwater flow direction is not expected to change in the near future, and there are no plans to modify the network in fiscal year 2003. Table A.3 lists constituents that exceeded maximum contaminant levels in fiscal year 2002. Upgradient/downgradient comparison values for indicator parameters were revised based on recent data, for use in fiscal year 2003 comparisons (Table A.6).

A.1.3 116-N-3 (1325-N) Liquid Waste Disposal Facility

The 116-N-3 liquid waste disposal facility is monitored in accordance with RCRA interim status indicator evaluation programs (40 CFR 265, as referenced by WAC 173-303-400). The closure plan for this facility was incorporated into a modification of the Hanford Site RCRA Permit in 1999 (Ecology 1994). Remedial actions will be integrated with the 100-NR-1 and 100-NR-2 Operable Units. The closure plan (DOE/RL-96-39) states that RCRA monitoring during closure activities will continue according to BHI-00725. That plan is supplemented by PNNL-13914, which includes additional information on sampling and analysis, quality control, and statistical evaluation methods.

During fiscal year 2002, upgradient and downgradient wells were sampled twice for contamination indicator parameters (pH, specific conductance, total organic carbon, and total organic halides) and once for groundwater quality and site-specific parameters (see Table A.4 and Figure A.2). Upgradient/downgradient comparison values for indicator parameters were revised based on recent data for use in fiscal year 2003 (Table A.7).

Average specific conductance values in downgradient wells 199-N-41 and 199-N-81 continued to exceed the critical mean value in fiscal year 2002. This was a continuation of previous exceedances noted in 1999 through 2001. DOE notified the Washington State Department of Ecology of that original exceedance and submitted an assessment report that concluded the exceedance was caused by past discharges of non-hazardous constituents to an upgradient facility. Detection monitoring will continue.

Groundwater flow direction is not expected to change in the near future, and there are no plans to modify the networks in fiscal year 2003. Table A.3 lists constituents that exceeded maximum contaminant levels in fiscal year 2002.

A.1.4 116-H-6 (183-H) Evaporation Basins

This unit continued to be monitored in accordance with a final status corrective-action program during fiscal year 2002 [WAC 173-303-645(11)(g)]. The unit was incorporated into the Hanford Site RCRA Permit (Ecology 1994). Groundwater remediation is integrated with the 100-HR-3 Operable Unit, where remediation for chromium is underway. While the pump-and-treat system is operating, RCRA monitoring consists of annual sampling of four wells for chromium, fluoride, nitrate, technetium-99, and uranium (PNNL-11573; Table A.8 and Figure A.3). The objective of monitoring during the operation of the pump-and-treat system is to determine whether concentrations of the contaminants of concern are decreasing. The wells were sampled in November 2001. Two semiannual letter reports that document the effectiveness of the corrective action program were submitted to the Washington State Department of Ecology during fiscal year 2002.[b]

The current monitoring network was designed to accommodate groundwater flow imposed by the pump-and-treat system, and no changes are planned for fiscal year 2003. Table A.3 lists constituents that exceeded maximum contaminant levels in fiscal year 2002.

A.1.5 216-A-29 Ditch

The 216-A-29 ditch continued to be monitored under an interim status indicator evaluation program in fiscal year 2002 (Table A.9 and Figure A.4). Groundwater contamination indicator parameter data from downgradient wells were compared to values established from the upgradient wells. Average specific conductance values at downgradient wells 299-E25-35 and 299-E25-48 exceeded the critical mean value and were caused by increases in sulfate, sodium, and calcium. The exceedances were reported previously and detection monitoring will continue, because the elevated specific conductance is linked to non-hazardous constituents. Replicate averages for other contamination indicator parameters were below their respective background values during fiscal year 2002. Upgradient/downgradient comparison values for fiscal year 2003 comparisons are listed in Table A.10. The current network effectively monitors the site.

A.1.6 216-B-3 Pond

In fiscal year 2002, groundwater monitoring at the 216-B-3 pond (B Pond) continued under an interim status indicator evaluation program. The current network includes three downgradient wells and one upgradient well (Figure A.5), which effectively monitors the site. Samples are collected semiannually in these wells for the list of constituents shown in Table A.11.

In May 2001, Washington State Department of Ecology issued a letter[c] providing special guidance for groundwater monitoring at B Pond because the standard indicator parameters evaluation and accompanying interim status statistical approach is inappropriate for detecting potential B-Pond-derived contaminants in groundwater. This guidance allows intra-well comparisons of results for gross alpha, gross beta, and specific conductance for a trial period of 2 years. Based on the results of this trial evaluation, Washington State Department of Ecology would decide whether to continue, modify, or abandon the alternative approach. The groundwater project released an update to the groundwater monitoring plan (PNNL-13367-ICN-1) in March 2002 to reflect these changes. The alternative statistical method consists of the combination of a Cumulative Sum (CUSUM) calculation to determine long-term trends, and a Shewhart procedure that is sensitive to sudden shifts in mean concentrations for each well individually. During fiscal year 2002, the Shewhart mean-plus-two-sigma level was briefly exceeded in well 699-43-45 for gross beta, and the CUSUM mean-plus-two-sigma levels for gross beta and specific conductance were marginally exceeded in this well. Table A.12 lists control limits for gross alpha, gross beta, and specific conductance.

A.1.7 216-B-63 Trench

In fiscal year 2002, groundwater monitoring provided no evidence that dangerous, non-radioactive constituents from the 216-B-63 trench have entered groundwater. The well network was sampled twice for the indicator parameters pH, specific conductance, total organic carbon, and total organic halides (Table A.13 and Figure A.6). All replicate averages for groundwater contamination indicator parameters were below their respective background values during

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[b] Letter report 02-GWVZ-0020 from J. G. Morse (U.S. Department of Energy, Richland, Washington) to J. Hedges (Washington State Department of Ecology, Kennewick, Washington), *Resource Conservation and Recovery Act (RCRA) Final Status/ Corrective Action Semiannual Reports*, dated April 16, 2002.

Letter report 03-WMD-0028 from J. G. Morse (U.S. Department of Energy, Richland, Washington) to J. Hedges (Washington State Department of Ecology, Kennewick, Washington), *Resource Conservation and Recovery Act (RCRA) Final Status/ Corrective Action Semiannual Reports for April through June 2002*, dated October 30, 2002.

[c] Letter from D. Goswami (Washington State Department of Ecology, Olympia, Washington) to M. Furman (U.S. Department of Energy, Richland, Washington), *Statistical Assessment for the 300 Area Resource Conservation and Recovery Act of 1976 (RCRA) Ground Water Monitoring Plan*, dated May 7, 2001.

fiscal year 2002. Upgradient/downgradient comparison values for statistical evaluations in fiscal year 2003 are listed in Table A.14. The current network effectively monitors the site.

A.1.8 216-S-10 Pond and Ditch

During fiscal year 2002, this facility continued to be monitored semiannually under a RCRA interim status indicator evaluation program (Table A.15 and Figure A.7). Statistical evaluations of indicator parameter data have not indicated that the facility has affected the groundwater quality in the uppermost aquifer beneath the site. Upgradient/downgradient comparison values for fiscal year 2003 are listed in Table A.16. The direction of groundwater flow and estimated flow rate are listed in Table A.2.

Because other network wells have gone dry, the 216-S-10 pond and ditch are currently monitored by one upgradient well and one shallow downgradient well. The groundwater project predicts that at the current rate of water table decline upgradient well 299-W26-7 will go dry in 2003. A revised groundwater monitoring plan (PNNL-14070) proposes a revised monitoring network for fiscal year 2003 and updates the list of constituents based on monitoring results from the past 11 years. Washington State Department of Ecology and DOE annually negotiate installation of future monitoring wells under Tri-Party Agreement Milestone M-24 (Ecology et al. 1998).

The chromium concentration rose in well 299-W26-7 during fiscal year 2002 to near the 100-μg/L maximum contaminant level, and reached 191 μg/L in December 2002. Chromium concentrations were even higher in this well between 1995 and 1998, reaching a high of 576 μg/L, then declining below 20 μg/L. This well is the upgradient well used for statistical comparisons of contamination indicator parameters, but is so close to the 216-S-10 pond that it may be affected by past discharges to the pond. The elevated chromium does not affect the indicator parameters significantly. Potential sources of chromium also exist upgradient of the site. The recent data from this well are questionable because the well is nearly dry, which may affect the sample chemistry.

A new groundwater monitoring plan was released in fiscal year 2002 (PNNL-14070). The plan proposes deepening the upgradient well and one of the dry, downgradient wells, and installing one new downgradient well in conjunction with the 200-UP-1 Operable Unit in 2003.

A.1.9 216-U-12 Crib

This RCRA unit continued to be monitored under an interim status groundwater quality assessment program in fiscal year 2002. Assessment monitoring began in 1993 because of elevated specific conductance in two downgradient wells. In fiscal year 2002, network monitoring wells were sampled quarterly for constituents of interest (Table A.17 and Figure A.8).

Based on the results of the assessment investigation (PNNL-11574), the site remains in interim status assessment monitoring because of continued elevated levels of nitrate. Site-wide monitoring evaluates the extent of this plume. The rate and direction of groundwater flow (see Table A.2) and the extent of contamination at this site are discussed in Section 2.8.

The crib will not receive additional effluents and is scheduled, according to provisions of the Hanford Site RCRA Permit (Ecology 1994), to be closed in accordance with WAC 173-303-610 in 2005.

Currently, the 216-U-12 crib is monitored by only two downgradient wells (299-W22-79 and 699-36-70A) because of declining water levels. Washington State Department of Ecology and DOE annually negotiate installation of future monitoring wells under Tri-Party Agreement Milestone M-24 (Ecology et al. 1998).

Sample results that exceeded drinking water standards and maximum contaminant levels are presented in Table A.3. Concentrations of nitrate, the primary constituent responsible for the elevated specific conductance, exceeded the 45-mg/L maximum contaminant level in both monitoring wells in fiscal year 2002 (see Table A.3).

A.1.10 316-5 Process Trenches

This site continued to be monitored with a final status corrective-action network (Table A.18; Figure A.9). The objective of groundwater monitoring during the corrective-action period is to monitor the trend of the constituents of concern in areas downgradient of the trenches to confirm that the concentrations are attenuating naturally, as expected by the CERCLA record of decision for the 300-FF-5 Operable Unit (ROD 1996a). A groundwater monitoring plan

(PNNL-13645) for corrective action has been implemented as a demonstration of an alternative monitoring approach. The two upgradient wells were eliminated and five other wells were added to the network downgradient of the trenches. The well network was changed to accommodate the monitoring objective during the corrective-action period. The new plan implemented an alternative statistical method for a trial period of 2 years. Based on the results of this trial evaluation, Washington State Department of Ecology would decide whether to continue, modify, or abandon the alternative approach. Results were analyzed using the Combined Shewhart-CUSUM Control chart statistical approach (Westgard et al. 1977; Lucas 1982). Also, each well showing an exceedance of maximum contaminant levels by one of the constituents of concern was sampled quarterly to better follow the trends of contaminant concentration. The other wells in the network continued to be sampled semiannually. Two semiannual letter reports(d) that document the effectiveness of the corrective action program were submitted to Washington State Department of Ecology during fiscal year 2002. Uranium and cis-1,2-dichloroethene continued to exceed concentration limits specified in the permit in one or more wells (see Table A.3).

A.1.11 Liquid Effluent Retention Facility

During fiscal year 2002, the Liquid Effluent Retention Facility was monitored by one upgradient and one downgradient well (Table A.19 and Figure A.10) because the other two downgradient wells failed to produce representative groundwater (see Appendix C for dry wells). Negotiations continue between Washington State Department of Ecology, DOE, and contractors in an effort to formulate a final status monitoring strategy for the Liquid Effluent Retention Facility. In January 2001, Washington State Department of Ecology directed DOE to suspend statistical evaluation of groundwater data at the facility.

A.1.12 Low-Level Waste Management Area 1

Groundwater monitoring under interim status requirements continued at this site in fiscal year 2002. The well network was sampled twice for groundwater contamination indicator and site-specific parameters (Table A.20 and Figure A.11). Downgradient monitoring wells 299-E33-34 and 299-E32-10 continued to exceed the critical mean for specific conductance during fiscal year 2002. This exceedance is related to the nitrate plume from the vicinity of the BY cribs and not Low-Level Waste Management Area 1. DOE submitted a letter of notification that also served as an assessment report to the Washington State Department of Ecology in 1999. Because no waste has been placed in the north portion of this site and there is a known nitrate plume from an upgradient source, no further action is required. Upgradient/downgradient comparison values for fiscal year 2003 statistical evaluations are listed in Table A.21. Results exceeding maximum contaminant levels are listed in Table A.3.

No wells in the network went dry in fiscal year 2002 and the monitoring network will remain the same in fiscal year 2003.

DOE submitted an application for a RCRA permit for all the burial grounds in fiscal year 2002 that included final-status groundwater monitoring under WAC 173-303-645. Washington State Department of Ecology reviewed the application and DOE will revise it in fiscal year 2003. Final-status monitoring will begin following the effective date of the permit.

A.1.13 Low-Level Waste Management Area 2

This site continued in RCRA interim status indicator evaluation during fiscal year 2002. Wells were sampled twice for groundwater contamination indicator and site-specific parameters (Table A.22 and see Figure A.6). Upgradient well 299-E34-7 continued to exceed the critical mean for specific conductance in fiscal year 2002. The major contributors to the increase are sulfate, chloride, and calcium. The source of these constituents is not known. This well also

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(d) Letter report 02-GWVZ-0020 from J. G. Morse (U.S. Department of Energy, Richland, Washington) to J. Hedges (Washington State Department of Ecology, Kennewick, Washington), *Resource Conservation and Recovery Act (RCRA) Final Status/Corrective Action Semiannual Reports*, dated April 16, 2002.

Letter report 03-WMD-0028 from J. G. Morse (U.S. Department of Energy, Richland, Washington) to J. Hedges (Washington State Department of Ecology, Kennewick, Washington), *Resource Conservation and Recovery Act (RCRA) Final Status/Corrective Action Semiannual Reports for April through June 2002*, dated October 30, 2002.

exceeded the critical mean values for total organic carbon and total organic halides in fiscal year 2002 (see Section 2.9.1.13). Table A.23 lists the upgradient/downgradient comparison values for fiscal year 2003 statistical evaluations. Table A.3 summarizes constituents exceeding maximum contaminant levels.

The monitoring network for Low-Level Waste Management Area 2 is distributed around the facility on all sides where an unconfined aquifer is present above the basalt surface. Thus, it is suitable for detecting releases from the facility. However, the continued water-level decline is causing additional wells to go dry. One well became unsampleable in fiscal year 2002 (see Appendix C). Monitoring wells in this area are all completed at the top of basalt.

A.1.14 Low-Level Waste Management Area 3

This RCRA site continued to be monitored under interim status indicator evaluation requirements. Groundwater monitoring wells were sampled twice in fiscal year 2002 (Table A.24 and Figure A.12). Groundwater contamination indicator parameter data from monitoring wells were statistically evaluated, and values from downgradient wells were compared to values established from the upgradient wells. Table A.25 lists upgradient/downgradient comparison values for fiscal year 2003 statistical evaluations. Contaminant concentrations that exceeded maximum contaminant levels are listed in Table A.3.

Because of the changing groundwater flow direction and the continuing decline in water levels, this network only marginally monitors this waste management area. Four wells were not able to be sampled during fiscal year 2002 due to declining water levels (see Appendix C). Under current flow directions, wells 299-W10-19 and 299-W10-20 remain upgradient of the east portion of the waste management area but are downgradient of the southwest part of the waste management area. Washington State Department of Ecology and DOE annually negotiate installation of future monitoring wells under Tri-Party Agreement Milestone M-24 (Ecology et al. 1998).

A.1.15 Low-Level Waste Management Area 4

Wells were sampled semiannually for contamination indicator parameters in accordance with RCRA interim status regulations (Table A.26 and Figure A.13). Downgradient well 299-15-16 continued to exceed the critical mean value for total organic halides in fiscal year 2002. This well was at one time an upgradient monitoring well and is still affected by contamination from other sources. DOE reported the exceedance to the U.S. Environmental Protection Agency (EPA) and Washington State Department of Ecology in 1999. Upgradient/downgradient comparison values for fiscal year 2003 statistical evaluations are listed in Table A.27. Contaminant concentrations that exceeded maximum contaminant levels are listed in Table A.3.

This monitoring network requires upgrading to satisfy RCRA requirements. There are currently three downgradient wells (including one deep well) and four upgradient wells (including one deep well). Washington State Department of Ecology and DOE annually negotiate installation of future monitoring wells under Tri-Party Agreement Milestone M-24 (Ecology et al. 1998).

A.1.16 Nonradioactive Dangerous Waste Landfill

This RCRA site continued to be monitored under an interim status indicator evaluation program in fiscal year 2002 (Table A.28 and Figure A.14). Statistical evaluations of groundwater contamination indicator parameters indicate the site has not adversely affected groundwater quality. However, average values of specific conductance in downgradient wells 699-25-34A, 699-25-34D, and 699-26-33 have been increasing in recent years and exceeded the critical mean value (566.3 µS/cm) again in fiscal year 2002. DOE notified the Washington State Department of Ecology of an earlier exceedance in fiscal year 2001. The rise in specific conductance is most likely due to waste discharges at the adjacent Solid Waste Landfill and are not due to the Nonradioactive Dangerous Waste Landfill. Therefore, no further action was taken. Specific conductance (and the other indicator parameters) will continue to be monitored at the Nonradioactive Dangerous Waste Landfill, as well as at the Solid Waste Landfill, to determine if the Nonradioactive Dangerous Waste Landfill is affecting groundwater quality. Table A.29 lists upgradient/downgradient comparison values based on recent data, for use in fiscal year 2003.

Well 699-25-34B was not sampled during fiscal year 2002 because of declining water levels. The groundwater project will attempt to lower the pump enough to obtain samples in fiscal year 2003. If that is unsuccessful, the well should be deepened or replaced because it is needed to maintain an adequate network for detection monitoring.

A.1.17 PUREX Cribs

The 216-A-10, 216-A-36B, and 216-A-37-1 cribs continued to be monitored under a RCRA interim status groundwater quality assessment program in fiscal year 2002 (Table A.30 and see Figure A.4). The sites are monitored as a single waste management area because they have similar hydrogeology and waste constituents.

Since fiscal year 2000, two wells (299-E17-9 near the 216-A-36B crib, and 299-E25-17 near the 216-A-37-1 crib) have been difficult to sample because of their age and low water levels. Wells 299-E17-16 and 299-E25-18 were selected to replace the original wells when they can no longer be sampled. Well 299-E17-9 could not be sampled during fiscal year 2002 and will be replaced by well 299-E17-16. However, well 299-E17-16 had lower contaminant concentrations than well 299-E17-9. In fiscal year 2003, the groundwater project will determine whether the well should be deepened or replaced with a new well. Washington State Department of Ecology and DOE annually negotiate installation of future monitoring wells under Tri-Party Agreement Milestone M-24 (Ecology et al. 1998).

The rate and extent of contamination are discussed in Section 2.9.2 of the main text. Knowledge of the groundwater flow direction and flow rate in the southeast portion of the 200 East Area did not change significantly during fiscal year 2002 (see Table A.2). Therefore, the network will not be modified in fiscal year 2003. Many of the far-field wells that formerly were sampled annually are now sampled every 3 years. These wells track the extent and flow rate of the extensive nitrate plume that changes very little in a 3-year period. This change was incorporated in two updates of the groundwater monitoring plan along with corrections to outdated procedural references (PNNL-11523). During fiscal year 2003, the far-field wells will also be incorporated in the 200-PO-1 Operable Unit under a sampling and analysis plan currently being written.

During fiscal year 2002, manganese and nitrate continued to exceed its maximum contaminant level in areas downgradient of the Plutonium-Uranium Extraction (PUREX) Plant cribs (see Table A.3). Manganese concentrations were elevated in previous years in wells downgradient of the 216-A-37-1 crib, but subsequently decreased to levels below the maximum contaminant level (50 µg/L). However, the concentration of manganese at well 299-17-9 (near the 216-A-36B crib) increased to a maximum of 191 µg/L in October 2000. In October 2001, it was down to 50.5 µg/L. The major nitrate plume extends beyond the near-field monitoring well network at the PUREX cribs. The far-field monitoring network (and the 200-PO-1 Operable Unit sampling and analysis plan starting in fiscal year 2003) monitors the nitrate plume.

A.1.18 Single-Shell Tanks Waste Management Area A-AX

This site continued to be monitored under an interim status indicator evaluation program in fiscal year 2002. Wells were sampled twice for groundwater contamination indicator and site-specific parameters (Table A.31 and Figure A.15). Indicator parameter data from monitoring wells were statistically evaluated, and values from downgradient wells were compared to those established from the upgradient wells. The indicator parameters (specific conductance, total organic carbon, and total organic halides) did not exceed critical mean values during fiscal year 2002. The pH value reported in downgradient well 299-E25-46 for the June 2002 sampling event was 6.64, which is below the critical range of 6.81 to 9.67. Verification sampling conducted in July 2002 showed this value was in error and that the correct pH value was 7.0. Table A.32 lists updated upgradient/downgradient comparison values for statistical evaluations in fiscal year 2003, and Table A.3 summarizes results exceeding maximum contaminant levels for fiscal year 2002.

The groundwater project revised the monitoring plan for this site in 2002 (PNNL-13023-ICN-1). The revision described an improved understanding of the local groundwater flow direction, redefined upgradient and downgradient monitoring wells, and revised the sampling and analysis schedule.

Table A.2 includes the general direction and an estimated rate of groundwater flow. The flow direction, determined using in situ flow measurements with the colloidal borescope and water elevations, is to the southeast. The saturated screen interval ranges from 1.9 to 3.8 meters thick in RCRA network wells while the aquifer thickness is ~27 meters. The average rate of water-table decline was 21 centimeters in 2002. If this rate continues, some of the RCRA-compliant wells at Waste Management Area A-AX will be dry in ~8 years. Meanwhile, the network monitors the waste management area effectively. Washington State Department of Ecology and DOE annually negotiate installation of future monitoring wells under Tri-Party Agreement Milestone M-24 (Ecology et al. 1998).

A.1.19 Single-Shell Tanks Waste Management Area B-BX-BY

RCRA groundwater quality assessment monitoring continued at this waste management area in fiscal year 2002. Exceedances of the critical mean value for specific conductance in February 1996 at a downgradient well initiated assessment monitoring. Assessment wells were sampled quarterly, and in some cases, semiannually, in fiscal year 2002. Nitrate and cyanide exceeded maximum contaminant levels in RCRA-compliant wells (see Table A.3). Section 2.9.1 discusses plume extents and contaminant trends.

Originally, the RCRA groundwater monitoring network was designed for groundwater flow toward the northwest, based on regional plume maps. This method was used to determine flow direction because the water table is almost flat in the immediate area of the farms. Assessment studies have determined a southward flow direction across the site (see Table A.2 and Section 2.9.1 of PNNL-13404). Contaminant migration and results from colloidal borescope investigations indicate a southeast flow direction at the south boundary of the waste management area. Additional wells may be needed. Washington State Department of Ecology and DOE annually negotiate installation of future monitoring wells under Tri-Party Agreement Milestone M-24 (Ecology et al. 1998).

In fiscal year 2002, the monitoring network included far-field wells (Table A.33 and Figure A.16). Some of these wells are RCRA-compliant, while others are older wells installed to monitor past-practice waste disposal sites. Water levels declined ~0.18 meters in fiscal year 2002. Although the aquifer is ~1.7 meters thick in the north and will eventually go dry, it is over 4 meters thick along the south border of the waste management area. Most of these wells can be used for at least 5 years. The new wells along the south boundary should be usable after the water table declines to a stable elevation.

A.1.20 Single-Shell Tanks Waste Management Area C

This RCRA site continued to be monitored under an interim status indicator evaluation program in fiscal year 2002. Wells were sampled quarterly at the request of the Washington State Department of Ecology due to rising trends in sulfate, nitrate, and calcium currently detected in both upgradient and downgradient wells. In addition, the required detection sampling was conducted twice for indicator and site-specific parameters (Table A.34 and see Figure A.13).

The groundwater project revised the monitoring plan for this site in 2002 (PNNL-13024-ICN-1). The revision presents an improved understanding of local groundwater flow direction, defines upgradient and downgradient wells, and updates the sampling schedule.

A general flow direction to the southwest has been established for this site using in situ flow measurements, plume tracking and water elevations corrected for borehole deviations from vertical. The monitoring network has been revised to reflect the change in interpretation (PNNL-13024-ICN-1). During fiscal year 2002, the site was monitored with the original configuration of wells. With the southwest flow direction, well 299-E27-7 is now the only upgradient well, and specific conductance is rising sharply. A critical mean for specific conductance cannot be calculated using data from this well until four quarters of stable data are available. Consequently, upgradient/downgradient comparisons will not be made for this site until these four quarters of data are obtained and specific conductance stabilizes in well 299-E27-7. The revised monitoring plan proposes new wells to increase monitoring effectiveness. Washington State Department of Ecology and DOE annually negotiate installation of future monitoring wells under Tri-Party Agreement Milestone M-24 (Ecology et al. 1998). A further discussion of chemical trends is contained in Section 2.9.1.15.

A.1.21 Single-Shell Tanks Waste Management Area S-SX

This site continued to be monitored under an interim status, groundwater quality assessment program during fiscal year 2002. DOE initiated the assessment program in response to a directive from Washington State Department of Ecology in 1996. Monitoring wells sampled during the report period and constituents analyzed are listed in Table A.35. The most recent revision of the monitoring plan was issued in February 2002 (ICN-PNNL-12114-September 1999.2). Nitrate and chromium, mobile tank farm contaminants regulated under RCRA, are elevated in downgradient wells. The highest concentrations in the network occur in well 299-W23-19 located adjacent to tank SX-115 in the southwest corner of the SX Tank Farm. This area appears to be the source of the downgradient occurrences of elevated nitrate. The moderately elevated carbon tetrachloride is attributed to past-practice upgradient sources (e.g., Plutonium Finishing Plant cribs, ditches, and trenches). The nearby upgradient crib, 216-S-25, was a major source of nitrate that passes beneath the south end of this waste management area. In addition, rapidly increasing concentrations of mobile tank waste contaminants were observed in well 299-W22-48.

The rate and direction of groundwater flow (see Table A.2) and the extent of contamination at Waste Management Area S-SX are discussed further in Section 2.8 of the main text, and in the updated assessment report for this waste management area (PNNL-13801).

A.1.22 Single-Shell Tanks Waste Management Area T

Waste Management Area T continued to be monitored under an interim status groundwater quality assessment program during fiscal year 2002 (Table A.36 and Figure A.19). The monitoring plan was revised to include new wells installed in recent years and to remove dry wells (PNNL-12057-ICN-1). Evaluation of groundwater data in 2002 indicates that no RCRA-regulated, dangerous-waste constituents from Waste Management Area T have affected groundwater. Chromium is found at concentrations greater than the maximum contaminant level, at 129 and 121 µg/L in downgradient wells 299-W11-41 and 299-W11-4, respectively. However, chromium concentration in well 299-W10-4, upgradient of the waste management area, ranged between 225 and 252 µg/L throughout fiscal year 2002. Well 299-W10-4 is adjacent to the 216-T-36 crib, which is one of the most likely sources of elevated chromium in the area of Waste Management Area T.

The rate of groundwater flow (see Table A.2) and the extent of contamination at this site are discussed in Section 2.8.

A.1.23 Single-Shell Tanks Waste Management Area TX-TY

Waste Management Area TX-TY continued to be monitored under an interim status groundwater quality assessment program during fiscal year 2002 (Table A.37 and see Figure A.19). The monitoring plan was revised to include new wells installed in recent years and to remove dry wells (PNNL-12072-ICN-1). Evaluation of groundwater data in 2002 indicates that chromium occurs in concentrations greater than the maximum contaminant level at downgradient well 299-W14-13. The concentration of chromium in that well ranged between 287 and 361 µg/L in fiscal year 2002. There is some evidence suggesting that the chromium may be from a source other than Waste Management Area TX-TY, but because no upgradient source has been identified the waste management area remains in groundwater quality assessment monitoring status.

The rate of groundwater flow (see Table A.2) and the extent of contamination at this site are discussed in Section 2.8.

A.1.24 Single-Shell Tanks Waste Management Area U

This unit was monitored under an interim status groundwater quality assessment program in fiscal year 2002 (Table A.38 and see Figure A.18). The average specific conductance value in downgradient well 299-W19-41 exceeded the critical mean in August 1999, triggering assessment monitoring. Results of initial assessment studies (PNNL-13282) concluded that there is evidence that both upgradient sources and sources within the waste management area contributed to the elevated nitrate observed in monitoring wells. Thus, assessment monitoring will continue in accordance with the monitoring plan (PNNL-13612).

The rate of groundwater flow (see Table A.2) and the extent of contamination at this site are discussed in Section 2.8.

A.2 Other Treatment/Storage/Disposal Sites

This section describes monitoring results for six facilities used for treatment, storage, or disposal of waste and regulated under regulations other than RCRA.

A.2.1 100 KW and KE Fuel Storage Basins

The fuel storage basins associated with the KW and KE Reactors currently store spent nuclear fuel that originated primarily in the N Reactor. The Spent Nuclear Fuels Project is underway to remove the fuel from the basins, improve the integrity of its encapsulation, and transport it to a more secure storage site in the Central Plateau region. The Spent Nuclear Fuels Project also will remove a large amount of highly radioactive sludge and shielding water that has accumulated in the basins. Tri-Party Agreement Milestone M-34-00 (Ecology et al. 1998) describes the scope and schedule for this major Hanford Site cleanup endeavor. Completion of the basin cleanup project is expected by 2006.

Groundwater monitoring near the basins is conducted to (a) describe groundwater movement in the area, and (b) characterize the impact of past and potential future shielding water leakage. DOE monitors groundwater around these facilities to comply with requirements for nuclear fuel and waste storage facilities (DOE Order 5400.1 [IV]9b). The Hanford Site environmental monitoring plan (DOE/RL-91-50) describes the regulatory basis for monitoring these facilities.

During fiscal year 2002, monitoring revealed no evidence of current leakage from either of these basins. Monitoring continues to track groundwater contamination caused by past leakage from the KE Basin. The monitoring network and sampling schedule were revised during fiscal year 2002 (PNNL-14033; Table A.39 and Figure A.20). The groundwater project performed a study in fiscal year 2002 to differentiate groundwater contamination caused by past leakage from the KE Basin from other potential sources, such as the possible release of tritium from materials contained in the 118-K-1 burial ground (PNNL-14031; see Section 2.3).

A.2.2 200 Areas Treated Effluent Disposal Facility

A state waste discharge permit (WAC 173-216) governs groundwater sampling and analysis in the three monitoring wells at this facility (Table A.40 and see Figure A.5). The constituent list and frequency of sampling are specified in the permit. A groundwater monitoring plan (PNNL-13032) describes details of the monitoring program. Wells were sampled quarterly during fiscal year 2002.

No permit criteria for constituents in groundwater were exceeded in fiscal year 2002. The groundwater monitoring network continues to show that effluent from the facility is not taking a direct route to the uppermost aquifer and differentiates the effects of the Treated Effluent Disposal Facility from those of B Pond.

A.2.3 4608 B/C Process Ponds and 400 Area Water Supply Wells

The 4608 B/C ponds (also called the 400 Area process ponds), are regulated under WAC 173-216. The permit, issued on August 1, 1996, and modified on February 10, 1998, defines groundwater enforcement limits (Table A.41 and Figure A.21). Groundwater quality met permit conditions in fiscal year 2002.

The water supply in the 400 Area, which comes from wells, is also monitored to maintain compliance with drinking water standards. In the past, tritium concentrations have exceeded the 20,000-pCi/L standard in the backup water supply wells, but levels remained below the standard in fiscal year 2002 (see Section 2.10). Water supply sampling indicates that tritium in the drinking water is maintained at a level below the 4-millirem-per-year dose equivalent standard. Sampling frequency was reduced from monthly to quarterly in fiscal year 2002.

A.2.4 Environmental Restoration Disposal Facility

This facility is a landfill authorized by CERCLA that is designed to meet RCRA requirements of Subpart N, 40 CFR 264. The groundwater monitoring network consists of one upgradient and three downgradient wells that are sampled semiannually (Table A.42). In addition, the facility has a system to collect and remove leachate that helps evaluate whether the liner system is performing within design standards. BHI-00873 describes the sampling plan for groundwater monitoring, and BHI-01641 describes results for calendar year 2001.

In calendar year 2002, leachate monitoring detected low levels of common metals, anions, and mobile radionuclides (see Section 3.2 of main text). Groundwater monitoring results showed that concentrations of some constituents of concern remained elevated, most likely as a result of migration of groundwater plumes from the 200 West Area. High zinc concentrations in one downgradient monitoring well may indicate continued galvanic corrosion of well components. This well previously exhibited high turbidity, which declined in late 2001 to levels comparable to the other monitoring wells in the system.

A.2.5 Solid Waste Landfill

State dangerous waste regulations (WAC 173-304) govern groundwater monitoring at this landfill. The final closure plan for the site has been implemented. Wells are sampled quarterly for constituents specified in WAC 173-304 plus the site-specific constituents chlorinated hydrocarbons (Table A.43 and see Figure A.14).

Statistical evaluations of the constituents specified in WAC 173-304 for landfills (Tables A.44 and A.45) revealed that six exceeded their background threshold levels (or range for pH) during fiscal year 2002:

1. Specific conductance exceeded its 583-µS/cm threshold level in all eight of the downgradient wells in the monitoring network.
2. Sulfate exceeded its 47.2-mg/L threshold level in three of the eight downgradient wells.
3. Reported results for pH were lower than the background threshold range (6.68 to 7.84) in four downgradient monitoring wells.
4. Chloride exceeded its 7,820-µg/L background threshold level in two downgradient wells in samples collected in August 2002.
5. One result for temperature and two for coliform bacteria exceeded their respective background threshold levels (20.7; 3.7 colonies/100 ml), but these may have been caused by errors in sampling or analysis.

Tritium exceeded its drinking water standard at many of the monitoring wells on the east side of the landfill, but the source is upgradient. Two chlorinated hydrocarbons exceeded WAC 173-200 groundwater quality criteria in at least one well of the monitoring network. They are as follows, with the number of wells having exceedances and the Washington Administrative Code limit:

- 1,1-dichloroethane (3) (1.0 µg/L)
- tetrachloroethene (9) (0.8 µg/L)

The monitoring network for the Solid Waste Landfill has two upgradient wells and eight downgradient wells and is adequate for meeting the requirements of WAC 173-304.

A.2.6 State-Approved Land Disposal Site

A state waste discharge permit (WAC 173-216) requires groundwater monitoring at this site. The permit was granted in June 1995, and the site began to operate in December 1995. Groundwater monitoring for tritium only is conducted in 19 wells near the facility (Table A.46 and Figure A.22). The permit stipulates requirements for groundwater monitoring and establishes enforcement limits for concentrations of 15 constituents and tritium in 3 additional wells immediately surrounding the facility (see Table A.46).

During fiscal year 2002, tritium concentrations in proximal wells 699-48-77A and 699-48-77D increased as a result of the resumption of tritium disposal that followed a 16-month hiatus in significant tritium discharges (see Section 2.8). Tritium concentrations remained high in well 699-48-77C. This reflects the result of the delayed penetration of effluent deeper into the aquifer from 1999 tritium discharges. Well 299-W7-5, south of the facility, produced historical maxima for tritium (790 and 860 pCi/L in July 2002). These results may signal the first incursion of tritium from the State-Approved Land Disposal Site at this location. Some wells along the south boundary of the State-Approved Land Disposal Site monitoring network (e.g., 299-W7-11 and 299-W6-8) have gone dry or are nearly dry. However, because of the original high density of wells located in this area, the drying of these few wells has not as yet significantly affected the network coverage.

No permit enforcement limits were exceeded during fiscal year 2002. Evaluation of the well network indicates that well coverage is currently adequate to satisfy groundwater monitoring requirements.

A.3 CERCLA Groundwater Operable Units

The groundwater and vadose zone beneath contaminated portions of the Hanford Site are divided into 11 groundwater operable units, discussed in alphanumeric order below.

A.3.1 100-BC-5

This operable unit underlies the 100-B/C Area. There is no active groundwater remediation, and monitoring has the same objectives as for the *Atomic Energy Act of 1954*. The CERCLA well network and constituent list are documented in Federal Facility Agreement and Consent Order (Ecology et al. 1998) Change Control Form No. M-15-99-03, dated

July 14, 1999 and in PNNL-13326. Sampling schedules and analyte selection are coordinated to meet the requirements of both regulations. Wells are sampled biennially or annually.

A.3.2 100-FR-3

This operable unit underlies the 100-F Area. There is no active groundwater remediation, and monitoring has the same objectives as for the *Atomic Energy Act of 1954*. The CERCLA monitoring network and constituent list are documented in Federal Facility Agreement and Consent Order (Ecology et al. 1998) Change Control Form No. M-015-01-07, dated December 13, 2001 and in PNNL-13327. The Hanford Groundwater Monitoring Project coordinates sampling schedules and analyte selection to meet the requirements of both regulations. Wells are sampled biennially to quarterly.

A.3.3 100-HR-3

This large operable unit encompasses the groundwater and vadose zone beneath the 100-D and 100-H Areas and the horn of the Hanford Site. There are two interim actions for groundwater remediation in the 100-HR-3 Operable Unit: a pump-and-treat system for chromium in the north 100-D Area and the 100-H Area and an in situ chromium treatment system in the southwest 100-D Area.

The extraction well network in the north region of the 100-D Area and in the 100-H Area continued to operate through fiscal year 2002. Two new extraction wells were put into use in the 100-D Area during the year. The purpose for the interim remedial action is to decrease the amount of hexavalent chromium that is entering the Columbia River via groundwater. The key documents that pertain to this interim action are the record of decision (ROD 1996b) and the performance monitoring plan (DOE/RL-96-84).

The specific objectives of the pump-and-treat system are to

- protect aquatic receptors in the river bottom from contaminants in groundwater entering the Columbia River
- protect human health by preventing exposure to contaminants in the groundwater
- provide information leading to a final remedy

The performance evaluation and annual summary report (DOE/RL-2002-05) indicated that the pump-and-treat systems reduces contaminant flux to the Columbia River by creating hydraulic barriers. The extraction wells capture and remove contaminants from the groundwater passing under the waste sites that otherwise would enter the Columbia River. Institutional controls prevent access to groundwater, thereby protecting human health. Data on water levels, contaminants, system treatment cost and efficiency, and geology are collected to support the project and to provide a decision basis for the future final remedy. The pump-and-treat systems are discussed in more detail in Sections 2.5 and 2.6 of the main text.

EPA, Washington State Department of Ecology, and DOE signed an amended record of decision for the 100-HR-3 Operable Unit in October 1999 (ROD 1999). The amendment adds a requirement for implementing in situ redox manipulation to remediate the chromium plume in the southwest 100-D Area. The goal of this treatment system is to reduce concentrations of hexavalent chromium to 20 µg/L or less in compliance wells. A design report/work plan defines groundwater monitoring requirements (DOE/RL-99-51). The system made progress toward remedial action objectives in fiscal year 2002. Additional wells were installed for injection/withdrawal and compliance monitoring, and a series of injections/withdrawals was conducted (see Section 2.5 in the main text).

Groundwater monitoring in other 100-HR-3 wells also continued during fiscal year 2002. The list of wells to be sampled and the analyses to be performed were agreed on and are described in National Priorities List Agreement/Change Control Form No. 107, dated November 20, 1996. Most wells are sampled annually, and the samples are analyzed for anions, metals, and radiological indicators. During fall 2001, aquifer sampling tubes and riverbank seepage were sampled. DOE/RL-96-90 and DOE/RL-96-84 describe additional monitoring that is required as part of the interim action.

A.3.4 100-KR-4

The 100-KR-4 Operable Unit includes the groundwater that underlies the 100-K Area. Monitoring activities under CERCLA continued during fiscal year 2002 as part of the remedial investigation that will lead to a future record-of-decision for final groundwater remedial action. A decision regarding final remedial action is expected to follow completion of source remedial actions and KW and KE Fuel Storage Basins cleanup activities. Institutional controls are currently in place to prevent human access to groundwater beneath the 100-K Area. Groundwater monitoring for the operable unit consists predominantly of annual sampling of wells, with analyses for anions, metals, and radiological indicators. The list of wells, frequency of sampling, and analyses to be performed are described in National Priorities List Agreement/Change Control Form No. 108, dated November 20, 1996, as updated by changes documented in a letter from DOE to the Washington State Department of Ecology and EPA in September 1998.(e)

An interim remedial action is underway to address groundwater contaminated by hexavalent chromium, which poses a threat to aquatic organisms that reside in the interface between the aquifer and the nearby Columbia River (ROD 1996b). A pump-and-treatment system is used to reduce the amount of chromium in groundwater in the area between the 116-K-2 trench and the river. The objectives for this interim remedial action, as stated in the record of decision, are to:

- protect aquatic receptors in the Columbia River bottom substrate from contaminants in groundwater entering the Columbia River
- protect human health by preventing exposure to contaminants in the groundwater
- provide information leading to a final remedy

The most recent performance evaluation and annual summary report (DOE/RL-2002-05, for results obtained during calendar year 2001) indicates that the pump-and-treat system captures most of the groundwater flow field occupied by the chromium plume. Removal of chromium from the extracted groundwater significantly reduces the amount of chromium available for movement into the river environment. Data on water levels, contaminants, system treatment cost and efficiency, and hydrogeology contribute to building a technical basis for a future final remedy decision. DOE/RL-96-90 and DOE/RL-96-84 describe the operational and environmental monitoring required as part of the interim action.

A.3.5 100-NR-2

This operable unit underlies the 100-N Area. A pump-and-treat system for strontium-90 continued to operate in fiscal year 2002. The environmental restoration contractor operates the system in response to an action memorandum(f) and a record of decision signed in September 1999 (Ecology 1999).

The goals of this pump-and-treat system are to

- reduce strontium-90 contamination flux from the groundwater to the Columbia River
- evaluate commercially available treatment options for strontium-90
- provide data necessary to set demonstrable strontium-90 groundwater cleanup standards

The system continued to meet these goals in fiscal year 2002 (see Section 2.4 of the main text). The pump-and-treat operation is successfully intercepting and capturing groundwater containing elevated concentrations of strontium-90, and reduces the amount of contamination discharging into the Columbia River (DOE/RL-2002-05). The pump-and-treat program collects hydraulic monitoring data, contaminant monitoring data, and treatment system operation data to assess treatment system performance and to provide the basis for selecting the final remedy.

National Priorities List Agreement/Change Control Form No. 113, dated March 25, 1997, specifies performance monitoring requirements for the N Springs pump-and-treat system. The basic requirement is to sample the process influent and effluent streams monthly for strontium-90 analysis and to place the analytical results in a database to which the regulator has access. Groundwater monitoring requirements are described by BHI-00164 and BHI-01165.

(e) Letter report 062039 from D. M. Wanek (U.S. Department of Energy, Richland, Washington) to S. M. Alexander (Washington State Department of Ecology) and D. R. Sherwood (U.S. Environmental Protection Agency), *Sampling Changes to the 100-HR-3 and 100-KR-4 Operable Units (OU)*, dated September 16, 1998.

(f) Letter from D. Butler (Washington State Department of Ecology, Olympia, Washington) and R. F. Smith (U.S. Environmental Protection Agency) to R. Izatt (U.S. Department of Energy, Richland Operations Office, Richland, Washington), *Action Memorandum: N-Springs Expedited Response Action Cleanup Plan, U.S. Department of Energy, Hanford Site, Richland, Washington*, dated September 23, 1994.

The remedial investigation for the 100-NR-2 Operable Unit also collected groundwater data in fiscal year 2002. Monitoring results, along with information gained by operating the pump-and-treat system, will be used to support selection of a final remediation alternative for the operable unit. Tri-Party Agreement (Ecology et al. 1998) Change Control Form No. M-15-96-08, signed on October 9, 1996, lists the wells and analyses to be performed to satisfy groundwater monitoring requirements for the 100-NR-2 Operable Unit (CERCLA) and the RCRA facilities.

The Sitewide Environmental Surveillance Project collects riverbank seepage annually. Authority for this activity comes from DOE orders for environmental monitoring. The results are presented in an annual report (e.g., Section 4.2 in PNNL-13910). The Near-Facility Environmental Monitoring Program, which is also mandated primarily by DOE orders, conducts additional groundwater and surface water monitoring. Samples are collected from 13 near-river well casings, which have been driven into the shoreline gravels, and also from a near-river monitoring well. The monitoring supports activities for waste management and environmental restoration and helps determine the effectiveness of effluent treatment and control practices. Results are presented annually (e.g., PNNL-13910, Appendix 2).

A.3.6 200-BP-5

This CERCLA groundwater operable unit, which encompasses the north portion of 200 East Area in the vicinity of B Plant, has similar monitoring objectives as for the *Atomic Energy Act of 1954* (surveillance). The operable unit includes the past-practice sites 216-B-5 injection well, BY cribs, and Gable Mountain Pond. CERCLA groundwater sampling is currently suspended in 200-BP-5 until waste management documentation is completed and approved. See Section 2.9.1 in the main text for additional discussion.

In fiscal year 2002, the groundwater project analyzed data quality objectives for monitoring the 200-BP-5 Operable Unit (PNNL-14049). DOE will release a sampling and analysis plan in fiscal year 2003.

A.3.7 200-PO-1

This groundwater operable unit, which encompasses the area of the tritium plume southeast of the 200 East Area, has the same monitoring objectives as monitoring for the *Atomic Energy Act of 1954* (surveillance) and RCRA (PUREX cribs assessment). See Section 2.9.2 in the main text for additional discussion.

In fiscal year 2002, the groundwater project analyzed data quality objectives for monitoring the 200-PO-1 Operable Unit (PNNL-14049). DOE will release a sampling and analysis plan in fiscal year 2003.

A.3.8 200-UP-1

During fiscal year 2002, the environmental restoration contractor continued to operate a pump-and-treat system in this operable unit, which underlies the southeast 200 West Area (Figure A.23).

The interim action objectives (ROD 1997) include the following:

- reduce contamination in the areas of highest concentration of technetium-99 and uranium to below 10 times (480 µg/L) the cleanup level under the *Model Toxics Control Act* (WAC 173-340) for uranium, and 10 times (9,000 pCi/L) the drinking water standard for technetium-99
- reduce potential adverse human health risks through reduction of contaminant mass
- prevent further movement of these contaminants from the highest concentration area
- provide information that will lead to the development and implementation of a final remedy that will be protective of human health and the environment

Results of the interim action are summarized annually (DOE/RL-2001-53). As of July 2002, the high concentration portions of the technetium-99 and uranium plumes were hydraulically contained but were not remediated to the levels required by the interim action objectives (ROD 1997). The capability for monitoring and tracking changes in plume configuration continues to be hampered by the lack of well control in the baseline plume, even though another monitoring well, 299-W19-43, was installed the end of fiscal year 2001. As a result, the plume maps and the discussion on the extent of remediation are based on historical information and a limited amount of data collected in fiscal year 2002. Additional monitoring wells will be installed in fiscal year 2003 and beyond to provide more complete coverage of the plumes. To accelerate remediation in the upgradient plume area, well 299-W19-36 was converted to an extraction well in fiscal year 2002. Monitoring well 299-W19-43 also will be converted to an extraction well in fiscal years 2003 or 2004. Section 2.8.3 of the main text discusses groundwater remediation in more detail.

A.3.9 200-ZP-1

The environmental restoration contractor continued to operate a pump-and-treat system in this operable unit, which underlies the northwest 200 West Area, in fiscal year 2002 (Figure A.24). The purpose of the pump-and-treat system is to prevent further movement of groundwater contamination from the high concentration portion of the carbon tetrachloride plume and to reduce contaminant mass (ROD 1995).

The interim action objectives (ROD 1995) include the following:

- prevent further movement of contamination from the highest concentration area of the plume (i.e., containing carbon tetrachloride inside of 2,000- to 3,000-μg/L contour)
- reduce contamination in the area of highest carbon tetrachloride concentrations
- provide information that will lead to development of a final remedy that will be protective of human health and the environment

The 200-ZP-1 pump-and-treat system made measurable progress toward meeting its specific objectives in fiscal year 2002. The high concentration portion of the carbon tetrachloride plume continues to move toward the extraction wells and appears to be hydraulically contained based on the contaminant plume maps, contaminant trends, and hydraulic capture analysis.

Contaminant concentrations appear to be declining in most of the extraction wells, implying that the peak of dissolved mass originating beneath the Plutonium Finishing Plant complex has arrived at these wells. The injection wells have diluted the west and south portions of the plume and are driving dissolved contaminant mass toward the extraction wells. Most monitoring wells in the core area of the plume have decreasing contaminant concentrations. Section 2.8.1 of the main text discusses groundwater remediation in more detail. Results of the interim action are summarized annually (DOE/RL-2001-53).

A.3.10 300-FF-5

This operable unit includes the groundwater beneath the 300 Area and two smaller areas farther inland. The northernmost of these is associated with the 618-11 burial ground, and southernmost with the 618-10 burial ground and 316-4 cribs. Groundwater beneath the 300 Area is monitored to (a) track the extent of contaminant plumes, and to (b) determine the rate at which the level of contamination is changing with time. The remedy described in the record of decision for the operable unit (ROD 1996a) is an interim action that involves imposing restrictions on the use of the groundwater until the level of contamination attenuates by natural processes until health-based criteria are met.

An operation and maintenance plan for the 300-FF-5 Operable Unit was revised during fiscal year 2002 (DOE/RL-95-73). The plan identifies tasks necessary to verify the effectiveness of natural processes as reducing the level of contamination in groundwater. New elements in the plan include increased water quality, sediment, and biota monitoring at the river, along with methods to determine the rate at which natural processes are decreasing the level of contamination. A sampling and analysis plan (DOE/RL-2002-11) also was prepared to implement the strategy presented in the operations and maintenance plan.

The principal contaminants of concern in groundwater beneath the 300 Area are uranium, trichloroethene, 1,2-dichloroethene, and tetrachloroethene (see Section 2.12 of the main text). Nitrate is also somewhat elevated. Monitoring results for fiscal year 2002 were consistent with historical trends and generally indicate a long-term decline in level of contamination, although the exact characteristics of this trend remain to be determined. An intensive investigation of uranium mobility in the vadose zone beneath the 300 Area Process Trenches was completed and provided new information on distribution coefficients for that contaminant (PNNL-14022).

During August and September 2001, the Washington State Department of Health and Pacific Northwest National Laboratory conducted a cooperative project. The purpose was to gain additional insight into the presence of 300 Area contaminants in the river environment. Samples of groundwater, riverbank seepage, river water, sediment, and biota were collected. Gross alpha and uranium were the only constituents found that exceeded ambient water quality criteria for protection of freshwater organisms, although additional constituents were found to be elevated relative to background levels (but below levels of concern). Analytical results for clam tissue samples were found to be a good indicator for the distribution of uranium in the near-shore environment. PNNL-13692 presents the results of the study. Additional sampling of shoreline media and biota is part of the sampling and analysis plan for the 300-FF-5 Operable Unit.

Plans to install two new monitoring wells near the 618-10 burial ground were prepared during fiscal year 2002. As a precursor to drilling, scientists conducted a soil gas survey along the perimeter of the burial ground on the downgradient side, to reveal the potential presence of tritium. Because vertical pipe units are present in the 618-10 burial ground, there is the possibility that a tritium plume has been created by conditions analogous to those at the 618-11 burial ground. The analytical results for the soil-gas samples did not reveal evidence for a high concentration tritium source, i.e., nearby buried source for tritium and/or a high concentration groundwater plume underlying the area. Installation of the two new wells is expected to proceed during February or March 2003. Concentration trends in existing wells near the burial ground and adjacent 316-4 cribs remained consistent with historical trends, i.e., reflective of the site-wide tritium plume and localized contamination associated with the 316-4 cribs. The contaminants of concern include tritium, uranium, tributyl phosphate, and hydrocarbons (possibly diesel and degreasing solvents; see Section 2.12 of the main text).

Monitoring results for groundwater samples collected near the 618-11 burial ground were also consistent with previous trends. Nearest the source, tritium concentrations declined somewhat during fiscal year 2002. There is some evidence to suggest continued downgradient migration of the relatively high concentration plume at monitoring network locations most distance from the source. The principal contaminant of concern is tritium, although nitrate is also slightly elevated above drinking water standards (see Section 2.12).

A.3.11 1100-EM-1

The 1100-EM-1 Operable Unit contains DOE's inactive Horn Rapids Landfill. Results of the CERCLA investigation for this operable unit are presented in the final remedial investigation study (DOE/RL-92-67) and the record of decision (ROD 1993). The selected remedy for groundwater is monitored natural attenuation of volatile organic compounds, with institutional controls on drilling of new water supply wells. Monitoring includes analysis for trichloroethene, its breakdown products (e.g., vinyl chloride and 1,1-dichloroethene), and nitrate in wells downgradient of DOE's inactive Horn Rapids Landfill, as recommended in the sampling plan (PNNL-12220).

Average trichloroethene concentrations continued to be below 5 µg/L in all of the 1100-EM-1 Operable Unit groundwater monitoring wells, including point of compliance wells 699-S27-E12A, 699-S28-E13A, and 699-S29-E13A, in fiscal year 2002. The point of compliance wells form a line downgradient of DOE's inactive Horn Rapids Landfill that is approximately perpendicular to the prevailing path of the trichloroethene plume. Groundwater modeling indicated that the trichloroethene plume was expected to attenuate to levels below 5 µg/L by the year 2017 (ROD 1993). However, the trichloroethene plume naturally attenuated to these levels by fiscal year 2001, 16 years ahead of the predicted date. Potential breakdown products vinyl chloride, 1,1-dichloroethene, cis-1,2-dichloroethene, and trans-1,2-dichloroethene continued to show levels less than their respective minimum detection levels during fiscal year 2002.

Nitrate levels continued to exceed the maximum contaminant level of 45 mg/L in fiscal year 2002. Nitrate concentrations in the 1100-EM-1 Operable Unit groundwater monitoring wells ranged between 58.9 and 188 mg/L in fiscal year 2002. The record of decision (ROD 1993) indicated that nitrate concentrations, some of which were higher in the early 1990s than at current levels, pose a low risk level and do not trigger remedial action.

Although not specified in the record of decision, chromium is monitored annually in one well downgradient of the 1171 Building in the former 1100 Area. The concentration of unfiltered chromium in this well averaged 84.6 µg/L, which is lower than the maximum contaminant level of 100 µg/L, in fiscal year 2002. Filtered chromium, which continued to be much less than the maximum contaminant level, was detected below the contract required detection limit at an average concentration of 3.2 µg/L in fiscal year 2002.

A.4 Drinking Water Standards and DOE Derived Concentrations Guides

Groundwater is not a primary source of drinking water for most Hanford Site workers. However, comparing groundwater chemistry to drinking water standards provides perspective for contaminant levels. Exceedances of maximum contaminant levels are summarized in Table A.47. Drinking water standards use the methods set out in 40 CFR 141, 40 CFR 142, and 40 CFR 143 to estimate the concentration in water that could result in a potential radiological dose of 4 millirem per year from consumption of each individual radionuclide. Similarly, DOE derived concentration guides provide estimates of radiological concentration that could result in a 100 millirem per year dose as defined in DOE Order 5400.5. Table A.48 summarizes exceedances of these limits by geographic region of the Hanford Site, and the number of wells exceeding the standard at least once during the fiscal year.

A.5 References

40 CFR 141. U.S. Environmental Protection Agency. "National Primary Drinking Water Regulations." *U.S. Code of Federal Regulations*.

40 CFR 142. U.S. Environmental Protection Agency. "National Primary Drinking Water Regulations Implementation." *U.S. Code of Federal Regulations*.

40 CFR 143. U.S. Environmental Protection Agency. "National Secondary Drinking Water Regulations." *U.S. Code of Federal Regulations*.

40 CFR 264. U.S. Environmental Protection Agency. "Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities." *U.S. Code of Federal Regulations*.

40 CFR 264, Subpart N. U.S. Environmental Protection Agency. "Landfills." *Code of Federal Regulations*.

40 CFR 265. U.S. Environmental Protection Agency. "Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities." *U.S. Code of Federal Regulations*.

Atomic Energy Act of 1954, as amended, Ch. 1073, 68 Stat. 919, 42 USC 2011 et seq.

BHI-00164, Rev. 1. 1995. *N Springs Expedited Response Action Performance Monitoring Plan*. B. Mukherjee, Bechtel Hanford, Inc., Richland, Washington.

BHI-00725. 1996. *100-N Pilot Project: Proposed Consolidated Groundwater Monitoring Program*. J. V. Borghese, M. J. Hartman, S. P. Luttrell, C. J. Perkins, J. P. Zoric, and S. C. Tindall, Bechtel Hanford, Inc., Richland, Washington.

BHI-00873. 1996. *Description of Work for Routine Groundwater Sampling at the Environmental Restoration Disposal Facility*. B. H. Ford, Bechtel Hanford, Inc., Richland, Washington.

BHI-01165. 1998. *N-Springs Expedited Response Action Performance Monitoring Plan: Update*. R. E. Peterson, CH2M HILL Hanford, Inc. for Bechtel Hanford, Inc., Richland, Washington.

BHI-01641. 2002. *Groundwater Monitoring and Sampling at the Environmental Restoration Disposal Facility, Calendar Year 2001*. C. W. Miller, C. S. Wright, and R. S. Edrington, CH2M HILL Hanford, Inc., Richland, Washington.

BNWL-1709. 1973. *Collection and Analysis of Pump Test Data for Transmissivity Values*. K. L. Kipp and R. D. Mudd, Battelle, Pacific Northwest Laboratory, Richland, Washington.

Comprehensive Environmental Response, Compensation, and Liability Act. 1980. As amended, Public Law 96-510, 94 Stat. 2767, 42 USC 9601 et seq.

DOE Order 5400.1. *General Environmental Protection Program*. U.S. Department of Energy, Washington, D.C.

DOE Order 5400.5. *Radiation Protection of the Public and the Environment*, as amended, U.S. Department of Energy, Washington, D.C.

DOE/RL-91-50, Rev. 3. 2000. *Environmental Monitoring Plan, United States Department of Energy, Richland Operations Office*. Prepared by personnel from Pacific Northwest National Laboratory, Fluor Daniel Hanford, Inc. and its subcontractor Waste Management Federal Services of Hanford, Inc., and Bechtel Hanford, Inc. for the U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-92-67, Draft B. 1992. *Final Remedial Investigation Study–Environmental Assessment Report for the 1100-EM-1 Operable Unit, Hanford.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-95-73, Rev. 1. 2002. *Operation and Maintenance Plan for the 300-FF-5 Operable Unit.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-96-01. 1996. *Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities for 1995.* Prepared by Earth and Environmental Technical Services, Westinghouse Hanford Company, for the U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-96-39. 1998. *100-NR-1 Treatment, Storage, and Disposal Units Corrective Measure Study/Closure Plan.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-96-84. 1996. *Remedial Design Report and Remedial Action Work Plan for the 100-HR-3 and 100-KR-4 Groundwater Operable Units' Interim Action.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-96-90, Rev. 0. 1997. *Interim Action Monitoring Plan for the 100-HR-3 and 100-KR-4 Operable Units.* Prepared by CH2M HILL Hanford, Inc. for the U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-99-51. 2000. *Remedial Design Report and Remedial Action Work Plan for the 100-HR-3 Groundwater Operable Unit In Situ Redox Manipulation.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2001-53. 2002. *Fiscal Year 2001 Annual Summary Report for the 200-UP-1 and 200-ZP-1 Operable Unit Pump-and-Treat Operations.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2002-05. 2002. *Calendar Year 2001 Annual Summary Report for the 100-R-3, 100-KR-4, and 100-NR-2 Operable Unit Pump-and-Treat Operations.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2002-11. 2002. *300-FF-5 Operable Unit Sampling and Analysis Plan.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Ecology. 1994. *Dangerous Waste Portion of the Resource Conservation and Recovery Act Permit for the Treatment, Storage, and Disposal of Dangerous Waste,* as amended. Permit Number WA7890008967, effective September 28, 1994. Washington State Department of Ecology, Olympia, Washington.

Ecology - Washington State Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy. 1998. *Hanford Federal Facility Agreement and Consent Order.* Document No. 89-10, Rev. 5 (The Tri-Party Agreement). Olympia, Washington.

Ecology. 1999. *Interim Remedial Action Record of Decision for the 100-NR-1 and -NR-2 Operable Units of the Hanford 100-N Area.* Washington State Department of Ecology, Olympia, Washington.

ICN-PNNL-12114-September 1999.2. 2002. *Interim Change Notice RCRA Assessment Plan for Single-Shell Tank Waste Management Area S-SX at the Hanford Site.* R. M. Smith, Pacific Northwest National Laboratory, Richland, Washington.

Lucas, J. M. 1982. "Combined Shewhart-CUSUM Quality Control Schemes." *Journal of Quality Technology* 14:51-59.

NAVD88. 1988. North American Vertical Datum of 1988.

PNL-5408. 1985. *Groundwater Monitoring at the Hanford Site, January-December 1984.* C. S. Cline, J. T. Rieger, J. R. Raymond, and P. A. Eddy, Pacific Northwest Laboratory, Richland, Washington.

PNL-6716. 1988. *Interim Characterization Report for the 300 Area Process Trenches.* R. Schalla, R. W. Wallace, R. L. Aaberg, S. P. Airhart, D. J. Bates, J.V.M. Carlile, C. S. Cline, D. I. Dennison, M. D. Freshley, P. R. Heller, E. J. Jensen, K. B. Olsen, R. G. Parkhurst, J. T. Rieger, and E. J. Westergard, Pacific Northwest Laboratory, Richland, Washington.

PNL-6728. 1988. *Geohydrologic Characterization of the Area Surrounding the 183-H Solar Evaporation Basins.* T. L. Liikala, R. L. Aaberg, N. J. Aimo, D. J. Bates, T. J Gilmore, E. J. Jensen, G. V. Last, P. L. Oberlander, K. B. Olsen, K. R. Oster, L. R. Roome, J. C. Simpson, S. S. Teel, and E. J. Westergard, Pacific Northwest Laboratory, Richland, Washington.

PNL-6820. 1989. *Hydrogeology for the 200 Areas Low-Level Burial Grounds - An Interim Report*. G. V. Last, B. N. Bjornstad, M. P. Bergeron, D. W. Wallace, D. R. Newcomer, J. A. Schramke, M. A. Chamness, C. S. Cline, S. P. Airhart, and J. S. Wilber, Pacific Northwest Laboratory, Richland, Washington.

PNL-8335. 1992. *Applications of Three Aquifer Test Methods for Estimating Hydraulic Properties Within the 100-N Area*. T. J Gilmore, F. A. Spane, Jr., D. R. Newcomer, and C. R. Sherwood, Pacific Northwest Laboratory, Richland, Washington.

PNL-10195. 1994. *Three-Dimensional Conceptual Model for the Hanford Site Unconfined Aquifer System: FY 1994*. P. D. Thorne, M. A. Chamness, V. R. Vermeul, Q. C. MacDonald, and S. E. Schubert, Pacific Northwest Laboratory, Richland, Washington.

PNNL-11523. 1997. *Combination RCRA Groundwater Monitoring Plan for the 216-A-10, 216-A-36B, and 216-A-37-1 PUREX Cribs*. J. W. Lindberg, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11573. 1997. *Groundwater Monitoring Plan for the 183-H Solar Evaporation Basins*. M. J. Hartman, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11574. 1997. *Results of RCRA Groundwater Quality Assessment Program at the 216-U-12 Crib*. B. A. Williams and C. J. Chou, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11620. 1997. *Liquid Effluent Retention Facility Final-Status Groundwater Monitoring Plan*. M. D. Sweeney, C. J. Chou, and B. N. Bjornstad, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11801. 1998. *Three-Dimensional Analysis of Future Groundwater Flow Conditions and Contaminant Plume Transport in the Hanford Site Unconfined Aquifer System: FY 1996 and 1997 Status Report*. C. R. Cole, S. K. Wurstner, M. P. Bergeron, M. D. Williams, and P. D. Thorne, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-12057-ICN-1. 2002. *Interim Change Notice for RCRA Assessment Plan for Single-Shell Tank Waste Management Area T at the Hanford Site*. D. G. Horton, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-12072-ICN-1. 2002. *Interim Change Notice for RCRA Assessment Plan for Single-Shell Tank Waste Management Area T at the Hanford Site*. D. G. Horton, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-12220. 1999. *Sampling and Analysis Plan Update for Groundwater Monitoring – 1100-EM-1 Operable Unit*. D. R. Newcomer, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-12227. 1999. *Groundwater Monitoring Plan for the Nonradioactive Dangerous Waste Landfill*. J. W. Lindberg and M. J. Hartman, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13014. 2000. *Groundwater Monitoring Plan for the Solid Waste Landfill*. J. W. Lindberg and C. J. Chou, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13022. 2000. *Groundwater Quality Assessment Plan for Single-Shell Waste Management Area B-BX-BY at the Hanford Site*. S. M. Narbutovskih, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13023-ICN-1. 2002. *Interim Change Notice for RCRA Groundwater Monitoring Plan for Single-Shell Tank Waste Management Area A-AX at the Hanford Site*. S. M. Narbutovskih, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13024-ICN-1. 2002. *Interim Change Notice RCRA Groundwater Monitoring Plan for Single-Shell Tank Waste Management Area C at the Hanford Site*. S. M. Narbutovskih, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13032. 2000. *Groundwater Monitoring Plan for the Hanford Site 200 Area Treated Effluent Disposal Facility*. D. B. Barnett, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13047. 1999. *Groundwater Monitoring Plan for the 216-A-29 Ditch*. M. D. Sweeney, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13121. 2000. *Groundwater Monitoring and Tritium-Tracking Plan for the 200 Area State-Approved Land Disposal Site*. D. B. Barnett, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13282. 2000. *Groundwater Quality Assessment for Waste Management Area U: First Determination*. F. N. Hodges and C. J. Chou, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13326. 2000. *Groundwater Sampling and Analysis Plan for the 100-BC-5 Operable Unit*. M. D. Sweeney, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13327. 2000. *Groundwater Sampling and Analysis Plan for the 100-FR-3 Operable Unit*. M. D. Sweeney, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13367-ICN-1. 2002. *Interim Change Notice for Groundwater Monitoring Plan for the Hanford Site 216-B-3 Pond RCRA Facility*. D. B. Barnett, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13378. 2001. *Results of Detailed Hydrologic Characterization Tests – Fiscal Year 1999*. F. A. Spane, Jr., P. D. Thorne, and D. R. Newcomer, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13404. 2001. *Hanford Site Groundwater Monitoring for Fiscal Year 2000*. M. J. Hartman, L. F. Morasch, and W. D. Webber (eds.), Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13441. 2000. *RCRA Groundwater Quality Assessment Report for Waste Management Area S-SX (November 1997 through April 2000)*. V. G. Johnson and C. J. Chou, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13514. 2001. *Results of Detailed Hydrologic Characterization Tests - Fiscal Year 2000*. F. A. Spane, P. D. Thorne, and D. R. Newcomer, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13612. 2001. *Groundwater Quality Assessment Plan for Single-Shell Tank Waste Management Area U*. R. M. Smith, F. N. Hodges, and B. A. Williams, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13645. 2001. *300 Area Process Trenches Groundwater Monitoring Plan*. J. W. Lindberg and C. J. Chou, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13692. 2002. *Survey of Radiological and Chemical Contaminants in the Near-Shore Environment at the Hanford Site 300 Area*. G. W. Patton, B. L. Tiller, E. J. Antonio, T. M. Poston, and S. P. Van Verst, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13801. 2002. *Groundwater Quality Assessment Report for Waste Management Area S-SX: (April 2000 through December 2001)*. V. G. Johnson and C. J. Chou, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13910. 2002. *Hanford Site Environmental Report for Calendar Year 2001*. T. M. Poston, R. W. Hanf, R. L. Dirkes, and L. F. Morasch (eds.), Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13910, Appendix 2. 2002. *Hanford Site Near-Facility Environmental Monitoring Data Report for Calendar Year 2001*. C. J. Perkins, B. M. Markes, S. M. McKinney, R. M. Mitchell, and R. C. Roos, Duratek Federal Services, Inc., Northwest Operations, Richland, Washington.

PNNL-13914. 2002. *Groundwater Monitoring Plan for the 1301-N, 1324-N/NA, and 1325-N RCRA Facilities*. M. J. Hartman, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-14022. 2002. *The 300 Area Uranium Leach and Adsorption Project*. R. J. Serne, C. F. Brown, H. T. Schaef, E. M. Pierce, J. W. Lindberg, Z. Wang, P. L. Gassman, and J. G. Catalano, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-14031. 2002. *Evaluation of Potential Sources for Tritium Detected in Groundwater at Well 199-K-111A, 100-K Area*. R. E. Peterson, F. A. Spane, K. B. Olsen, and M. D. Williams, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-14033. 2002. *Groundwater Monitoring and Assessment Plan for the 100-K Area Fuel Storage Basins*. R. E. Peterson, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-14049. 2002. *Data Quality Objectives Summary Report — Designing a Groundwater Monitoring Network for the 200-BP-5 and 200-PO-1 Operable Units.* E. C. Thornton and J. W. Lindberg, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-14070. 2002. *Groundwater Monitoring Plan for the 216-S-10 Pond and Ditch.* B. A. Williams and C. J. Chou, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-14112. 2002. *Groundwater Monitoring Plan for the 216-B-63 Trench on the Hanford Site.* M. D. Sweeney, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-14113. 2002. *Results of Detailed Hydrologic Characterization Tests - Fiscal Year 2001.* F. A. Spane, Jr., P. D. Thorne, and D. R. Newcomer, Pacific Northwest National Laboratory, Richland, Washington.

Record of Decision (ROD). 1993. *Record of Decision, USDOE Hanford 1100 Area, Hanford Site, Richland Washington (1100-EM-1, 1100-EM-2, 1100-EM-3, and 1100-IU-1 Operable Units).* Washington State Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Record of Decision (ROD). 1995. *Declaration of the Record of Decision for the 200-ZP-1 Operable Unit.* Washington State Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Record of Decision (ROD). 1996a. *Declaration of the Record of Decision for the 300-FF-1 and 300-FF-5 Operable Units.* Washington State Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Record of Decision (ROD). 1996b. *Declaration of the Record of Decision for the 100-HR-3 and 100-KR-4 Operable Units.* Washington State Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Record of Decision (ROD). 1997. *Declaration of the Record of Decision for the 200-UP-1 Operable Unit.* Washington State Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Record of Decision (ROD). 1999. *Amended Record of Decision, Decision Summary and Responsiveness Summary for the 100-HR-3 Operable Unit.* U.S. Environmental Protection Agency, Region X, Seattle, Washington.

Resource Conservation and Recovery Act. 1976. As amended, Public Law 94-580, 90 Stat. 2795, 42 USC 6901 et seq.

RHO-RE-ST-12 P. 1984. *An Assessment of Aquifer Intercommunication in the B Pond, Gable Mountain Pond Area.* M. J. Graham, G. V. Last, and K. R. Fecht, Rockwell Hanford Operations, Richland, Washington.

RHO-ST-42. 1981. *Hydrology of the Separations Area.* M. J. Graham, M. D. Hall, S. R. Strait, and W. R. Brown, Rockwell Hanford Operations, Richland, Washington.

Shapiro, S. S. 1980. "How to Test Normality and Other Distributional Assumptions." In *ASQC Basic References in Quality Control: Statistical Techniques*, Vol. 3, E. J. Dudewicz (ed.), American Society of Quality Control, Milwaukee, Wisconsin.

WAC 173-160. *Minimum Standards for Construction and Maintenance of Wells.* Washington Administrative Code, Olympia, Washington.

WAC 173-200. *Water Quality Standards for Ground Waters of the State of Washington.* Washington Administrative Code, Olympia, Washington.

WAC 173-216. *State Waste Discharge Program.* Washington Administrative Code, Olympia, Washington.

WAC 173-303. *Dangerous Waste Regulations.* Washington Administrative Code, Olympia, Washington.

WAC 173-303-400. *Interim Status Facility Standards.* Washington Administrative Code, Olympia, Washington.

WAC 173-303-610. *Closure and Post-Closure*. Washington Administrative Code, Olympia, Washington.

WAC 173-303-645. *Releases from Regulated Units*. Washington Administrative Code, Olympia, Washington.

WAC 173-304. *Minimum Functional Standards for Solid Waste Handling*. Washington Administrative Code, Olympia, Washington.

WAC 173-304-490. *Ground Water Monitoring Requirements*. Washington Administrative Code, Olympia, Washington.

WAC 173-340. *Model Toxics Control Act – Cleanup*. Washington Administrative Code, Olympia, Washington.

Westgard, J. O., T. Groth, T. Aronson, and C. De Verdier. 1977. "Combined Shewhart-CUSUM Control Chart for Improved Quality Control in Clinical Chemistry." *Clinical Chemistry* 28(10):1881-1887.

WHC-EP-0021. 1987. *Interim Hydrogeologic Characterization Report and Groundwater Monitoring System for the Nonradioactive Dangerous Waste Landfill, Hanford Site, Washington*. D. C. Weekes, S. P. Luttrell, and M. R. Fuchs, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-C018H-RPT-003. 1994. *1994 Characterization Report for the State Approved Land Disposal Site*. L. C. Swanson, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-EN-AP-015. 1989. *Revised Ground-Water Monitoring Plan for the 200 Areas Low-Level Burial Grounds*. G. V. Last and B. N. Bjornstad, prepared by Pacific Northwest Laboratory for Westinghouse Hanford Company, Richland, Washington.

WHC-SD-EN-AP-018. 1990. *Interim-Status Ground Water Monitoring Plan for the 216-S-10 Pond and Ditch*. S. P. Airhart, J. V. Borghese, and S. Dudziak, prepared by Pacific Northwest Laboratory for Westinghouse Hanford Company, Richland, Washington.

WHC-SD-EN-AP-019. 1990. *Interim-Status Ground-Water Monitoring Plan for the 216-U-12 Crib*. E. J. Jensen, M. A. Chamness, S. M. Goodwin, S. H. Hall, and D. R. Newcomer, prepared by Pacific Northwest Laboratory for Westinghouse Hanford Company, Richland, Washington.

WHC-SD-EN-AP-024. 1990. *Interim Status Groundwater Monitoring Plan for the 200 East Area Liquid Effluent Retention Facility*. J. S. Schmid, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-EN-AP-108. 1993. *Interim-Status Groundwater Quality Assessment Plan for the 216-U-12 Crib*. B. A. Williams and C. J. Chou, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-EN-DP-047. 1992. *Borehole Completion Data Package for the 216-A-29 RCRA Facility Monitoring Wells: Calendar Year 1991*. G. L. Kasza, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-EN-DP-052. 1993. *Borehole Completion Data Package for the 216-S-10 Facility, CY-1992*. B. A. Williams and D. B. Barnett, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-EN-ES-004. 1993. *Site Characterization Report: Results of Detailed Evaluation of the Suitability of the Site Proposed for Disposal of 200 Areas Treated Effluent*. J. D. Davis, D. B. Barnett, L. C. Swanson, W. J. McMahon, and C. D. Palomares, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-EN-EV-002. 1990. *Interim Hydrogeologic Characterization Report for the 216-B-3 Pond*. Westinghouse Hanford Company, Richland, Washington.

WHC-SD-EN-EV-003, Rev. 1. 1992. *Results of Groundwater Quality Assessment Monitoring at the 1301-N and 1324-N/NA Facilities*. M. J. Hartman, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-EN-TI-019. 1992. *Hydrogeologic Model for the 200 East Groundwater Aggregate Area*. M. P. Connelly, B. H. Ford, J. W. Lindberg, S. J. Trent, C. D. Delaney, and J. V. Borghese, Westinghouse Hanford Company and Pacific Northwest Laboratory, Richland, Washington.

Table A.1. RCRA Interim and Final Status Groundwater Monitoring Projects, September 2002

	Interim Status TSD Unit Groundwater Monitoring		Final Status TSD Unit Groundwater Monitoring				
TSD Units, date initiated	Indicator Parameter Evaluation(a)	Groundwater Quality Assessment, date initiated	Detection Evaluation	Compliance Evaluation	Corrective Action, date initiated	Groundwater Monitoring Regulations	Calendar Year Scheduled for Part B or Closure
116-N-1 (1301-N) LWDF, December 1987			X(b)			40 CFR 265.93(b) WAC 173-303-400	1999(c)
120-N-1, 120-N-2 (1324-N/NA) LWDF, December 1987			X(b)			40 CFR 265.93(b) WAC 173-303-400	1999(c)
116-N-3 (1325-N) LWDF, December 1987			X(b)			40 CFR 265.93(b) WAC 173-303-400	1999(c)
116-H-6 (183-H) evaporation basins, June 1985					X, 1998	40 CFR 264 WAC 173-303-645(11)	1994(c)
216-A-29 ditch, November 1988	X					40 CFR 265.93(b) WAC 173-303-400	2005(c)
216-B-3 pond, November 1988	X(d)					40 CFR 265.93(b) WAC 173-303-400	2003(c)
216-B-63 trench, August 1991	X					40 CFR 265.93(b) WAC 173-303-400	2005(c)
216-S-10 pond and ditch, August 1991	X					40 CFR 265.93(b) WAC 173-303-400	2005(c)
216-U-12 crib, September 1991		X, 1993				40 CFR 265.93(d) WAC 173-303-400	2005(c)
316-5 process trenches, June 1985					X,(d) 1998	40 CFR 264 WAC 173-303-645(11)	1996(c,e)
LERF, July 1991						40 CFR 265.93(b) WAC 173-303-400	1998(f)
LLWMA 1, September 1988	X					40 CFR 265.93(b) WAC 173-303-400	2002(g)

Table A.1. (contd)

	Interim Status TSD Unit Groundwater Monitoring		Final Status TSD Unit Groundwater Monitoring				
TSD Units, date initiated	Indicator Parameter Evaluation(a)	Groundwater Quality Assessment, date initiated	Detection Evaluation	Compliance Evaluation	Corrective Action, date initiated	Groundwater Monitoring Regulations	Calendar Year Scheduled for Part B or Closure
LLWMA 2, September 1988	X					40 CFR 265.93(b) WAC 173-303-400	2002(g)
LLWMA 3, October 1988	X					40 CFR 265.93(b) WAC 173-303-400	2002(g)
LLWMA 4, October 1988	X					40 CFR 265.93(b) WAC 173-303-400	2002(g)
NRDWL, October 1986	X					40 CFR 265.93(b) WAC 173-303-400	2004(c)
PUREX cribs(h) 1988		X, 1997				40 CFR 265.93(d) WAC 173-303-400	TBD(c)
WMA A-AX, February 1990	X					40 CFR 265.93(b) WAC 173-303-400	TBD
WMA B-BX-BY, February 1990		X, 1996				40 CFR 265.93(d) WAC 173-303-400	TBD
WMA C, February 1990	X					40 CFR 265.93(b) WAC 173-303-400	TBD
WMA S-SX, October 1991		X, 1996				40 CFR 265.93(d) WAC 173-303-400	TBD
WMA T, February 1990		X, 1993				40 CFR 265.93(d) WAC 173-303-400	TBD
WMA TX-TY, September - October 1991		X, 1993				40 CFR 265.93(d) WAC 173-303-400	TBD

Table A.1. (contd)

	Interim Status TSD Unit Groundwater Monitoring		Final Status TSD Unit Groundwater Monitoring				
TSD Units, date initiated	Indicator Parameter Evaluation[(a)]	Groundwater Quality Assessment, date initiated	Detection Evaluation	Compliance Evaluation	Corrective Action, date initiated	Groundwater Monitoring Regulations	Calendar Year Scheduled for Part B or Closure
WMA U, October 1990		X, 2000				40 CFR 265.93(b) WAC 173-303-400	TBD

(a) Contamination indicator parameters (pH, specific conductance, total organic carbon, and total organic halides) used to determine if a facility is affecting groundwater quality. Exceeding the established limits means that additional evaluation and sampling are required (i.e., groundwater quality assessment). An X in the assessment column indicates whether an evaluation was needed or an assessment was required.
(b) Monitored according to interim status plan as specified in closure plans.
(c) Closure/post-closure plan; TSD unit will close under WAC 173-303-610.
(d) Implementing alternative statistical method for a 2-year trial period as a demonstration of, and in accordance with, a Washington State Department of Ecology directive (letter from D. Goswami to M. Furman, dated May 7, 2001).
(e) Closure plan pending Washington State Department of Ecology approval.
(f) Statistical evaluations suspended in January 2001 because only one downgradient well is not dry.
(g) Draft facility Part B permit application and final status groundwater monitoring plan submitted in 2002.
(h) 216-A-10, 216-A-36B, and 216-A-37-1 combined into one RCRA monitoring unit. RCRA monitoring will be performed according to interim status groundwater quality assessment requirements.

LERF = Liquid effluent retention facility.
LLWMA = Low-level waste management area.
LWDF = Liquid waste disposal facility.
NRDWL = Nonradioactive Dangerous Waste Landfill.
PUREX = Plutonium-Uranium Extraction (Plant).
RCRA = *Resource Conservation and Recovery Act.*
TBD = To be determined.
TSD = Treatment, storage, or disposal (unit).
WMA = Waste management area.

Table A.2. Estimates of Groundwater Flow Rates at Hanford Site Facilities

Site	Flow Direction	Flow Rate (m/d)	Method	Hydraulic Conductivity (m/d) (source)	Effective Porosity(a)	Gradient(b)	Comments
116-N-1 LWDF	NW	0.07 to 1.3	Darcy	6.1 to 37 (PNL-8335)	0.1 to 0.3	0.0034	Gradient calculated between wells 199-N-66 and 199-N-2.
120-N-1 and 120-N-2	NW	0.07 to 1.3	Darcy	6.1 to 37 (PNL-8335)	0.1 to 0.3	0.0035	Gradient calculated between wells 199-N-72 and 199-N-26.
116-N-3 LWDF	N	0.04 to 0.76	Darcy	6.1 to 37 (PNL-8335)	0.1 to 0.3	0.0021	Gradient calculated between wells 199-N-28 and 199-N-81.
116-H-6 evaporation basins	E	0.10 to 2.8	Darcy	15 to 140 (PNL-6728)	0.1 to 0.3	0.002	Gradient calculated between wells 199-H4-14 and 199-H4-3. Flow meter in wells 199-H4-7 and 199-H3-2A (Section 3.3 in DOE/RL-96-01).
		0.65 to 4.9	Flow meter				
200 Area TEDF	SW	0.004	Darcy	1.1 (WHC-SD-EN-ES-004)	0.25(c)	~0.001	Gradient calculated between wells 699-41-35 and 699-40-36.
216-A-29 ditch	WSW	~0.01 to ~0.04	Darcy	18 (WHC-SD-EN-DP-047)	0.1 to 0.3	~0.0002	
216-B-3 pond	SW	0.008	Darcy	1.0 (WHC-SD-EN-EV-002, PNL-10195)	0.25	~0.002	Gradient calculated between wells 699-44-39B and 699-42-42B.
216-B-63 trench	SW	0.03 to 0.4	Darcy	52 to 200 (WHC-SD-EN-EV-002)	0.1 to 0.3	~0.0002	
216-S-10 pond	ESE	0.04 to 2.1	Darcy	10 (WHC-SD-EN-DP-052) 12 to 150 (BNWL-1709)	0.1 to 0.3	0.0012 to 0.0014	Gradient decreases to the south. Gradients calculated between wells 299-W26-12, 299-W26-7, and 699-32-77.
216-U-12 crib	ESE	0.02 to 0.08	Darcy	4.2 to 5.4 (PNNL-13378)	0.1 to 0.3	0.0016	Wells are dry. Gradient calculated using regional water-table maps.
316-5 process trenches	SE	10.7 (PNL-5408)	Movement of PCE spill				
	SE	0.16 to 48	Darcy	150 to 15,000 (PNL-6716)	0.1 to 0.3	0.00033	Normal river state (not high).
LERF	W	0.04 to 2.4	Darcy	6.1 to 120 (PNNL-11620)	0.1 to 0.3	0.002	

Table A.2. (contd)

Site	Flow Direction	Flow Rate (m/d)	Method	Hydraulic Conductivity (m/d) (source)	Effective Porosity(a)	Gradient(b)	Comments
LLWMA 1	NW	0.01 to 0.5	Darcy	73 to 760 (PNL-6820)	0.1 to 0.3	0.00006	Uncertainty with gradient and rate of flow.
LLWMA 2	W	~0.04 to ~0.5	Darcy	430 to 2,000 (PNL-6820)	0.1 to 0.3	~0.00003	Gradient calculated between wells 299-E34-10 and 299-E27-9.
LLWMA 3	ENE	0.0001 to 0.12	Darcy	0.02 to 9.8 (PNL-6820)	0.1 to 0.3	0.0012	
LLWMA 4	E to ENE	0.2 to 0.6	Darcy	24 (PNL-6820)	0.1 to 0.3	0.0024	
NRDWL	125° E of N (based on plume maps)	0.026 to 0.23	Darcy	518 to 1,524 (WHC-EP-0021)	0.1 to 0.3	0.000015	Uncertainty with gradient and rate of flow. Flow direction inferred from plume maps.
PUREX cribs	SE	0.0009 to 0.45	Darcy	18 to 3,000 (PNNL-11523)	0.1 to 0.3	0.000015	Uncertainty with gradient and rate of flow. Flow direction inferred from plume maps.
SALDS	NE	0.08 to 0.8	Darcy	3.5 to 36.3 (WHC-SD-C018H-RPT-003)	0.25(c)	0.006	Gradient was calculated from maximum head difference between wells 699-48-77A and 699-48-77D in fiscal year 2002.
SWL	125° E of N (based on plume maps)	0.032 to 0.19	Darcy	640 to 1,280 (PNL-6820)	0.1 to 0.3	0.000015	Uncertainty with gradient and rate of flow. Flow direction inferred from plume maps.
WMA A-AX	SE	1.6 to 3.0	Darcy	1,981 to 2,519 (WHC-SD-EN-TI-019)	0.2 to 0.3	0.00024	
WMA B-BX-BY	WSW to SW (north half) SSE to SE (south half)	0.5	Darcy	1,615 (WHC-SD-EN-TI-019)	0.3	0.000096	
WMA C	SW	1.0 to 1.9	Darcy	1,067 to 2,073 (WHC-SD-EN-TI-019)	0.3	0.00027	
WMA S-SX	E to ESE	0.07 to 0.14	Contaminant travel time (PNNL-13441)	NA	NA	NA	Based on inferred contaminant travel time between 216-S-25 crib and downgradient wells 299-W23-15 and 299-W22-46, and between wells 299-W22-46 and 299-W22-83.
		0.009 to 0.36	Darcy	0.58 to 17.2 (aquifer test data)	0.09 to 0.12	0.0018 to 0.0019	Based on aquifer tests (PNNL-13514 and PNNL-14113).

Table A.2. (contd)

Site	Flow Direction	Flow Rate (m/d)	Method	Hydraulic Conductivity (m/d) (source)	Effective Porosity[a]	Gradient[b]	Comments
WMA T	5°N of E to 8°S of E	0.003 to 0.024	Darcy	1 to 28 (PNNL-13378; PNNL-14113)	0.1 to 0.3	0.001	Flow direction based on trend surface analysis.
WMA TX-TY	E to SE (north half)	0.014 to 0.026	Darcy	0.05 to 19.6 (PNNL-13514; PNNL-13378; PNNL-14113)	0.1 to 0.3	0.001	
	S or SW (south half)	0.29	Darcy	0.05 to 19.6 (PNNL-13514; PNNL-13378; PNNL-14113)	0.1 to 0.3	0.007	Gradient and flow rate affected by 200-ZP-1 pump-and treat in south part of WMA.
WMA U	E	0.008 to 0.20	Darcy	1.2 to 9.5 (PNNL-13378)	0.1 to 0.3	0.0021	

(a) Effective porosity assumed to be between 0.1 and 0.3, a representative range for the unconfined aquifer system.
(b) March 2002 unless noted otherwise.
(c) RHO-ST-42, RHO-RE-ST-12 P, PNNL-11801.
LERF = Liquid effluent retention facility.
LLWMA = Low-level waste management area.
LWDF = Liquid waste disposal facility.
NA = Not applicable.
NRDWL = Nonradioactive Dangerous Waste Landfill.
PCE = Tetrachloroethene.
PUREX = Plutonium-Uranium Extraction (Plant).
SALDS = State-Approved Land Disposal Site.
SWL = Solid Waste Landfill.
TEDF = Treated Effluent Disposal Facility.
WMA = Waste management area.

Table A.3. RCRA Monitoring Results Exceeding Maximum Contaminant Levels (regulated units listed in alphanumeric order)$^{(a)}$

Constituent, units	Filter	Well Name	Upgradient/ Downgradient	Number of Exceedances	Maximum Result	Maximum Contaminant Level
116-N-1 Liquid Waste Disposal Facility						
Nitrate, µg/L	N	199-N-3	Down	5	75,900	45,000
120-N-1 and 120-N-2 Facilities						
Nitrate, µg/L	N	199-N-59	Down	1	54,400	45,000
116-N-3 Liquid Waste Disposal Facility						
Nitrate, µg/L	N	199-N-32	Down	1	46,100	45,000
116-H-6 Evaporation Basins						
Chromium, µg/L	N	199-H4-12C	Down	1	149	100
	Y	199-H4-12C	Down	1	138	100
Hexavalent chromium, µg/L	Y	199-H4-12C	Down	3	148	100
Nitrate, µg/L	N	199-H4-3	Down	1	86,700	45,000
	N	199-H4-7	Down	2	64,600	45,000
216-S-10 Pond						
Carbon tetrachloride, µg/L	N	299-W27-2	Down	1	5	5
Nickel, µg/L	Y	299-W27-2	Down	1	118	100
216-U-12 Crib						
Carbon tetrachloride, µg/L	N	699-36-70A	Down	1	9	5
Methylene chloride, µg/L	N	699-36-70A	Down	1	11	5
Nitrate, µg/L	N	299-W22-79	ND	5	69,500	45,000
	N	699-36-70A	Down	5	84,600	45,000
316-5 Process Trenches						
cis-1,2-dichloroethene, µg/L	N	399-1-16B	Down	4	160	70
Uranium, µg/L	N	399-1-10A	Down	2	32	30
	N	399-1-11	Down	1	37	30
	N	399-1-16A	Down	2	68	30
	N	399-1-17A	Down	4	53	30
	N	399-1-21A	Down	1	35	30
	N	399-1-7	Down	3	71	30
Low-Level Waste Management Area 1						
Antimony, µg/L	Y	299-E32-6	Down	1	6	6
	Y	299-E33-29	Up	1	7	6
Nitrate, µg/L	N	299-E28-26	Up	2	58,900	45,000
	N	299-E32-10	Down	2	139,000	45,000
	N	299-E32-2	Down	2	60,600	45,000
	N	299-E32-3	Down	2	57,100	45,000
	N	299-E32-5	Down	2	53,100	45,000
	N	299-E32-6	Down	2	60,200	45,000
	N	299-E32-7	Down	1	50,500	45,000
	N	299-E32-9	Down	2	54,400	45,000
	N	299-E33-34	Down	2	429,000	45,000
	N	299-E33-35	Up	2	126,000	45,000
Low-Level Waste Management Area 2						
Nitrate, µg/L	N	299-E34-7	Up	1	131,000	45,000
Low-Level Waste Management Area 3						
Carbon tetrachloride, µg/L	N	299-W10-19	Up	3	49	5
	N	299-W10-20	Up	1	62	5
	N	299-W10-21	Up	2	440	5
	N	299-W7-4	Down	2	520	5
	N	299-W7-5	Down	1	3	5
	N	299-W7-7	Down	1	7	5

Table A.3. (contd)

Constituent, units	Filter	Well Name	Upgradient/ Downgradient	Number of Exceedances	Maximum Result	Maximum Contaminant Level
Chromium, µg/L	Y	299-W7-7	Down	1	116	100
Nickel, µg/L	Y	299-W7-1	Down	2	229	100
Nitrate, µg/L	N	299-W10-19	Up	3	51,400	45,000
	N	299-W10-20	Up	1	97,400	45,000
	N	299-W10-21	Up	2	128,000	45,000
	N	299-W7-4	Down	2	81,900	45,000
	N	299-W7-5	Down	1	47,400	45,000
Low-Level Waste Management Area 4						
Carbon tetrachloride, µg/L	N	299-W15-15	Up	8	44	5
	N	299-W15-16	Down	3	1,200	5
	N	299-W15-17	Down	2	13	5
	N	299-W18-21	Up	4	20	5
	N	299-W18-23	Up	3	98	5
	N	299-W18-24	Down	4	60	5
Nitrate, µg/L	N	299-W15-15	Up	2	110,000	45,000
	N	299-W15-16	Down	1	53,100	45,000
	N	299-W18-21	Up	2	98,300	45,000
	N	299-W18-23	Up	2	58,900	45,000
	N	299-W18-24	Down	2	86,800	45,000
Nonradioactive Dangerous Waste Landfill						
Methylene chloride, µg/L	N	699-26-35A	Up	1	38	5
Plutonium-Uranium Extraction (PUREX) Cribs						
Nitrate, µg/L	N	299-E17-1	Down	2	75,300	45,000
	N	299-E17-14	Down	4	124,000	45,000
	N	299-E17-19	Down	2	67,700	45,000
	N	299-E17-9	Down	1	233,000	45,000
	N	299-E24-18	Up	1	46,000	45,000
Single-Shell Tanks Waste Management Area A-AX						
Antimony, µg/L	Y	299-E24-19	Down	1	7	6
Chromium, µg/L	Y	299-E24-19	Down	3	1,000	100
	Y	299-E25-46	Down	1	281	100
Nickel, µg/L	Y	299-E24-19	Down	3	447	100
Single-Shell Tanks Waste Management Area B-BX-BY						
Antimony, µg/L	Y	299-E32-29	ND	1	7	6
Cyanide, µg/L	N	299-E33-38	ND	2	263	200
	N	299-E33-7	ND	3	321	200
Nitrate, µg/L	N	299-E33-15	ND	2	452,000	45,000
	N	299-E33-16	ND	3	611,000	45,000
	N	299-E33-17	ND	2	253,000	45,000
	N	299-E33-18	ND	4	137,000	45,000
	N	299-E33-20	ND	3	168,000	45,000
	N	299-E33-26	ND	5	282,000	45,000
	N	299-E33-31	ND	4	220,000	45,000
	N	299-E33-32	ND	4	98,700	45,000
	N	299-E33-38	ND	4	469,000	45,000
	N	299-E33-39	ND	2	47,800	45,000
	N	299-E33-42	ND	4	95,600	45,000
	N	299-E33-44	ND	4	326,000	45,000
	N	299-E33-7	ND	4	602,000	45,000
	N	299-E33-9	ND	4	122,000	45,000
Single-Shell Tanks Waste Management Area S-SX						
Carbon tetrachloride, µg/L	N	299-W22-48	Down	1	10	5
	N	299-W22-49	Down	1	11	5
	N	299-W22-50	Down	1	20	5
	N	299-W23-15	Down	2	220	5

Table A.3. (contd)

Constituent, units	Filter	Well Name	Upgradient/ Downgradient	Number of Exceedances	Maximum Result	Maximum Contaminant Level
Nitrate, µg/L	N	299-W22-46	Down	4	56,200	45,000
	N	299-W22-48	Down	4	74,400	45,000
	N	299-W22-50	Down	3	63,700	45,000
	N	299-W23-19	Down	1	1,000,000	45,000
	N	299-W23-21	Up	4	62,400	45,000
Single-Shell Tanks Waste Management Area T						
Carbon tetrachloride, µg/L	N	299-W10-1	Up	1	810	5
	N	299-W10-22	ND	1	550	5
	N	299-W10-23	Down	1	1,600	5
	N	299-W10-4	Up	2	1,800	5
	N	299-W11-42	Down	2	1,800	5
	N	299-W11-7	ND	1	700	5
Chromium, µg/L	Y	299-W10-4	Up	4	252	100
	Y	299-W11-41	Down	4	134	100
	Y	299-W11-42	Down	5	131	100
Fluoride, µg/L	N	299-W10-24	Down	2	4,300	4,000
	N	299-W11-42	Down	2	4,400	4,000
Nitrate, µg/L	N	299-W10-1	Up	4	132,000	45,000
	N	299-W10-22	ND	2	176,000	45,000
	N	299-W10-23	Down	4	360,000	45,000
	N	299-W10-24	Down	5	297,000	45,000
	N	299-W10-28	Up	4	1,460,000	45,000
	N	299-W10-4	Up	3	1,740,000	45,000
	N	299-W10-8	Down	3	169,000	45,000
	N	299-W11-12	Down	3	157,000	45,000
	N	299-W11-24	Down	1	418,000	45,000
	N	299-W11-28	Down	2	266,000	45,000
	N	299-W11-39	Down	3	62,400	45,000
	N	299-W11-40	Down	5	197,000	45,000
	N	299-W11-41	Down	4	584,000	45,000
	N	299-W11-42	Down	4	708,000	45,000
	N	299-W11-7	ND	2	147,000	45,000
	N	299-W11-12	Down	1	135,000	45,000
Nitrite, µg/L	N	299-W11-24	Down	1	7,550	3,300
Trichloroethene, µg/L	N	299-W10-1	Up	1	7	5
	N	299-W10-22	ND	1	5	5
	N	299-W10-23	Down	1	12	5
	N	299-W10-4	Up	2	14	5
	N	299-W11-42	Down	2	11	5
	N	299-W11-7	ND	1	5	5
Single-Shell Tanks Waste Management Area TX-TY						
Carbon tetrachloride, µg/L	N	299-W14-14	Down	1	590	5
	N	299-W14-6	Down	1	290	5
	N	299-W15-40	Up	1	3,400	5
	N	299-W15-41	Down	1	1,400	5
Chromium, µg/L	Y	299-W14-13	Down	4	361	100
Nitrate, µg/L	N	299-W10-17	ND	2	243,000	45,000
	N	299-W10-26	Down	4	92,500	45,000
	N	299-W10-27	Down	5	96,900	45,000
	N	299-W14-13	Down	4	390,000	45,000
	N	299-W14-14	Down	4	113,000	45,000
	N	299-W14-15	Down	4	95,600	45,000
	N	299-W14-16	Down	5	90,300	45,000
	N	299-W14-17	Down	4	182,000	45,000
	N	299-W14-18	Down	4	111,000	45,000
	N	299-W14-5	Down	3	108,000	45,000
	N	299-W14-6	Down	4	93,400	45,000
	N	299-W15-40	Up	4	98,700	45,000
	N	299-W15-41	Down	4	67,700	45,000

Table A.3. (contd)

Constituent, units	Filter	Well Name	Upgradient/ Downgradient	Number of Exceedances	Maximum Result	Maximum Contaminant Level
Nitrate, µg/L (contd)	N	299-W15-765	Up	4	170,000	45,000
	Y	299-W14-5	Down	1	89,400	45,000
	N	299-W14-18	Down	1	3,940	3,300
Trichloroethene, µg/L	N	299-W15-40	Up	1	16	5
	N	299-W15-41	Down	1	6	5
Single-Shell Tanks Waste Management Area U						
Carbon tetrachloride, µg/L	N	299-W18-30	Down	4	200	5
	N	299-W18-31	Up	1	120	5
	N	299-W18-40	Up	1	200	5
	N	299-W19-12	Down	1	200	5
	N	299-W19-41	Down	1	130	5
	N	299-W19-42	Down	1	350	5
	N	299-W19-44	Down	1	56	5
	N	299-W19-45	Down	1	940	5

(a) Samples collected between October 1, 2001 and September 30, 2002. Primary maximum contaminant levels for dangerous, non-radioactive constituents except for 116-H-6 Evaporation Basins and 316-5 Area Process Trenches, which include radionuclides specified in Site Permit.

ND = Not determined.

Table A.4. Monitoring Wells and Constituents for 100-N Area Units (adapted from PNNL-13914)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurement	Well Standard
		116-N-1 (1301-N) Liquid Waste Disposal Facility		
199-N-2^{64}	Top of unconfined	Semiannual	Quarterly	PRE
199-N-3^{64}	Top of unconfined	Semiannual	Semiannual	PRE
199-N-34^{83}	Top of unconfined	Semiannual	Quarterly	PRE
199-N-57^{87}	Top of unconfined	Semiannual	Quarterly	RCRA
199-N-105A^{95}	Unconfined	Semiannual	--	RCRA(a)
		120-N-1 and 120-N-2 (1324-N/NA) Liquid Waste Disposal Facilities		
199-N-59^{87}(b)	Top of unconfined	Semiannual	Quarterly	RCRA
199-N-71^{91}	Top of unconfined	Semiannual	Quarterly	RCRA
199-N-72^{91}	Top of unconfined	Semiannual	Quarterly	RCRA
199-N-73^{91}	Top of unconfined	Semiannual	Quarterly	RCRA
199-N-77^{92}(c)	Bottom of unconfined	Semiannual	Semiannual	RCRA
		116-N-3 (1325-N) Liquid Waste Disposal Facility		
199-N-28^{83}(c)	Top of unconfined	Semiannual	Quarterly	PRE
199-N-32^{83}	Top of unconfined	Semiannual	Semiannual	PRE
199-N-41^{84}	Top of unconfined	Semiannual	Quarterly	PRE
199-N-74^{91}	Top of unconfined	Semiannual	Quarterly	RCRA
199-N-81^{93}	Top of unconfined	Semiannual	Quarterly	RCRA

Contamination Indicator Parameters	Site-Specific Parameters	
pH (field)	Alkalinity(d)	ICP metals (filtered)(d)
Specific conductance (field)	Anions(d)	Turbidity
Total organic carbon	Gross alpha(e)	
Total organic halides		

(a) Extraction well; screened over entire thickness of aquifer.
(b) Well yielded too little water to sample in March 2002; sampled in September 2002.
(c) Used for supplemental information; no statistical evaluations.
(d) Annually for 116-N-1 and 116-N-3 liquid waste disposal facilities.
(e) Gross alpha analyzed for wells 199-N-59 and 199-N-77 only.
Bold italic = Upgradient wells.
Superscript = Year of installation.
ICP = Inductively coupled plasma emission spectroscopy.
PRE = Well not constructed to RCRA standards.
RCRA = Well constructed to RCRA standards.

Table A.5. Critical Means for 116-N-1 (1301-N) Liquid Waste Disposal Facility for Fiscal Year 2003 Comparisons(a)

Constituent, unit	n	df	t_c	Average Background	Standard Deviation	Critical Mean	Upgradient/ Downgradient Comparison Value
Specific conductance, µS/cm	8	7	5.4079	512.1	112.4	1,157	1,157
Field pH	8	7	6.0818	7.893	0.102	[7.23, 8.55]	[7.23, 8.55]
Total organic carbon,(b) µg/L	8	7	5.4079	370.31	265.076	1,891	1,890(c)
Total organic halides,(b) µg/L	8	7	5.4079	5.023	2.352	18.5	18.5

(a) Based on semiannual sampling events from September 2000 to March 2002 for upgradient well 199-N-57 and from March 2001 to September 2002 for well 199-N-34.
(b) Critical means calculated from values reported below vendor's specified method detection limit.
(c) Rounded to the nearest tenth.
df = Degrees of freedom (n-1).
n = Number of background replicate averages.
t_c = Bonferroni critical t-value for appropriate df and 20 comparisons.

Table A.6. Critical Means for 120-N-1 and 120-N-2 (1324-N/NA) Liquid Waste Disposal Facilities for Fiscal Year 2003 Comparisons(a)

Constituent, unit	n	df	t_c	Average Background	Standard Deviation	Critical Mean	Upgradient/ Downgradient Comparison Value
Specific conductance, µS/cm	5	4	8.1216	369.7	17.3	524	524
Field pH	5	4	9.7291	8.145	0.046	[7.66, 8.63]	[7.66, 8.63]
Total organic carbon,(b) µg/L	5	4	8.1216	284.5	195.195	2,021	2,020(c)
Total organic halides,(b) µg/L	5	4	8.1216	6.788	2.217	26.5	26.5

(a) Based on semiannual sampling events from September 2000 to September 2002 for upgradient well 199-N-71.
(b) Critical means calculated from values reported below vendor's specified method detection limit.
(c) Rounded to the nearest tenth.
df = Degrees of freedom (n-1).
n = Number of background replicate averages.
t_c = Bonferroni critical t-value for appropriate df and 16 comparisons.

Table A.7. Critical Means for 116-N-3 (1325-N) Liquid Waste Disposal Facility for Fiscal Year 2003 Comparisons(a)

Constituent, unit	n	df	t_c	Average Background	Standard Deviation	Critical Mean	Upgradient/ Downgradient Comparison Value
Specific conductance, µS/cm	5	4	8.1216	356.4	9.7	443	443
Field pH	5	4	9.7291	8.12	0.030	[7.80, 8.44]	[7.80, 8.44]
Total organic carbon,(b) µg/L	5	4	8.1216	212.5	104.088	1,139	1,140(c)
Total organic halides,(b) µg/L	5	4	8.1216	7.35	2.419	28.9	28.9

(a) Based on semiannual sampling events from September 2000 to September 2002 for upgradient well 199-N-74.
(b) Critical means calculated from values reported below vendor specified method detection limit.
(c) Rounded to the nearest tenth.
df = Degrees of freedom (n-1).
n = Number of background replicate averages.
t_c = Bonferroni critical t-value for appropriate df and 16 comparisons.

Table A.8. Monitoring Wells and Constituents for the 116-H-6 (183-H) Evaporation Basins (adapted from PNNL-11573)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurement	Well Standard
199-H4-3^{74}	Top of unconfined	Annual	Semiannual	PRE
199-H4-7^{86}(a)	Top of unconfined	Annual	Semiannual	RCRA
199-H4-12A^{86}(a)	Top of unconfined	Annual	Semiannual	RCRA
199-H4-12C^{86}	Mid-depth unconfined	Annual	Semiannual	RCRA

Dangerous Waste Constituents

Chromium (filtered)
Nitrate
Fluoride
Technetium-99
Uranium

Site-Specific Parameters

Alkalinity
Anions
ICP metals (filtered)
pH
Specific conductance
Turbidity

(a) Extraction well.
Superscript = Year of installation.
ICP = Inductively coupled plasma emission spectroscopy.
PRE = Well not constructed to RCRA standards.
RCRA = Well constructed to RCRA standards.

Table A.9. Monitoring Wells and Constituents for the 216-A-29 Ditch (adapted from PNNL-13047)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurement	Well Standard
299-E25-26^{85}	Upper unconfined	Semiannual	Quarterly	RCRA
299-E25-28$^{86(a)}$	Deep unconfined	Semiannual	Quarterly	RCRA
299-E25-32P^{88}	Top of unconfined	Semiannual	Quarterly	RCRA
299-E25-34^{88}	Top of unconfined	Semiannual	Quarterly	RCRA
299-E25-35^{88}	Top of unconfined	Semiannual	Quarterly	RCRA
299-E25-48^{92}	Top of unconfined	Semiannual	Quarterly	RCRA
299-E26-12^{91}	Top of unconfined	Semiannual	Quarterly	RCRA
299-E26-13^{91}	Top of unconfined	Semiannual	Quarterly	RCRA
699-43-45^{89}	Top of unconfined	Semiannual	Quarterly	RCRA

Contamination Indicator Parameters	Site-Specific Parameters	
pH (field)	Alkalinity	Phenols
Specific conductance (field)	Anions	Turbidity
Total organic carbon	ICP metals (filtered)$^{(b)}$	
Total organic halides		

(a) Used for supplemental information; no statistical evaluations.
(b) Analyzed annually.
Bold italic = Upgradient wells.
Superscript = Year of installation.
ICP = Inductively coupled plasma emission spectroscopy.
RCRA = Well constructed to RCRA standards.

Table A.10. Critical Means for the 216-A-29 Ditch for Fiscal Year 2003 Comparisons$^{(a)}$

Constituent, unit	n	df	t_c	Average Background	Standard Deviation	Critical Mean	Upgradient/ Downgradient Comparison Value
Specific conductance, µS/cm	4	3	15.145	234.2	1.8	265	265
Field pH	4	3	19.118	8.316	0.039	[7.48, 9.16]	[7.48, 9.16]
Total organic carbon, µg/L	5	4	9.7291	549	175.112	2,415	2,420$^{(c)}$
Total organic halides,$^{(b,d)}$ µg/L	4	3	15.145	NC	NC	NC	16.1

(a) Based on semiannual sampling events from June 2001 to June 2002 for upgradient well 699-43-45 except for total organic carbon (January 2001 to June 2002).
(b) Critical mean cannot be calculated because essentially all measurements are below vendor's specified method detection limit.
(c) Rounded to the nearest tenth.
(d) Upgradient/downgradient comparison value is the most recent determined limit of quantitation (see Table B.23).
df = Degrees of freedom (n-1).
n = Number of background replicate averages.
NC = Not calculated.
t_c = Bonferroni critical t-value for appropriate df and 32 comparisons.

Table A.11. Monitoring Wells and Constituents for the 216-B-3 Pond (adapted from PNNL-13367-ICN-1)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurement	Well Standard
699-42-42B^{88}	Top of uppermost	Semiannual	Quarterly	RCRA
699-43-44^{99}	Bottom of uppermost	Semiannual	Semiannual	RCRA
699-43-45^{89}	Top of uppermost	Semiannual	Quarterly	RCRA
699-44-39B^{92}	Top of uppermost	Semiannual	Quarterly	RCRA

Site-Specific Indicator Parameters	Site-Specific Parameters	
Gross alpha	Anions[a]	Nitrate[b]
Gross beta	Arsenic[b]	Phenols[a]
Specific conductance (field)	Metals (filtered, unfiltered)[a,c]	Tritium[b]
	Iodine-129[b]	Turbidity

(a) Analyzed annually.
(b) Constituents of sitewide concern; selected wells analyzed under *Atomic Energy Act of 1954* monitoring.
(c) ICP plus cadmium, lead, mercury, and silver.
Bold italic = Upgradient well.
Superscript = Year of installation.
ICP = Inductively coupled plasma emission spectroscopy.
RCRA = Well constructed to RCRA standards.

Table A.12a. Specific Conductance Baseline Periods, Summary Statistics, and Various Control Limits for the B Pond System Wells

	699-42-42B (µS/cm)	699-43-45 (µS/cm)	699-44-39B (µS/cm)
Baseline period	7/27/97 - 6/12/01	11/10/99 - 6/13/01	1/9/98 - 6/12/01
Number of samples	8	8	8
Mean ($\bar{x}$)	255.50	226.03	262.22
Standard deviation (s)	11.23	6.23	22.55
CV (%)[a]	4.4	2.8	8.6
Fitted distribution[b]	Normal	Normal	Normal
Control limit ($\bar{x}$ + 2s)	278	238	307
Control limit ($\bar{x}$ + 3s)	289	245	330
Control limit ($\bar{x}$ + 3.5s)	295	248	341
Control limit ($\bar{x}$ + 4s)	300	251	352
Control limit ($\bar{x}$ + 4.5s)	306	254	364

(a) Coefficient of variation = $(s/\bar{x}) * 100$.
(b) Based on goodness-of-fit test results.

Table A.12b. Gross Alpha Baseline Periods, Summary Statistics, and Various Control Limits for the B Pond System Wells

	699-42-42B (pCi/L)	699-43-44 (pCi/L)	699-43-45 (pCi/L)	699-44-39B (pCi/L)
Baseline period	7/22/97 - 6/12/01	9/22/99 - 6/13/02	1/13/97 - 1/18/01	4/10/97 - 6/12/01
Number of samples	8	8	8	8
Mean ($\bar{x}$)	1.76	1.99	1.03	1.65
Standard deviation (s)	0.64	0.84	0.52	0.52
CV (%)[a]	36.5	42.3	50.6	31.3
Fitted distribution[b]	Normal	Normal	Normal	Normal
Control limit ($\bar{x}$ + 2s)	3.04	3.67	2.07	2.68
Control limit ($\bar{x}$ + 3s)	3.68	4.52	2.59	3.20
Control limit ($\bar{x}$ + 3.5s)	4.00	4.94	2.85	3.46
Control limit ($\bar{x}$ + 4s)	4.32	5.36	3.11	3.72
Control limit ($\bar{x}$ + 4.5s)	4.65	5.78	3.37	3.97

(a) Coefficient of variation = (s/$\bar{x}$) * 100.
(b) Based on goodness-of-fit test results.

Table A.12c. Gross Beta Baseline Periods, Summary Statistics, and Various Control Limits for the B Pond System Wells

	699-42-42B (pCi/L)	699-43-44 (pCi/L)	699-43-45 (pCi/L)	699-44-39B (pCi/L)
Baseline period	7/22/97 - 6/12/01	9/22/99 - 6/13/02	1/13/97 - 1/18/01	4/10/97 - 6/12/01
Number of samples	8	8	8	8
Mean ($\bar{x}$)	6.51	6.06	5.91	5.88
Standard deviation (s)	1.11	1.04	1.09	2.35
CV (%)[a]	18.9	17.1	18.4	40.0
Fitted distribution[b]	Log-Normal	Normal	Normal	Normal
Control limit ($\bar{x}$ + 2s)	9.0	8.1	8.1	10.6
Control limit ($\bar{x}$ + 3s)	10.7	9.2	9.2	12.9
Control limit ($\bar{x}$ + 3.5s)	11.6	9.7	9.7	14.1
Control limit ($\bar{x}$ + 4s)	12.6	10.2	10.3	15.3
Control limit ($\bar{x}$ + 4.5s)	13.7	10.7	10.8	16.4

(a) Coefficient of variation = (s/$\bar{x}$) * 100.
(b) Based on goodness-of-fit test results.

Table A.13. Monitoring Wells and Constituents for the 216-B-63 Trench (adapted from PNNL-14112)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurement	Well Standard
299-E27-8^{87}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E27-9^{87}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E27-11^{89}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E27-16^{90}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E27-17^{91}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E27-18^{92}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E27-19^{92}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E33-33^{90}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E33-36^{90}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E33-37^{90}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E34-8^{90}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E34-10^{91}	Top of unconfined	Semiannual	Semiannual	RCRA

Contamination Indicator Parameters	Site-Specific Parameters	
pH (field)	Alkalinity(a)	ICP metals (filtered)(a)
Specific conductance (field)	Anions(a)	Phenols(a)
Total organic carbon	Gross alpha(b)	Turbidity
Total organic halides	Gross beta(b)	

(a) Analyzed annually.
(b) Analyzed to support *Atomic Energy Act of 1954* monitoring.
Bold italic = Upgradient wells.
Superscript = Year of installation.
ICP = Inductively coupled plasma emission spectroscopy.
RCRA = Well constructed to RCRA standards.

Table A.14. Critical Means for the 216-B-63 Trench for Fiscal Year 2003 Comparisons(a)

Constituent, unit	n	df	t_c	Average Background	Standard Deviation	Critical Mean	Upgradient/ Downgradient Comparison Value
Specific conductance, μS/cm	20	19	4.267	407.5	25.6	519	519
Field pH	20	19	4.572	8.056	0.081	[7.68, 8.44]	[7.68, 8.44]
Total organic carbon, μg/L	20(b)	19	4.267	538.25	188.654	1,363	1,360(c)
Total organic halides,(d,e) μg/L	20	19	4.267	NC	NC	NC	16.1

(a) Based on semiannual sampling events from October 2000 to April 2002 for upgradient wells 299-E27-8, 299-E27-9, 299-E27-11, 299-E27-17, and 299-E34-10.
(b) Excluded one unrepresentative measurement of 11,000 μg/L collected on October 20, 2000, from well 299-E27-9.
(c) Rounded to the nearest tenth.
(d) Critical mean cannot be calculated because essentially all measurements are below vendor's specified method detection limit.
(e) Upgradient/downgradient comparison value is the most recently determined limit of quantitation (see Table B.23).
df = Degrees of freedom (n-1).
n = Number of background replicate averages.
NC = Not calculated.
t_c = Bonferroni critical t-value for appropriate df and 48 comparisons.

Table A.15. Monitoring Wells and Constituents for the 216-S-10 Pond and Ditch (adapted from PNNL-14070)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurement	Well Standard
299-W26-7^{91}	Top of unconfined	Semiannual	Semiannual	RCRA
299-W26-13^{99}	Top of unconfined	Semiannual	Semiannual	RCRA
299-W27-2$^{92(a)}$	Base of unconfined	Semiannual	Semiannual	RCRA

Contamination Indicator Parameters	Site-Specific Parameters	
pH	Alkalinity(b)	Phenols(c,d)
Specific conductance	Anions(c)	Turbidity(b)
Total organic carbon(d)	Hexavalent chromium (filtered)(b)	Volatile organic compounds(b)
Total organic halides(d)	ICP metals (filtered)(c)	

(a) Used for supplemental information; no statistical evaluation.
(b) Analyzed semiannually.
(c) Analyzed annually only.
(d) Not analyzed in well 299-W27-2.
Bold italic = Upgradient wells.
Superscript = Year of installation.
ICP = Inductively coupled plasma emission spectroscopy.
RCRA = Well constructed to RCRA standards.

Table A.16. Critical Means for the 216-S-10 Pond and Ditch for Fiscal Year 2003 Comparisons(a)

Constituent, unit	n	df	t_c	Average Background	Standard Deviation	Critical Mean	Upgradient/ Downgradient Comparison Value
Specific conductance, µS/cm	4	3	9.4649	269.4	3.3	304	304
Field pH	4	3	11.9838	8.266	0.083	[7.16, 9.37]	[7.16, 9.37]
Total organic carbon,(b,c) µg/L	4	3	9.4649	248.25	127.38	1,596	1,600(d)
Total organic halides,(e) µg/L	4	3	9.4649	NC	NC	NC	16.1

(a) Based on semiannual sampling events from June 1999 to January 2001 for upgradient well 299-W26-7, except for total organic carbon that was collected from December 1998 to January 2001.
(b) Excluding unrepresentative measurement of 1,040 µg/L collected on December 1998 from well 299-W26-7.
(c) Critical mean calculated from values reported below vendor's specified method detection limit.
(d) Rounded to the nearest tenth.
(e) Critical mean cannot be calculated because essentially all measurements are below vendor specified detection limit. Upgradient/downgradient comparison value is the most recently determined limit of quantitation (see Table B.23).
df = Degrees of freedom (n-1).
n = Number of background replicate averages.
NC = Not calculated.
t_c = Bonferroni critical t-value for appropriate df and 8 comparisons.

Table A.17. Monitoring Wells and Constituents for the 216-U-12 Crib (adapted from WHC-SD-EN-AP-019 and WHC-SD-EN-AP-108)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurement	Well Standard
299-W22-79^{98}	Top of unconfined	Quarterly	Quarterly	RCRA
699-36-70A^{94}	Top of unconfined	Quarterly	Quarterly	RCRA

Contamination Indicator Parameters

pH (field)
Specific conductance (field)

Site-Specific Parameters

Alkalinity(a,b)
Anions
ICP metals (filtered)(a)
Iodine-129(b,d)
Technetium-99(b)
Total dissolved solids(c)
Turbidity

(a) Analyzed annually.
(b) Analyzed to support *Atomic Energy Act of 1954* monitoring.
(c) Well 699-36-70A only.
(d) Analyzed semiannually.
Superscript = Year of installation.
ICP = Inductively coupled plasma emission spectroscopy.
RCRA = Well constructed to RCRA standards.

Table A.18. Monitoring Wells and Constituents for the 316-5 Process Trenches (adapted from PNNL-13645)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurement	Well Standard
399-1-7^{85}	Top of unconfined	Quarterly	Quarterly	RCRA
399-1-8^{85}	Bottom of unconfined	Semiannual	Semiannual	RCRA
399-1-10A^{86}	Top of unconfined	Quarterly	Quarterly	RCRA
399-1-10B^{91}	Bottom of unconfined	Semiannual	Semiannual	RCRA
399-1-11^{86}	Top of unconfined	Quarterly	Quarterly	RCRA
399-1-16A^{86}	Top of unconfined	Quarterly	Quarterly	RCRA
399-1-16B^{87}	Bottom of unconfined	Quarterly	Quarterly	RCRA
399-1-17A^{86}	Top of unconfined	Quarterly	Quarterly	RCRA
399-1-17B^{86}	Bottom of unconfined	Semiannual	Semiannual	RCRA
399-1-21A^{91}	Top of unconfined	Semiannual	Semiannual	RCRA
399-1-21B^{91}	Bottom of unconfined	Semiannual	Semiannual	RCRA

Field-Measured Parameters

pH
Specific conductance
Turbidity

Site-Specific Parameters

cis-1,2-dichloroethene
Tetrachloroethene
Trichloroethene
Uranium

Superscript = Year of installation.
RCRA = Well constructed to RCRA standards.

Table A.19. Monitoring Wells and Constituents for the Liquid Effluent Retention Facility (adapted from WHC-SD-EN-AP-024)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurement	Well Standard
299-E26-10^{90}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E26-11^{89}	Top of unconfined	Quarterly	Semiannual	RCRA

Contamination Indicator Parameters[(a)]	Site-Specific Parameters	
pH (field)	Alkalinity[(b)]	ICP metals (filtered)[(b)]
Specific conductance (field)	Ammonium[(b)]	Phenols[(b)]
Total organic carbon	Anions[(b)]	Temperature
Total organic halides	Gross alpha[(b,c)]	Turbidity
	Gross beta[(b,c)]	Volatile organic compounds

(a) Statistical evaluations suspended in January 2001 because only one downgradient well is not dry.
(b) Analyzed annually.
(c) Analyzed to support *Atomic Energy Act of 1954* monitoring.
Bold italic = Upgradient well.
Superscript = Year of installation.
ICP = Inductively coupled plasma emission spectroscopy.
RCRA = Well constructed to RCRA standards.

Table A.20. Monitoring Wells and Constituents for Low-Level Waste Management Area 1 (adapted from WHC-SD-EN-AP-015)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurement	Well Standard
299-E28-26^{87}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E28-27^{87}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E28-28^{90}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E32-2^{87}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E32-3^{87}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E32-4^{87}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E32-5^{89}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E32-6^{91}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E32-7^{91}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E32-8^{91}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E32-9^{91}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E32-10^{92}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E33-28^{87}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E33-29^{87}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E33-30^{87}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E33-34^{90}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E33-35^{90}	Top of unconfined	Semiannual	Semiannual	RCRA

RCRA Contamination Indicator Parameters

pH (field)
Specific conductance (field)
Total organic carbon
Total organic halides

Performance Assessment Parameters

Technetium-99

RCRA Site-Specific Parameters

Alkalinity
Anions
Gross alpha(b)
Gross beta(b)
ICP metals (filtered)
Lead (filtered)
Mercury (filtered)
Phenols(a)
Tritium(b)
Turbidity
Uranium(b)

(a) Analyzed annually.
(b) Analyzed to support *Atomic Energy Act of 1954* monitoring.
Bold italic = Upgradient wells.
Superscript = Year of installation.
ICP = Inductively coupled plasma emission spectroscopy.
RCRA = Well constructed to RCRA standards.

Table A.21. Critical Means for Low-Level Waste Management Area 1 for Fiscal Year 2003 Comparisons[(a)]

Constituent, unit	n	df	t_c	Average Background	Standard Deviation	Critical Mean	Upgradient/ Downgradient Comparison Value
Specific conductance, µS/cm	28	27	4.1542	457.1	53.355	683	683
Field pH	28	27	4.4138	8.019	0.113	[7.51, 8.53]	[7.51, 8.53]
Total organic carbon, µg/L	28	27	4.1542	487.32	204.43	1,352	1,350[(c)]
Total organic halides,[(b,d)] µg/L	28[(d)]	27	4.1542	NC	NC	NC	16.1

(a) Based on semiannual sampling events from December 2000 to June 2002 for upgradient wells 299-E28-26, 299-E28-27, 299-E28-28, 299-E32-4, 299-E33-28, 299-E33-29, and 299-E33-35.

(b) Critical mean cannot be calculated because essentially all of the measurements are below vendor's specified method detection limit. Upgradient/downgradient comparison value is the most recently determined limit of quantitation (see Table B.23).

(c) Rounded to the nearest tenth.

(d) Excluding one unrepresentative measurement of 352 µg/L collected from well 299-E33-28 on June 5, 2001.

df = Degrees of freedom (n-1).
n = Number of background replicate averages.
NC = Not calculated.
t_c = Bonferroni critical t-value for appropriate df and 68 comparisons.

Table A.22. Monitoring Wells and Constituents for Low-Level Waste Management Area 2 (adapted from WHC-SD-EN-AP-015)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurement	Well Standard
299-E27-8^{87}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E27-9^{87}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E27-10^{90}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E27-11^{89}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E27-17^{91}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E34-2^{87}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E34-3^{87}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E34-5^{87}(a)	Top of unconfined	Semiannual	Semiannual	RCRA
299-E34-7^{89}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E34-9^{91}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E34-10^{91}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E34-12^{92}	Top of unconfined	Semiannual	Semiannual	RCRA

RCRA Contamination Indicator Parameters

pH (field)
Specific conductance (field)
Total organic carbon
Total organic halides

Performance Assessment Parameters

Iodine-129
Technetium-99
Uranium

RCRA Site-Specific Parameters

Alkalinity
Anions
Gross alpha(c)
Gross beta(c)
ICP metals (filtered)
Lead (filtered)
Mercury (filtered)
Phenols(b)
Polychlorinated biphenyls
Tritium(c)
Turbidity

(a) Used for supplemental information; no statistical evaluation.
(b) Analyzed annually.
(c) Analyzed to support *Atomic Energy Act of 1954* monitoring.
Bold italic = Upgradient wells.
Superscript = Year of installation.
ICP = Inductively coupled plasma emission spectroscopy.
RCRA = Well constructed to RCRA standards.

Table A.23. Critical Means for Low-Level Waste Management Area 2 for Fiscal Year 2003 Comparisons(a)

Constituent, unit	n	df	t_c	Average Background	Standard Deviation	Critical Mean	Upgradient/ Downgradient Comparison Value
Specific conductance, µS/cm	8	7	6.1788	594.8	75.5	1,090	1,090
Field pH	8	7	6.9197	8.067	0.100	[7.33, 8.80]	[7.33, 8.80]
Total organic carbon, µg/L	8	7	6.1788	703.44	218.203	2,133	2,130(b)
Total organic halides,(c,d) µg/L	8	7	6.1788	3.344	1.299	11.9	16.1

(a) Based on semiannual sampling events from April 1999 to May 2002 for upgradient well 299-E27-10 and from December 2000 to May 2002 for well 299-E34-3. Data from well 299-E34-7 are excluded due to elevated levels of all indicator parameters.
(b) Rounded to the nearest tenth.
(c) Critical mean calculated from values below vendor's specified method detection limit.
(d) Upgradient/downgradient comparison value is the most recently determined limit of quantitation (see Table B.23).
df = Degrees of freedom (n-1).
n = Number of background replicate averages.
t_c = Bonferroni critical t-value for appropriate df and 44 comparisons.

Table A.24. Monitoring Wells and Constituents for Low-Level Waste Management Area 3 (adapted from WHC-SD-EN-AP-015)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurement	Well Standard
299-W7-1[87]	Top of unconfined	Semiannual	Semiannual	RCRA
299-W7-3[87(a)]	Deep unconfined	Semiannual	Semiannual	RCRA
299-W7-4[87]	Top of unconfined	Semiannual	Semiannual	RCRA
299-W7-5[87]	Top of unconfined	Semiannual	Semiannual	RCRA
299-W7-7[89]	Top of unconfined	Semiannual	Semiannual	RCRA
299-W7-12[91]	Top of unconfined	Semiannual	Semiannual	RCRA
299-W8-1[87]	Top of unconfined	Semiannual	Semiannual	RCRA
***299-W10-14**[87(a)]*	Deep unconfined	Semiannual	Semiannual	RCRA
***299-W10-19**[92]*	Top of unconfined	Semiannual	Semiannual	RCRA
***299-W10-20**[93]*	Top of unconfined	Semiannual	Semiannual	RCRA
***299-W10-21**[93]*	Top of unconfined	Semiannual	Semiannual	RCRA

RCRA Contamination Indicator Parameters
pH (field)
Specific conductance (field)
Total organic carbon
Total organic halides

RCRA Site-Specific Parameters	
Alkalinity	Mercury (filtered)
Anions	Phenols
Gross alpha[(b)]	Tritium[(b)]
Gross beta[(b)]	Turbidity
ICP metals (filtered)	Volatile organic compounds
Lead (filtered)	

Performance Assessment Parameters	
Iodine-129	Uranium
Technetium-99	

(a) Used for supplemental information; no statistical evaluations.
(b) Analyzed to support *Atomic Energy Act of 1954* monitoring.
Bold italic = Upgradient wells.
Superscript = Year of installation.
ICP = Inductively coupled plasma emission spectroscopy.
RCRA = Well constructed to RCRA standards.

Table A.25. Critical Means for Low-Level Waste Management Area 3 for Fiscal Year 2003 Comparisons[(a)]

Constituent, unit	n	df	t_c	Average Background	Standard Deviation	Critical Mean	Upgradient/ Downgradient Comparison Value
Specific conductance, µS/cm	12	11	4.7979	491.2	69.3	837	837
Field pH	12	11	5.2381	8.146	0.164	[7.25, 9.04]	[7.25, 9.04]
Total organic carbon, µg/L	12	11	4.7979	509.17	132.705	1,172	1,170[(b)]
Total organic halides, µg/L	12	11	4.7979	214.365	224.729	1,336.2	1,336.2

(a) Based on semiannual sampling events from March 2001 to September 2002 for upgradient wells 299-W10-19 and 299-W10-21 and from October 2000 to March 2002 for well 299-W10-20.

(b) Rounded to the nearest tenth.

df = Degrees of freedom (n-1).

n = Number of background replicate averages.

t_c = Bonferroni critical t-value for appropriate df and 36 comparisons.

Table A.26. Monitoring Wells and Constituents for Low-Level Waste Management Area 4 (adapted from WHC-SD-EN-AP-015)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurement	Well Standard
299-W15-15^{87}	Top of unconfined	Semiannual	Semiannual	RCRA
299-W15-16^{87}	Top of unconfined	Semiannual	Semiannual	RCRA
299-W15-17$^{87(a)}$	Deep unconfined	Semiannual	Semiannual	RCRA
299-W18-21^{87}	Top of unconfined	Semiannual	Semiannual	RCRA
299-W18-22$^{87(a)}$	Deep unconfined	Semiannual	Semiannual	RCRA
299-W18-23^{87}	Top of unconfined	Semiannual	Semiannual	RCRA
299-W18-24^{87}	Top of unconfined	Semiannual	Semiannual	RCRA

RCRA Contamination Indicator Parameters

- pH (field)
- Specific conductance (field)
- Total organic carbon
- Total organic halides

Performance Assessment Parameters

- Iodine-129
- Technetium-99
- Uranium

RCRA Site-Specific Parameters

- Alkalinity
- Anions
- Gross alpha$^{(b)}$
- Gross beta$^{(b)}$
- ICP metals (filtered)
- Lead (filtered)
- Mercury (filtered)
- Phenols
- Tritium$^{(b)}$
- Turbidity
- Volatile organic compounds

(a) Used for supplemental information; no statistical evaluations.
(b) Analyzed to support *Atomic Energy Act of 1954* monitoring.
Bold italic = Upgradient wells.
Superscript = Year of installation.
ICP = Inductively coupled plasma emission spectroscopy.
RCRA = Well constructed to RCRA standards.

Table A.27. Critical Means for Low-Level Waste Management Area 4 for Fiscal Year 2003 Comparisons$^{(a)}$

Constituent, unit	n	df	t_c	Average Background	Standard Deviation	Critical Mean	Upgradient/ Downgradient Comparison Value
Specific conductance,$^{(b)}$ µS/cm	12	11	4.4375	471.3	66.3	778	778
Field pH	12	11	4.8638	7.956	0.133	[7.28, 8.63]	[7.28, 8.63]
Total organic carbon, µg/L	12	11	4.4375	462.917	261.564	1,671	1,670$^{(c)}$
Total organic halides, µg/L	12	11	4.4375	30.073	16.702	107.2	107.2

(a) Based on semiannual sampling events from January 2001 to August 2002 for upgradient wells 299-W15-15, 299-W18-21, and 299-W18-23 except for specific conductance (July 2000 to August 2002).
(b) Excluding outliers.
(c) Rounded to the nearest tenth.
df = Degrees of freedom (n-1).
n = Number of background replicate averages.
t_c = Bonferroni critical t-value for appropriate df and 20 comparisons.

Table A.28. Monitoring Wells and Constituents for the Nonradioactive Dangerous Waste Landfill (adapted from PNNL-12227)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurement	Well Standard
699-25-33A^{87}(a)	Top of LPU(b)	Semiannual	Semiannual	RCRA
699-25-34A^{86}	Top of unconfined	Semiannual	Semiannual	RCRA
699-25-34B^{86}(c)	Top of unconfined	Semiannual	Semiannual	RCRA
699-25-34D^{92}	Top of unconfined	Semiannual	Semiannual	RCRA
699-26-33^{86}	Top of unconfined	Semiannual	Semiannual	RCRA
699-26-34A^{86}	Top of unconfined	Semiannual	Semiannual	RCRA
699-26-34B^{92}	Top of unconfined	Semiannual	Semiannual	RCRA
699-26-35A^{86}	Top of unconfined	Semiannual	Semiannual	RCRA
699-26-35C^{87}(a)	Top of LPU(b)	Semiannual	Semiannual	RCRA

Contamination Indicator Parameters	Site-Specific Parameters	
pH (field)	Anions	Turbidity
Specific conductance (field)	ICP metals (filtered)	Volatile chlorinated hydrocarbons
Total organic carbon	Phenols(d)	
Total organic halides		

(a) Used for supplemental information; no statistical evaluation.
(b) Low-permeability unit (LPU) in upper Ringold Formation.
(c) Not sampled in fiscal year 2002 because of declining water levels.
(d) Analyzed annually.
Bold italic = Upgradient wells.
Superscript = Year of installation.
ICP = Inductively coupled plasma emission spectroscopy.
RCRA = Well constructed to RCRA standards.

Table A.29. Critical Means for Nonradioactive Dangerous Waste Landfill for Fiscal Year 2003 Comparisons(a)

Constituent, unit	n	df	t_c	Average Background	Standard Deviation	Critical Mean	Upgradient/ Downgradient Comparison Value
Specific conductance, µS/cm	8	7	5.7282	539.0	16.3	638	638
Field pH	8	7	6.4295	7.247	0.088	[6.64, 7.85]	[6.64, 7.85]
Total organic carbon,(b) µg/L	8	7	5.7282	221.25	178.185	1,304	1,300(c)
Total organic halides,(b,d,e) µg/L	8	7	5.7282	3.468	1.711	13.9	16.1

(a) Based on most recent sampling events from October 2000 to August 2002 for upgradient well 699-26-34A and from November 2001 to August 2002 for well 699-26-35A.
(b) Critical mean calculated from values reported below vendor's specified method detection limit.
(c) Rounded to the nearest tenth.
(d) Upgradient/downgradient comparison value is the most recently determined limit of quantitation (see Table B.23).
(e) Excluding suspect measurement of 11.6 µg/L collected on October 20, 2000 from well 699-26-34A.
df = Degrees of freedom (n-1).
n = Number of background replicate averages.
t_c = Bonferroni critical t-value for appropriate df and 28 comparisons.

Table A.30. Monitoring Wells and Constituents for PUREX Cribs 216-A-10, 216-A-36B, and 216-A-37-1 (adapted from PNNL-11523)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurement	Well Standard
Upgradient Wells				
299-E24-18^{88}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E25-31^{87}	Top of unconfined	Semiannual	Semiannual	RCRA
Near-Field Wells – 216-A-10 Crib				
299-E17-1^{55}	Top of unconfined	Semiannual	Semiannual	PRE
299-E17-19^{88}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E24-16^{88}	Top of unconfined	Quarterly	Quarterly	RCRA
Near-Field Wells – 216-A-36B Crib				
299-E17-9^{68}	Top of unconfined	Semiannual	Semiannual	PRE
299-E17-14^{88}	Top of unconfined	Quarterly	Quarterly	RCRA
299-E17-18^{88}	Top of unconfined	Semiannual	Semiannual	RCRA
Near-Field Wells – 216-A-37-1 Crib				
299-E25-17^{76}	Top of unconfined	Semiannual	Semiannual	PRE
299-E25-19^{76}	Top of unconfined	Quarterly	Quarterly	PRE
699-37-47A^{96}	Top of unconfined	Semiannual	Semiannual	RCRA
Far-Field Wells				
57 wells	Unconfined	Triannual(a)	Triannual(a)	RCRA, PRE

Contamination Indicator Parameters	Site-Specific Parameters	
pH (field)(b)	Alkalinity	ICP metals (filtered)
Specific conductance (field)(b)	Ammonium ion	Iodine-129(b,c)
	Anions(b)	Phenols
	Arsenic (filtered)	Strontium-90(c)
	Gross alpha(c)	Tritium(b,c)
	Gross beta(c)	Turbidity(b)

(a) Some far-field wells sampled annually.
(b) Far-field wells analyzed for these constituents only.
(c) Analyzed to support *Atomic Energy Act of 1954* monitoring.
Superscript = Year of installation.
ICP = Inductively coupled plasma emission spectroscopy.
PRE = Well not constructed to RCRA standards.
PUREX = Plutonium-Uranium Extraction (Plant).
RCRA = Well constructed to RCRA standards.

Table A.31. Monitoring Wells and Constituents for Waste Management Area A-AX (adapted from PNNL-13023-ICN-1)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurement	Well Standard
299-E24-19^{89}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E24-20^{91}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E25-40^{89}(a)	Top of unconfined	Semiannual	Semiannual	RCRA
299-E25-41^{89}	Top of unconfined	Semiannual	Semiannual	RCRA
299-E25-46^{92}	Top of unconfined	Semiannual	Semiannual	RCRA

Contamination Indicator Parameters	Site-Specific Parameters	
pH (field)	Alkalinity	Phenols(b)
Specific conductance (field)	Anions	Strontium-90(c)
Total organic carbon	Gross beta(c)	Technetium-99(c)
Total organic halides	Gross gamma(c)	Tritium(b,c)
	ICP metals (filtered)	Turbidity
	Iodine-129(c)	Uranium(c)

(a) Information only; not used in statistical evaluations.
(b) Annually.
(c) Analyzed to support *Atomic Energy Act of 1954* monitoring.
Bold italic = Upgradient wells.
Superscript = Year of installation.
ICP = Inductively coupled plasma emission spectroscopy.
RCRA = Well constructed to RCRA standards.

Table A.32. Critical Means for Waste Management Area A-AX for Fiscal Year 2003 Comparisons(a)

Constituent, unit	n	df	t_c	Average Background	Standard Deviation	Critical Mean	Upgradient/ Downgradient Comparison Value
Specific conductance, µS/cm	4	3	12.9240	350.3	10.0	494	494
Field pH	4	3	16.3263	8.181	0.074	[6.82, 9.54]	[6.82, 9.54]
Total organic carbon, µg/L	4	3	12.9240	559.375	113.732	2,203	2,200(b)
Total organic halides,(c) µg/L	4	3	12.9240	NC	NC	NC	16.1

(a) Based on semiannual sampling events from December 2000 to June 2002 for upgradient well 299-24-20.
(b) Rounded to the nearest tenth.
(c) Critical mean cannot be calculated because essentially all measurements are below vendor's specified method detection limit. Upgradient/downgradient comparison value is the most recently determined limit of quantitation (see Table B.23).
df = Degrees of freedom (n-1).
n = Number of background replicate averages.
t_c = Bonferroni critical t-value for appropriate df and 20 comparisons.

Table A.33. Monitoring Wells and Constituents for Waste Management Area B-BX-BY (adapted from PNNL-13022)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurement	Well Standard
Near-Field Wells				
299-E28-8$^{57(a)}$	Unconfined	Quarterly	Quarterly	PRE
299-E33-7^{55}	Unconfined	Quarterly	Quarterly	PRE
299-E33-9$^{49(a)}$	Unconfined	Quarterly	Quarterly	PRE
299-E33-10$^{55(a)}$	Unconfined	Semiannual	Semiannual	PRE
299-E33-15$^{53(a)}$	Unconfined	Semiannual	Quarterly	PRE
299-E33-16$^{53(a)}$	Unconfined	Quarterly	Quarterly	PRE
299-E33-17$^{53(a)}$	Unconfined	Semiannual	Quarterly	PRE
299-E33-18^{50}	Unconfined	Quarterly	Quarterly	PRE
299-E33-20$^{56(a)}$	Unconfined	Semiannual	Quarterly	PRE
299-E33-21$^{57(a)}$	Unconfined	Semiannual	Quarterly	PRE
299-E33-31^{89}	Unconfined	Quarterly	Quarterly	RCRA
299-E33-32^{89}	Unconfined	Quarterly	Quarterly	RCRA
299-E33-38^{91}	Unconfined	Quarterly	Quarterly	RCRA
299-E33-39^{91}	Unconfined	Quarterly	Quarterly	RCRA
299-E33-41^{91}	Unconfined	Quarterly	Quarterly	RCRA
299-E33-42^{91}	Unconfined	Quarterly	Quarterly	RCRA
299-E33-43^{91}	Unconfined	Quarterly	Quarterly	RCRA
299-E33-44^{98}	Unconfined	Quarterly	Quarterly	RCRA
299-E33-334^{00}	Unconfined	Quarterly	Quarterly	RCRA
299-E33-335^{00}	Unconfined	Quarterly	Quarterly	RCRA
299-E33-337^{01}	Unconfined	Quarterly	Quarterly	RCRA
299-E33-338^{01}	Unconfined	Quarterly	Quarterly	RCRA
299-E33-339^{01}	Unconfined	Quarterly	Quarterly	RCRA
Far-Field Wells				
299-E33-26^{69}	Unconfined	Quarterly	Quarterly	PRE
299-E33-28^{87}	Unconfined	Semiannual	Quarterly	RCRA
299-E33-29^{87}	Unconfined	Semiannual	Quarterly	RCRA

Contamination Indicator Parameters	Site-Specific Parameters	
pH	Alkalinity	Low-level gamma (cobalt-60, cesium-137)$^{(b)}$
Specific conductance	Anions	Strontium-90$^{(b)}$
Total organic carbon	Cyanide	Technetium-99$^{(b)}$
	Gross alpha$^{(b)}$	Tritium$^{(b)}$
	Gross beta$^{(b)}$	Turbidity
	ICP metals (filtered)	Uranium$^{(b)}$
	Iodine-129$^{(b)}$	

(a) Sampled to support RCRA assessment.
(b) Analyzed to support *Atomic Energy Act of 1954* monitoring.
Bold italic = Upgradient wells.
Superscript = Year of installation.
ICP = Inductively coupled plasma emission spectroscopy.
PRE = Well not constructed to RCRA standards.
RCRA = Well constructed to RCRA standards.

Table A.34. Monitoring Wells and Constituents for Waste Management Area C (adapted from PNNL-13024-ICN-1)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurement	Well Standard
299-E27-7$^{82(a)}$	Top of unconfined	Semiannual	Quarterly	PRE
299-E27-12^{89}	Top of unconfined	Semiannual	Quarterly	RCRA
299-E27-13^{89}	Top of unconfined	Semiannual	Quarterly	RCRA
299-E27-14^{89}	Top of unconfined	Semiannual	Quarterly	RCRA
299-E27-15$^{89(a)}$	Top of unconfined	Semiannual	Quarterly	RCRA

Contamination Indicator Parameters	Site-Specific Parameters	
pH (field)	Alkalinity	ICP metals (filtered)
Specific conductance (field)	Anions	Phenols
Total organic carbon	Cyanide	Technetium-99$^{(b)}$
Total organic halides	Gamma scan$^{(b)}$	Total uranium$^{(b)}$
	Gross beta$^{(b)}$	Turbidity

(a) Used for supplemental information; no statistical evaluation.
(b) Analyzed to support *Atomic Energy Act of 1954* monitoring.
Bold italic = Upgradient well.
Superscript = Year of installation.
ICP = Inductively coupled plasma emission spectroscopy.
PRE = Well not constructed to RCRA standards.
RCRA = Well constructed to RCRA standards.

Table A.35. Monitoring Wells and Constituents for Waste Management Area S-SX (adapted from ICN-PNNL-12114-September 1999.2)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurement	Well Standard
299-W22-44^{91}	Top of unconfined	Quarterly	Quarterly	RCRA
299-W22-45^{92}	Top of unconfined	Quarterly	Quarterly	RCRA
299-W22-46^{91}	Top of unconfined	Quarterly	Quarterly	RCRA
299-W22-48^{99}	Top of unconfined	Quarterly	Quarterly	RCRA
299-W22-49^{99}	Top of unconfined	Quarterly	Quarterly	RCRA
299-W22-50^{99}	Top of unconfined	Quarterly	Quarterly	RCRA
299-W22-80^{00}	Top of unconfined	Quarterly	Quarterly	RCRA
299-W22-81^{00}	Top of unconfined	Quarterly	Quarterly	RCRA
299-W22-82^{00}	Top of unconfined	Quarterly	Quarterly	RCRA
299-W22-83^{00}	Top of unconfined	Quarterly	Quarterly	RCRA
299-W22-84^{01}	Top of unconfined	Quarterly	Quarterly	RCRA
299-W22-85^{01}	Top of unconfined	Quarterly	Quarterly	RCRA
299-W23-15^{91}	Top of unconfined	Quarterly	Quarterly	RCRA
299-W23-19^{99}	Top of unconfined	Quarterly	Quarterly	RCRA
299-W23-20^{00}	Top of unconfined	Quarterly	Quarterly	RCRA
299-W23-21^{00}	Top of unconfined	Quarterly	Quarterly	RCRA

Contamination Indicator Parameters

pH (field)
Specific conductance (field)
Total organic carbon(a)

Site-Specific Parameters

Alkalinity
Anions(c)
Gamma scan (cesium-137)(b,d)
Gross beta(b,e)
ICP metals (filtered)
Iodine-129(a,b)

Strontium-90(a,b)
Technetium-99(b)
Tritium(b)
Turbidity
Uranium(b)

(a) Analysis done only on wells 299-W22-84 and 299-W22-85 quarterly through fiscal year 2002.
(b) Analyzed to support *Atomic Energy Act of 1954* monitoring.
(c) In all but four wells, bromide is included to monitor for tracer bromide.
(d) Analysis done only on wells 299-W22-84 and 299-W22-85 quarterly and well 299-W23-19 annually.
(e) Analysis done only on wells 299-W22-84, 299-W22-85, and 299-W23-19 quarterly.
Bold italic = Upgradient wells.
Superscript = Year of installation.
ICP = Inductively coupled plasma emission spectroscopy.
RCRA = Well constructed to RCRA standards.

Table A.36. Monitoring Wells and Constituents for Waste Management Area T (adapted from PNNL-12057-ICN-1)

Well	Hydrogeologic Unit Monitored	Sampling Frequency(a)	Water-Level Measurement	Well Standard
299-W10-1^{47}	Unconfined	Quarterly	Quarterly	PRE
299-W10-4^{52}	Top of unconfined	Quarterly	Quarterly	PRE
299-W10-8^{73}	Top of unconfined	Quarterly	Quarterly	PRE
299-W10-22^{94}	Top of unconfined	Semiannual	Quarterly	RCRA
299-W10-23^{98}	Top of unconfined	Quarterly	Quarterly	RCRA
299-W10-24^{98}	Top of unconfined	Quarterly	Quarterly	RCRA
299-W10-28^{01}	Top of unconfined	Quarterly	Quarterly	RCRA
299-W11-7^{51}	Unconfined	Semiannual	Semiannual	PRE
299-W11-12^{53}	Top of unconfined	Quarterly	Quarterly	PRE
299-W11-39^{00}	Top of unconfined	Quarterly	Quarterly	RCRA
299-W11-40^{00}	Top of unconfined	Quarterly	Quarterly	RCRA
299-W11-41^{00}	Top of unconfined	Quarterly	Quarterly	RCRA
299-W11-42^{00}	Top of unconfined	Quarterly	Quarterly	RCRA

Contamination Indicator Parameters

pH(c)
Specific conductance(c)

Site-Specific Parameters(b)

Alkalinity
Anions
Gamma scan (cesium-137, cobalt-60)(d)
Gross alpha(d)
Gross beta(d)
ICP metals (filtered)
Iodine-129(d)
Strontium-90(d)
Technetium-99(d)
Tritium(d)
Turbidity(c)

(a) Sampling frequency varies by constituent.
(b) Constituent list varies by well.
(c) Field measured parameter.
(d) Analyzed to support *Atomic Energy Act of 1954* monitoring.

Bold italic = Upgradient wells.
Superscript = Year of installation.
ICP = Inductively coupled plasma emission spectroscopy.
PRE = Well not constructed to WAC 173-160 standards.
RCRA = Well constructed to WAC 173-160 standards.

Table A.37. Monitoring Wells and Constituents for Waste Management Area TX-TY (adapted from PNNL-12072-ICN-1)

Well	Hydrogeologic Unit Monitored	Sampling Frequency(a)	Water-Level Measurement	Well Standard
299-W10-17^{91}	Top of unconfined	Dry(b)	Dry	RCRA
299-W10-26^{99}	Top of unconfined	Quarterly	Quarterly	RCRA
299-W10-27^{01}	Top of unconfined	Quarterly	Quarterly	RCRA
299-W14-5^{74}	Top of unconfined	Quarterly	Quarterly	PRE
299-W14-6^{74}	Top of unconfined	Quarterly	Quarterly	PRE
299-W14-13^{98}	Top of unconfined	Quarterly	Quarterly	RCRA
299-W14-14^{98}	Top of unconfined	Quarterly	Quarterly	RCRA
299-W14-15^{00}	Top of unconfined	Quarterly	Quarterly	RCRA
299-W14-16^{00}	Top of unconfined	Quarterly	Quarterly	RCRA
299-W14-17^{00}	Top of unconfined	Quarterly	Quarterly	RCRA
299-W14-18^{02}	Top of unconfined	Quarterly	Quarterly	RCRA
299-W15-40^{98}	Top of unconfined	Quarterly	Quarterly	RCRA
299-W15-41^{00}	Top of unconfined	Quarterly	Quarterly	RCRA
299-W15-763^{01}	Top of unconfined	Quarterly	Quarterly	RCRA
299-W15-765^{02}	Top of unconfined	Quarterly	Quarterly	RCRA

Contamination Indicator Parameters

pH (field)(d)
Specific conductance (field)(d)

Site-Specific Parameters(c)

Alkalinity
Anions
Gamma scan (cesium-137, cobalt-60)(e)
Gross alpha(e)
Gross beta(e)
ICP metals (filtered)
Iodine-129(e)
Strontium-90(e)
Technetium-99(e)
Tritium(e)
Turbidity(d)

(a) Sampling frequency varies by constituent.
(b) Dry well; last sampled February 2002.
(c) Constituent list varies by well.
(d) Field measured parameter.
(e) Analyzed to support *Atomic Energy Act of 1954* monitoring.
Bold italic = Upgradient wells.
Superscript = Year of installation.
ICP = Inductively coupled plasma emission spectroscopy.
PRE = Well not constructed to WAC 173-160 standards.
RCRA = Well constructed to WAC 173-160 standards.

Table A.38. Monitoring Wells and Constituents for Waste Management Area U (adapted from PNNL-13612)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurement	Well Standard
299-W18-30[91]	Top of unconfined	Quarterly	Quarterly	RCRA
299-W18-31[91]	Top of unconfined	Quarterly	Quarterly	RCRA
299-W18-40[01]	Top of unconfined	Quarterly	Quarterly	RCRA
299-W19-12[83(a)]	Top of unconfined	Quarterly	Quarterly	RCRA(b)
299-W19-41[99]	Top of unconfined	Quarterly	Quarterly	RCRA
299-W19-42[99]	Top of unconfined	Quarterly	Quarterly	RCRA
299-W19-44[01]	Top of unconfined	Quarterly	Quarterly	RCRA
299-W19-45[01]	Top of unconfined	Quarterly	Quarterly	RCRA

Contamination Indicator Parameters	Site-Specific Parameters	
pH (field)	Alkalinity	Iodine-129(c,d)
Specific conductance (field)	Anions	Technetium-99(d)
	Gamma scan(c,d)	Tritium(c,d)
	Gross alpha(c,d)	Volatile organic compounds(c)
	ICP metals (filtered)	

(a) Used for supplemental information; no statistical evaluations.
(b) Old well, but construction meets RCRA standards.
(c) Annually.
(d) Analyzed to support *Atomic Energy Act of 1954* monitoring.
Bold italic = Upgradient wells.
Superscript = Year of installation.
ICP = Inductively coupled plasma emission spectroscopy.
RCRA = Well constructed to RCRA standards.

Table A.39. Monitoring Wells and Constituents for the 100 KE and 100 KW Basins (adapted from PNNL-14033)

Well	Hydrogeologic Unit Monitored	Sampling Frequency$^{(a)}$	Water-Level Measurement	Well Standard
199-K-27^{79}	Top of unconfined	Quarterly	Quarterly	PRE
199-K-29^{79}	Top of unconfined	Quarterly	Quarterly	PRE
199-K-30^{79}	Top of unconfined	Quarterly	Quarterly	PRE
199-K-32A^{92}	Top of unconfined	Quarterly	Quarterly	RCRA
199-K-33^{92}	Top of unconfined	Semiannual	Semiannual	RCRA
199-K-34^{92}	Top of unconfined	Quarterly	Quarterly	RCRA
199-K-106A^{94}	Top of unconfined	Quarterly	Quarterly	RCRA
199-K-107A^{94}	Top of unconfined	Quarterly	Quarterly	RCRA
199-K-108A^{94}	Top of unconfined	Semiannual	Semiannual	RCRA
199-K-109A^{94}	Top of unconfined	Quarterly	Quarterly	RCRA
199-K-110A^{94}	Top of unconfined	Semiannual	Semiannual	RCRA
199-K-111A^{94}	Top of unconfined	Quarterly	Quarterly	RCRA

Field Parameters		Site-Specific Parameters	
pH	Temperature	Anions	ICP metals (filtered)
Specific conductance	Turbidity	Carbon-14	Strontium-90
		Gross alpha	Technetium-99
		Gross beta	Tritium

(a) Sampling frequency varies by constituent.
Superscript = Year of installation.
ICP = Inductively coupled plasma emission spectroscopy.
PRE = Well not constructed to RCRA standards.
RCRA = Well constructed to RCRA standards.

Table A.40. Monitoring Wells, Constituents, and Enforcement Limits for the 200 Areas Treated Effluent Disposal Facility (adapted from PNNL-13032)

Well	Hydrogeologic Unit	Sampling Frequency	Water-Level Measurement	Well Standard
699-40-36^{92}	Ringold confined	Quarterly	Quarterly	RCRA
699-41-35^{92}	Ringold confined	Quarterly	Quarterly	RCRA
699-42-37^{92}	Ringold confined	Quarterly	Quarterly	RCRA

Constituent$^{(a)}$	Enforcement Limit (μg/L)
Cadmium	5
Lead	10
pH	6.5 - 8.5 pH units

(a) Also monitored for ICP metals, anions, trace metals, alkalinity, specific conductance, total dissolved solids, turbidity, gross alpha, gross beta, and low-level tritium (annually). No enforcement limits for those constituents.
Bold italic = Upgradient well.
Superscript = Year of installation.
ICP = Inductively coupled plasma emission spectroscopy.
RCRA = Well constructed to RCRA standards.

Table A.41. Monitoring Wells, Constituents, and Enforcement Limits for the 400 Area Process Ponds (specified in state waste discharge permit)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurement	Well Standard
699-2-6A^{97}	Unconfined aquifer	Quarterly	Quarterly	RCRA
699-2-7^{78}	Unconfined aquifer	Quarterly	Quarterly	PRE
699-8-17^{50}	Unconfined aquifer	Quarterly	Quarterly	PRE

Constituent	Enforcement Limit (µg/L)$^{(a,b)}$
Cadmium (unfiltered)	10
Chromium (unfiltered)	50
Lead (unfiltered)	50
Manganese (unfiltered)	50
Mercury (unfiltered)	2
pH	Monitor only
Sulfate	Monitor only
Total organic carbon	Monitor only

(a) Defined as the average of four quarterly measurements from a well. Average to be calculated using the four most recent quarterly measurements from a well.

(b) Enforcement limit in groundwater shall be met in point-of-compliance well 699-2-7.

Bold italic = Upgradient well.
Superscript = Year of installation.
PRE = Well not constructed to RCRA standards.
RCRA = Well constructed to RCRA standards.

Table A.42. Monitoring Wells and Constituents for the Environmental Restoration Disposal Facility (adapted from BHI-00873)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurement	Well Standard
699-35-66A^{57}	Top of unconfined	Semiannual	Semiannual	PRE
699-36-67^{96}	Top of unconfined	Semiannual	Semiannual	RCRA
699-36-70A^{94}	Top of unconfined	Semiannual	Semiannual	RCRA
699-37-68^{96}	Top of unconfined	Semiannual	Semiannual	RCRA

Field Parameters	Site-Specific Parameters	
pH (field)	Alkalinity	ICP metals (filtered)
Specific conductance (field)	Anions	Iodine-129
Turbidity	Arsenic (filtered)	Radium
	Carbon-14	Technetium-99
	Carbon tetrachloride	Total dissolved solids
	Gross alpha	Total organic halides
	Gross beta	Uranium

Bold italic = Upgradient well.
Superscript = Year of installation.
ICP = Inductively coupled plasma emission spectroscopy.
PRE = Well not constructed to RCRA standards.
RCRA = Well constructed to RCRA standards.

Table A.43. Monitoring Wells and Constituents for the Solid Waste Landfill (adapted from PNNL-13014)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurement	Well Standard
699-22-35^{93}	Top of unconfined	Quarterly	Quarterly	RCRA
699-23-34A^{87}	Top of unconfined	Quarterly	Quarterly	RCRA
699-23-34B^{93}	Top of unconfined	Quarterly	Quarterly	RCRA
699-24-33^{48}(a)	Top of unconfined	Quarterly(b)	Quarterly	PRE
699-24-34A^{87}	Top of unconfined	Quarterly	Quarterly	RCRA
699-24-34B^{87}	Top of unconfined	Quarterly	Quarterly	RCRA
699-24-34C^{87}	Top of unconfined	Quarterly	Quarterly	RCRA
699-24-35^{87}	Top of unconfined	Quarterly	Quarterly	RCRA
699-25-34C^{87}	Top of unconfined	Quarterly	Quarterly	RCRA
699-26-35A^{86}	Top of unconfined	Quarterly	Quarterly	RCRA

Parameters/Constituents Required by WAC 173-304-490

Ammonia as nitrogen
Chemical oxygen demand
Chloride
Specific conductance
Dissolved iron
Dissolved zinc
Manganese
Nitrate
Nitrite
pH
Sulfate
Temperature
Total coliform
Total organic carbon

Site-Specific Parameters

Anions
ICP metals (filtered)
Volatile organic compounds

(a) Used for supplemental information; no statistical evaluations.
(b) Well sampled for supporting data.
Bold italic = Upgradient wells.
Superscript = Year of installation.
ICP = Inductively coupled plasma emission spectroscopy.
PRE = Well not constructed to RCRA standards.
RCRA = Well constructed to RCRA standards.

Table A.44. Sampling Results for Required Constituents(a) at the Solid Waste Landfill

Constituent, unit	Value(b)	Date	Well 699-22-35	Well 699-23-34A	Well 699-23-34B	Well 699-24-33	Well 699-24-34A	Well 699-24-34B(c)	Well 699-24-34C	Well 699-24-35	Well 699-25-34C	Well 699-26-35A(d)
Temperature, °C	20.7	October 2001	17.3	17.6	17.9	19.4	18.4	18.4	18.6	17.3	17.9	19.3
		February 2002	17.4	17.2	17.1	18.6	18	18	17.7	17.1	18.2	19.3
		May 2002	17.8	18.3	18	19.8	18.3	18.4	18.1	17.6	19.6	19.1
		August 2002	19.3	20.2	19.4	26(e,f)	18.9	18.3	20.7	19	20.4	20.4
Specific conductance, µS/cm	583	October 2001	866(e)	749(e)	809(e)	775(e)	698(e)	711(e)	739(e)	609(e)	640(e)	549
		February 2002	865(e)	759(e)	816(e)	783(e)	706(e)	613(e)	755(e)	609(e)	688(e)	547
		May 2002	864(e)	765(e)	810(e)	777(e)	709(e)	723(e)	751(e)	613(e)	673(e)	548
		August 2002	853(e)	762(e)	814(e)	784(e)	710(e)	731(e)	773(e)	614(e)	689(e)	555
Field pH	[6.68, 7.84]	October 2001	6.9	6.64(e)	6.67(e)	6.9	6.65(e)	6.64(e)	6.87	6.94	7.23	7.19
		February 2002	6.93	6.59(e)	6.68	6.83	6.7(e)	6.7(e)	7	6.89	7.35	7.22
		May 2002	6.9	6.58(e)	6.7(e)	6.85	6.65(e)	6.66(e)	7.14	6.82	7.69	7.23
		August 2002	6.94	6.64(e)	6.67(e)	6.82	6.65(e)	6.65(e)	6.76	6.84	7.49	7.21
Total organic carbon, µg/L	1,090	October 2001	<120	<120	<120	<150	<120	<120	<120	<120	<150	<120
		February 2002	210	240	180	240	240	360	220	340	350	165
		May 2002	680	395	310	220	340	260	360	310	390	480
		August 2002	<140	290	210	180	<140	<140	570	<140	<140	243
Chloride, µg/L	7,820	October 2001	5,800	5,600	5,800	5,900	5,500	6,000	6,000	5,500	7,600	6,600
		February 2002	6,200	6,100	6,200	6,300	6,200	6,000	6,700	5,900	7,700	7,300
		May 2002	6,400	6,650	6,500	4,700	5,500	6,100	6,100	5,600	7,400	6,700
		August 2002	7,800	7,100	8,300(e)	7,150	6,800	6,600	7,100	6,700	8,200(e)	7,300
Nitrate, µg/L (as NO_3^-)	29,000	October 2001	15,500	12,800	15,500	13,700	11,500	12,400	13,700	11,100	16,400	17,300
		February 2002	15,500	13,700	16,400	13,700	12,000	12,800	13,700	11,500	15,900	16,800
		May 2002	14,600	13,950	14,600	14,200	11,100	12,000	12,400	10,600	12,400	15,500
		August 2002	15,100	13,700	15,100	12,800	11,500	12,400	12,400	11,100	13,700	15,100
Nitrite, µg/L (as NO_2^-)	161	October 2001	<6.57	<6.57	<6.57	<6.57	<6.57	<6.57	<6.57	<6.57	<6.57	<6.57
		February 2002	<36.10	<36.10	<36.10	<36.10	<36.10	<36.10	<36.10	<36.10	<36.10	<36.10
		May 2002	<36.10	<36.10	<36.10	<36.10	<36.10	<36.10	<36.10	<36.10	<36.10	<36.10
		August 2002	<36.10	<36.10	<36.10	<36.10	<36.10	<36.10	<36.10	<36.10	<36.10	<36.10
Ammonium, µg/L (as NH_3^-)	90	October 2001	<15.7	<15.7	<15.7	<15.7	<15.7	<15.7	<15.7	<15.7	<15.7	<15.7
		February 2002	<14.5	<14.5	<14.5	<14.5	<14.5	<14.5	<14.5	<14.5	<14.5	25.8
		May 2002	<14.5	<14.5	<14.5	<14.5	<14.5	<14.5	<14.5	<14.5	<14.5	<14.5
		August 2002	<14.5	<14.5	<14.5	<14.5	<14.5	<14.5	<14.5	<14.5	<14.5	<14.5
Sulfate, µg/L	47,200	October 2001	51,200(e)	47,500(e)	51,200(e)	41,700	44,900	45,300	40,100	45,300	43,300	38,900
		February 2002	49,800(e)	47,500(e)	49,100(e)	41,100	45,100	44,600	40,000	45,100	42,000	39,400
		May 2002	52,500(e)	52,700(e)	51,000(e)	44,200	47,200	45,500	42,000	47,000	44,200	40,400
		August 2002	51,300(e)	51,800(e)	51,300(e)	46,070	48,100(e)	45,400	42,400	48,200(e)	43,500	40,300

Table A.44. (contd)

Constituent, unit	Value[b]	Date	Well 699-22-35	Well 699-23-34A	Well 699-23-34B	Well 699-24-33	Well 699-24-34A	Well 699-24-34B[c]	Well 699-24-34C	Well 699-24-35	Well 699-25-34C	Well 699-26-35A[d]
Iron, filtered, µg/L	160	October 2001	35.4	39.9	57.4	53	66	53.2	45.4	<6.8	80.6	44.5
		February 2002	40.4	50.7	45.5	39.7	45.2	45.6	30.1	36.3	<26.9	<26.6
		May 2002	31.2	37.4	38.6	<8.2	67.8	35.6	28.4	39.5	43.3	<8.2
		August 2002	44.5	53.3	40.4	42.4	53.8	49	139	40.2	60.4	<15.9
Zinc, filtered, µg/L	34.9	October 2001	<2.0	<2	4	15.2	<2	2.3	10.8	4	3.6	5.8
		February 2002	<7.4	<7.4	<7.4	14.1	<7.4	<7.4	10.1	<7.4	<7.4	12
		May 2002	<12.2	<12.2	<12.2	13	<12.2	<12.2	<12.2	<12.2	<12.2	<12.2
		August 2002	2.3	2.8	2.2	10.1	4.1	<2.2	10.4	2.2	4	6.2
Manganese, filtered, µg/L	10	October 2001	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
		February 2002	4.2	4.8	4.6	3.8	4	3.9	2.9	3.7	3.8	<1.4
		May 2002	3.5	3.45	3.6	3.3	4.6	3.2	3	3.6	3.8	1.8
		August 2002	4	4.2	3.9	3.7	4.5	4.1	8.4	3.3	5.1	2.3
Chemical oxygen demand, mg/L	10	October 2001	<3.9	<3.9	<3.9	<3.9	<3.9	<3.9	<3.9	<3.9	<3.9	<3.9
		February 2002	<3.9	<3.9	<3.9	<3.9	<3.9	<3.9	<3.9	<3.9	<3.9	<3.9
		May 2002	<7.5	<7.5	<7.5	<7.5	<7.5	<7.5	<7.5	<7.5	<7.5	<7.5
		August 2002	<7.5	<7.5	<7.5	<7.5	<7.5	<7.5	<7.5	<7.5	<7.5	<7.5
Coliform bacteria, Col/100 ml	3.7	October 2001	[g]	[g]	[g]	[g]	[g]	[g]	[g]	[g]	[g]	[g]
		February 2002	0	0	0	0	0	0	0	0	0	0
		May 2002	0	0	0	0	0	0	0	0	0	0
		August 2002	0	52.1[e]	0	0	0	[g]	0	260[e]	0	0

(a) WAC 173-304.
(b) Number obtained from Table A.45, background threshold value column.
(c) Well actually sampled September 2002.
(d) Well actually sampled March 2002.
(e) Exceeding background threshold values.
(f) Probable measurement error.
(g) Sample not collected.

Table A.45. Results of Shapiro and Francia Test for Normality and Background Threshold Values for the Solid Waste Landfill

Constituent,[a] unit	Test Statistic, W' Log Value	Test Statistic, W' Raw Data	Critical Value,[b] W'α	Upper Tolerance Limit	Background Threshold Value
Temperature, °C	0.953 s	0.961 s	0.963	20.7[c]	20.7
Specific conductance, µS/cm	0.978 ns	NA	0.960	583[d]	583
Field pH	0.988 ns	NA	0.963	[6.68, 7.84][d]	[6.68, 7.84]
Total organic carbon, µg/L	NC	NC	NC	842[c] 1,090[e]	1,090
Chloride, µg/L	0.954 s	0.962 s	0.963	7,820[c]	7,820
Nitrate (as NO_3^-), µg/L	0.833 s	0.844 s	0.963	29,000[c]	29,000
Nitrite (as NO_2^-), µg/L	NC	NC	NC	161[f]	161
Ammonium (as NH_3^-) , µg/L	NC	NC	NC	90[c] 65.2[e]	90
Sulfate, µg/L	0.983 ns	NA	0.963	47,200[d]	47,200
Iron, dissolved, µg/L	0.960 s	0.802 s	0.962	160[c] 65.3[e]	160
Zinc, dissolved, µg/L	NC	NC	NC	42.3[c] 5.9[e]	42.3
Manganese, dissolved, µg/L	NC	NC	NC	10[c] 3.6[e]	10
Coliform bacteria, colonies/100 ml	NC	NC	NC	3.7[f]	3.7
Chemical oxygen demand, µg/L	NC	NC	NC	10,000[f]	10,000

(a) Constituents are specified in WAC 173-304-490(2)(d). Data collected from March 1993 to May 2000 from upgradient well 699-24-35 and 699-26-35A.
(b) Obtained from Table A-9 (Shapiro 1980) for α = 5%.
(c) Maximum value reported.
(d) Based on log-normal distribution.
(e) Based on limit of quantitation using method detection limit (see Table B.23).
(f) Based on laboratory practical quantitation limit.
NA = Not applicable.
NC = Not calculated; insufficient measured values.
ns = Not significant at 0.05 level of significance.
s = Significant at 0.05 level of significance.

Table A.46. Monitoring Wells, Constituents, and Enforcement Limits for the State-Approved Land Disposal Site (adapted from PNNL-13121)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurement	Well Standard
299-W6-6$^{(91)}$	Bottom of unconfined	Annual	Annual	RCRA
299-W6-7$^{(91)}$	Top of unconfined	Annual	Annual	RCRA
299-W6-8$^{(91)}$	Top of unconfined	Annual	Annual	RCRA
299-W6-11$^{(92)}$	Top of unconfined	Annual	Annual	RCRA
299-W6-12$^{(92)}$	Top of unconfined	Annual	Annual	RCRA
299-W7-1$^{(87)}$	Top of unconfined	Annual	Annual	RCRA
299-W7-3$^{(87)}$	Bottom of unconfined	Semiannual	Semiannual	RCRA
299-W7-5$^{(87)}$	Top of unconfined	Semiannual	Semiannual	RCRA
299-W7-6$^{(87)}$	Top of unconfined	Semiannual	Semiannual	RCRA
299-W7-7$^{(89)}$	Top of unconfined	Semiannual	Semiannual	RCRA
299-W7-8$^{(89)}$	Top of unconfined	Annual	Annual	RCRA
299-W7-9$^{(90)}$	Top of unconfined	Annual	Annual	RCRA
299-W7-11$^{(91)}$	Top of unconfined	Semiannual	Semiannual	RCRA
299-W7-12$^{(91)}$	Top of unconfined	Annual	Annual	RCRA
299-W8-1$^{(87)}$	Top of unconfined	Annual	Semiannual	RCRA
699-48-71$^{(56)}$	Unconfined	Annual	Annual	PRE
699-48-77A$^{(92)(a)}$	Ringold unit E; upper	Quarterly	Monthly	RCRA
699-48-77C$^{(94)(a)}$	Ringold unit E; mid to lower	Quarterly	Monthly	RCRA
699-48-77D$^{(94)(a)}$	Ringold unit E; upper	Quarterly	Monthly	RCRA
699-49-79$^{(48)}$	Top of unconfined	Annual	Annual	PRE
699-51-75$^{(57)}$	Top of unconfined	Semiannual	Semiannual	PRE
699-51-75P$^{(57)}$	Lower unconfined	Annual	Annual	PRE

Constituent	Enforcement Limit (µg/L)	Constituent	Enforcement Limit (µg/L)
Acetone	160	Lead, total	50
Benzene	5	Mercury, total	2
Cadmium, total	10	pH	6.5 - 8.5 pH units
Chloroform	6.2	Strontium-90	Monitor only
Copper, total	70	Sulfate	250,000
Gross alpha	Monitor only	Tetrahydrofuran	100
Gross beta	Monitor only	Total dissolved solids	500,000
		Tritium	Monitor only

(a) Monitored for full constituent list. Other wells analyzed for tritium only.
Superscript = Year of installation.
PRE = Well not constructed to RCRA standards.
RCRA = Well constructed to RCRA standards.

Table A.47. Monitoring Results Exceeding Maximum Contaminant Levels by Geographic Region, Fiscal Year 2002

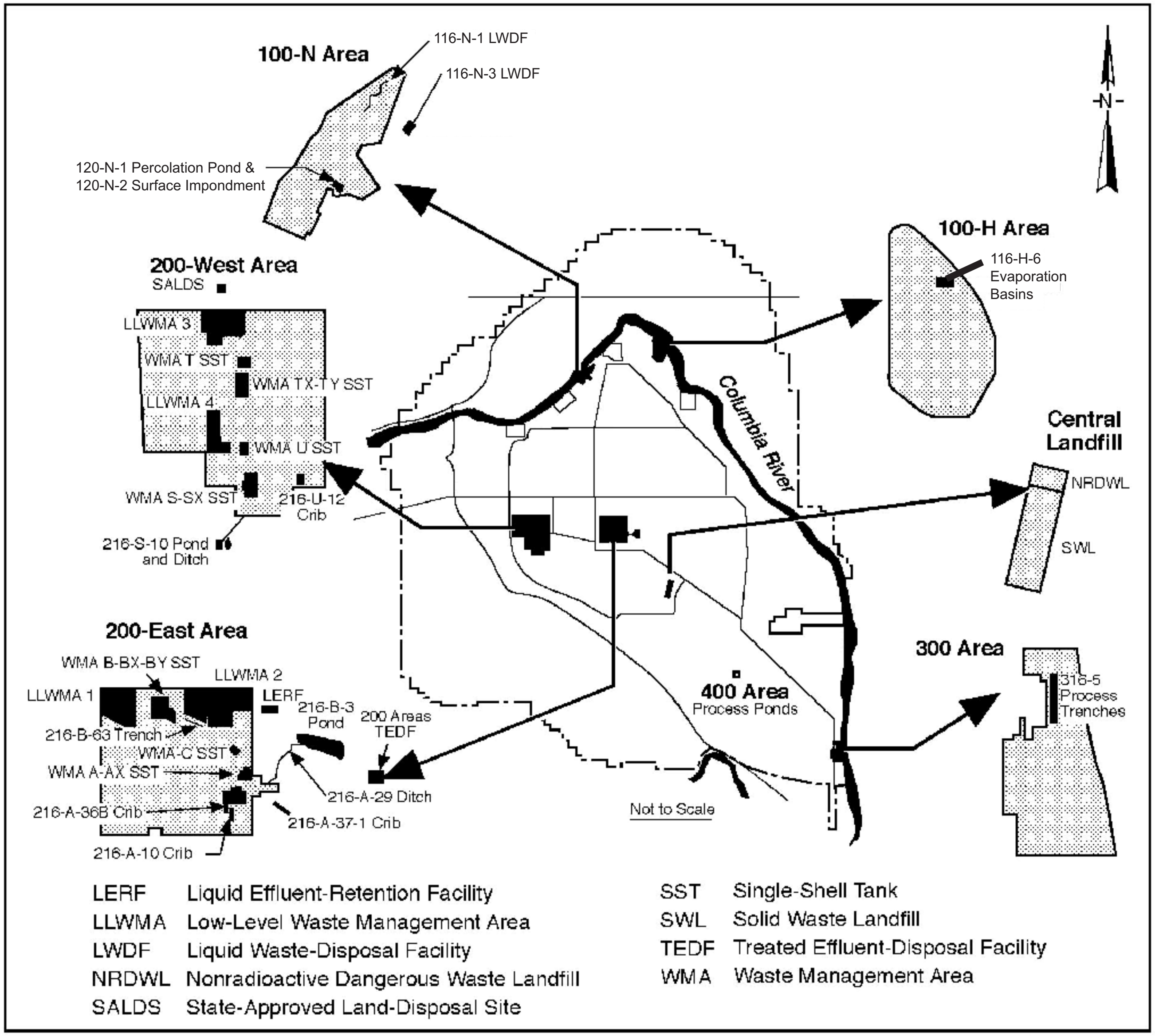
Constituent, units	Primary Maximum Contaminant Level (MCL)	Area with Wells Exceeding MCL	Number of Wells Exceeding MCL	Maximum Concentration in Groundwater
Antimony, µg/L (*filtered and unfiltered samples*)	6	100-D	7	67
		100-H	1	437
		200 East	3	7.3
Arsenic, µg/L (*filtered and unfiltered samples*)	10	100-D	1	80
Cadmium, µg/L (*filtered and unfiltered samples)*	5.0	100-D	2	6.1
Carbon tetrachloride, µg/L	5.0	200 West	84	6,900
Chloroform, µg/L	100	200 West	1	680
Chromium, µg/L (*includes total and hexavalent chromium; filtered and unfiltered samples*)	100	100-D	48	5,660
		100-F	1	98
		100-H	3	149
		100-K	10	1,310
		100-N	1	168
		200 East	2	1,000
		200 West	6	381
Cyanide, µg/L	200	200 East	2	321
Fluoride, mg/L	4.0	200 West	2	4.4
		Richland North	2	4.1(a)
Methylene chloride, µg/L	5.0	200 West	7	250
Nickel, µg/L (*filtered and unfiltered samples)*	100	100-D	1	257
		100-N	1	108
		200 East	1	447
		200 West	3	229
Nitrate (as NO_3^-), mg/L	45	100-D	18	90
		100-F	9	106
		100-H	4	87
		100-K	7	94
		100-N	5	76
		200 East	26	611
		200 West	73	1,740
		300	1	90
		400	1	81
		Richland North	25	251(a)
Nitrite (as NO_2^-), mg/L	3.3	100-D	5	9.9
		200 West	3	7.6
Trichloroethene, µg/L	5.0	100-F	3	18
		100-K	2	11
		200 West	23	16

(a) From offsite contaminant source.

Table A.48. Monitoring Results Exceeding Drinking Water Standards by Geographic Region, Fiscal Year 2002

Constituent, units	Drinking Water Standard (DWS)	DOE Derived Concentration Guide	Area with Wells Exceeding DWS	Number of Wells Exceeding DWS	Maximum Concentration in Groundwater
Carbon-14, pCi/L	2,000	70,000	100-K	5	12,900
Gross alpha, pCi/L	15	NA	200 East	7	241
			200 West	2	570
			300	1	45
Gross beta, pCi/L	50	NA	100-B/C	3	81
			100-D	2	401
			100-F	1	63
			100-H	3	142
			100-K	5	4,500
			100-N	7	9,310
			200 East	23	3,740
			200 West	31	33,900
Iodine-129, pCi/L	1.0	500	200 East(a)	9	11.2
			200 West	7	32
Strontium-90, pCi/L	8.0	1,000	100-B/C	5	39
			100-D	1	13
			100-F	3	33
			100-H	4	38
			100-K	6	2,100
			100-N	15	18,500
			200 East	1	21
			200 West	1	76
Technetium-99, pCi/L	900	100,000	200 East(a)	16	10,500
			200 West	14	99,700
Tritium, pCi/L	20,000	2,000,000	100-B/C	2	30,600
			100-K	7	588,000
			100-N	8	39,300
			200 East(a)	21	4,170,000
			200 West	23	1,690,000
			618-11	5	4,230,000
Uranium, µg/L	30	790	200 East	13	391
			200 West	15	3,110
			300	9	141

(a) Includes wells in the 600 Area affected by contaminants migrating from the 200 East Area.
NA = Not applicable.



wdw03010/ G00080088.3

Figure A.1. Regulated Units on the Hanford Site Requiring Groundwater Monitoring. The 216-A-10, 216-A-36B, and 216-A-37-1 cribs are monitored as a single waste management area.

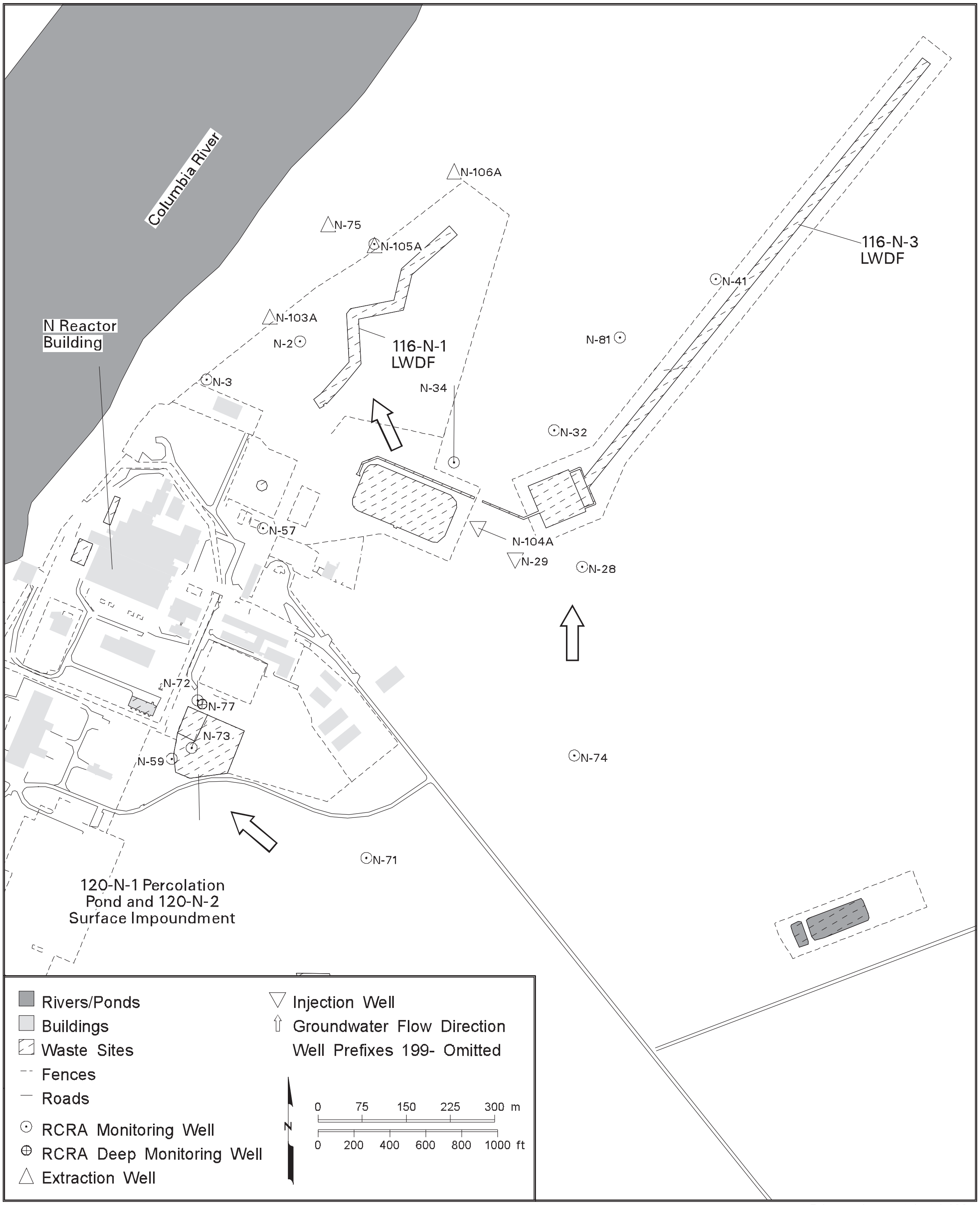


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Figure A.2. Groundwater Monitoring Wells for 100-N Area RCRA Sites

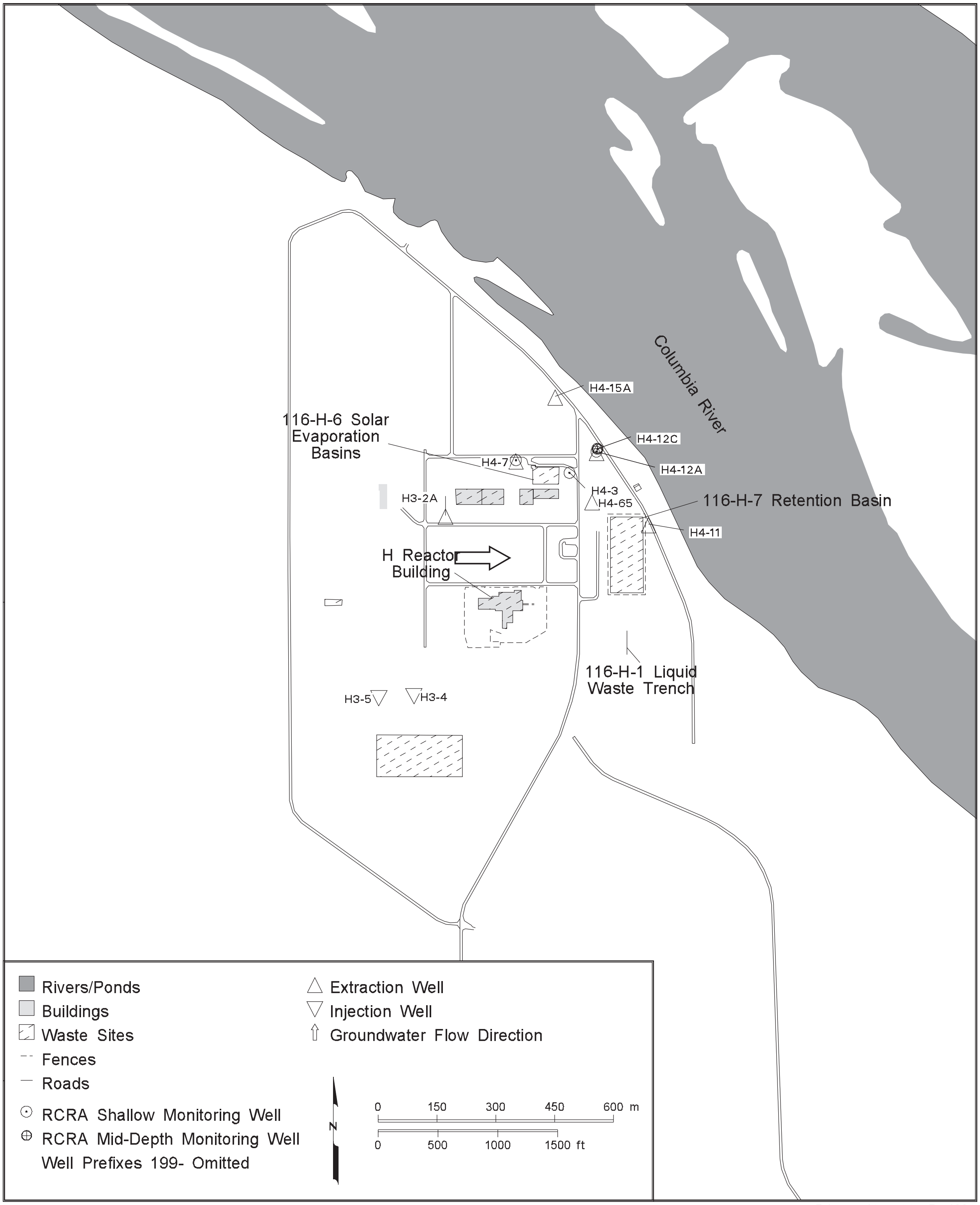

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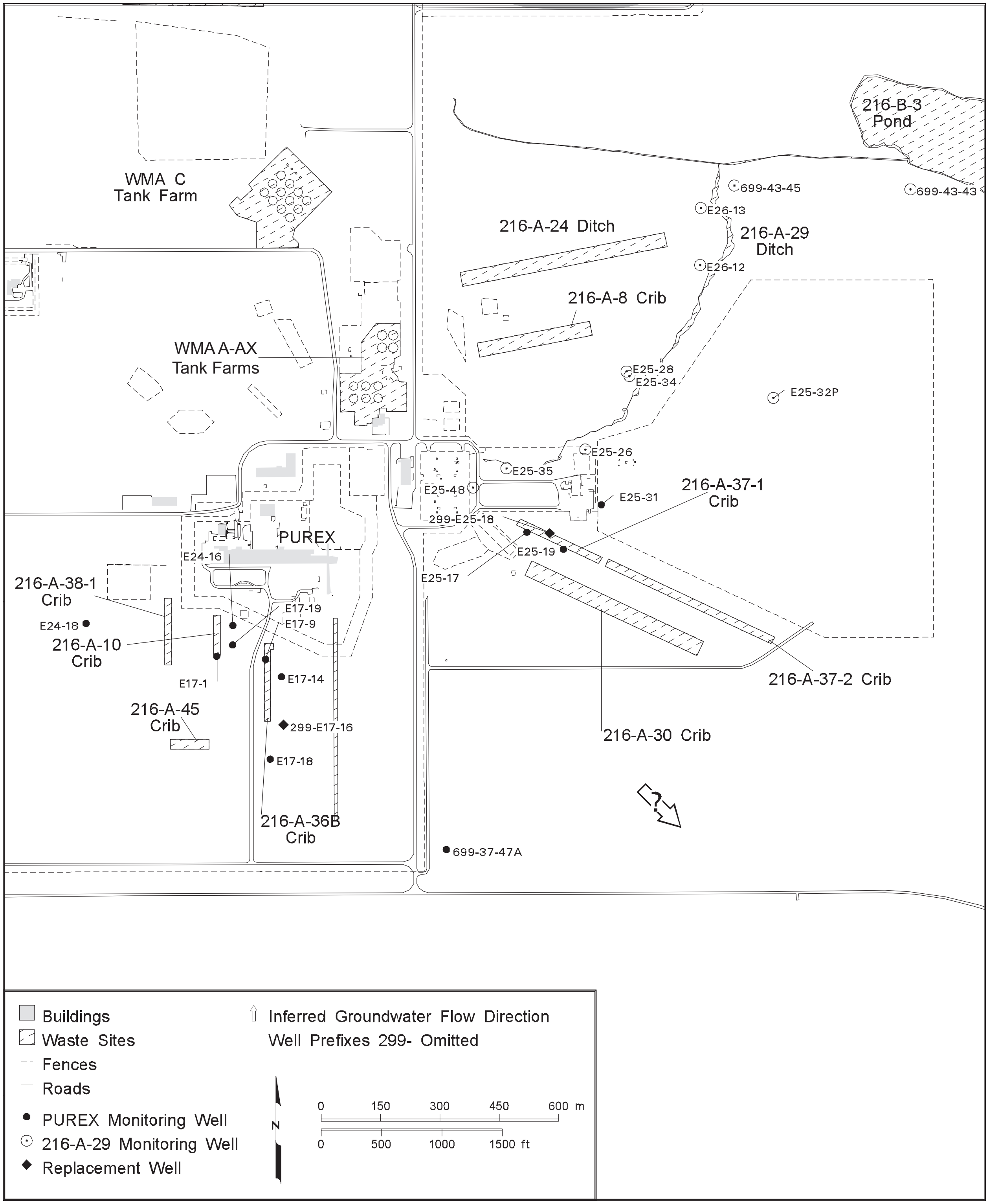
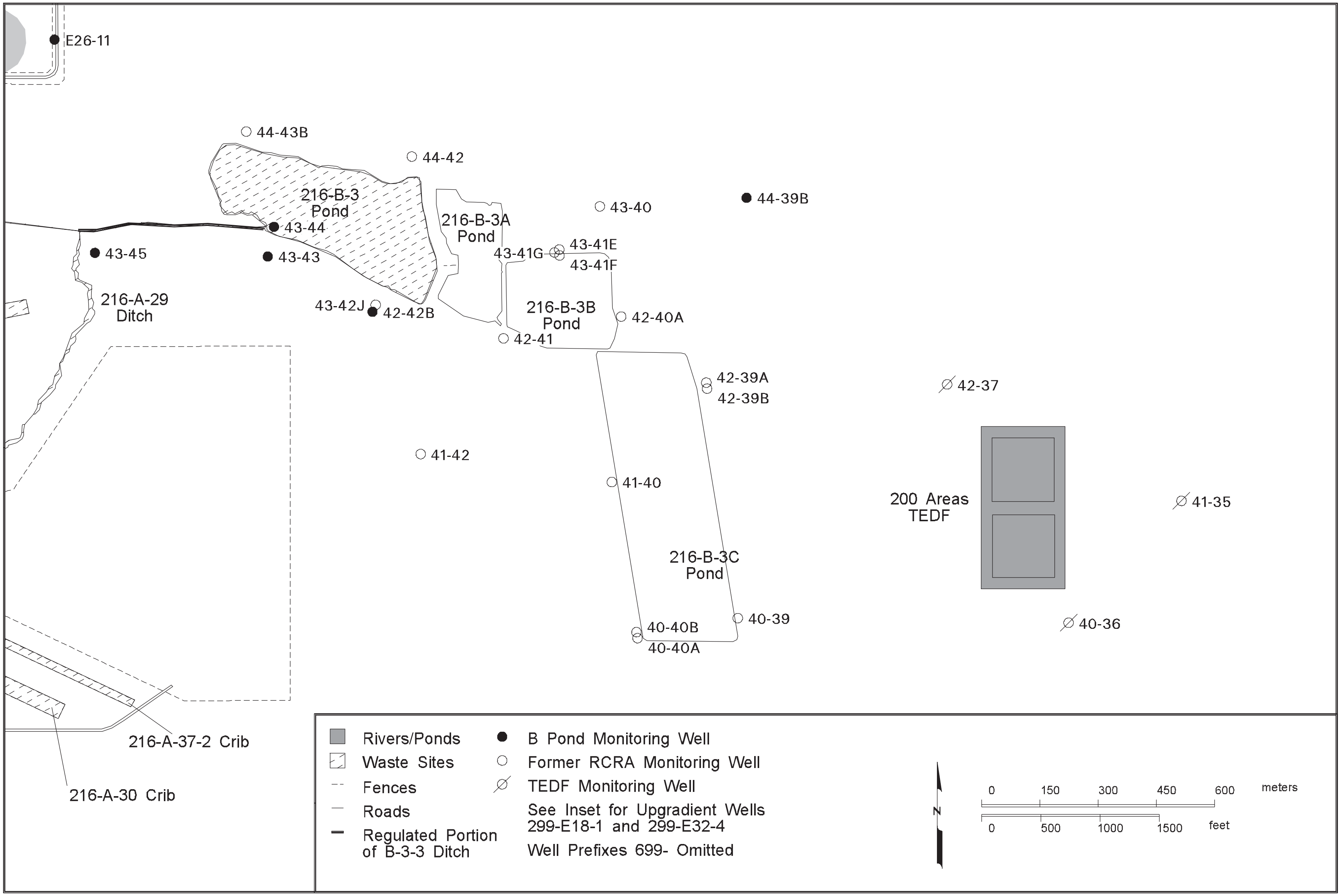
Figure A.3. Groundwater Monitoring Wells at the 116-H-6 (183-H) Evaporation Basins



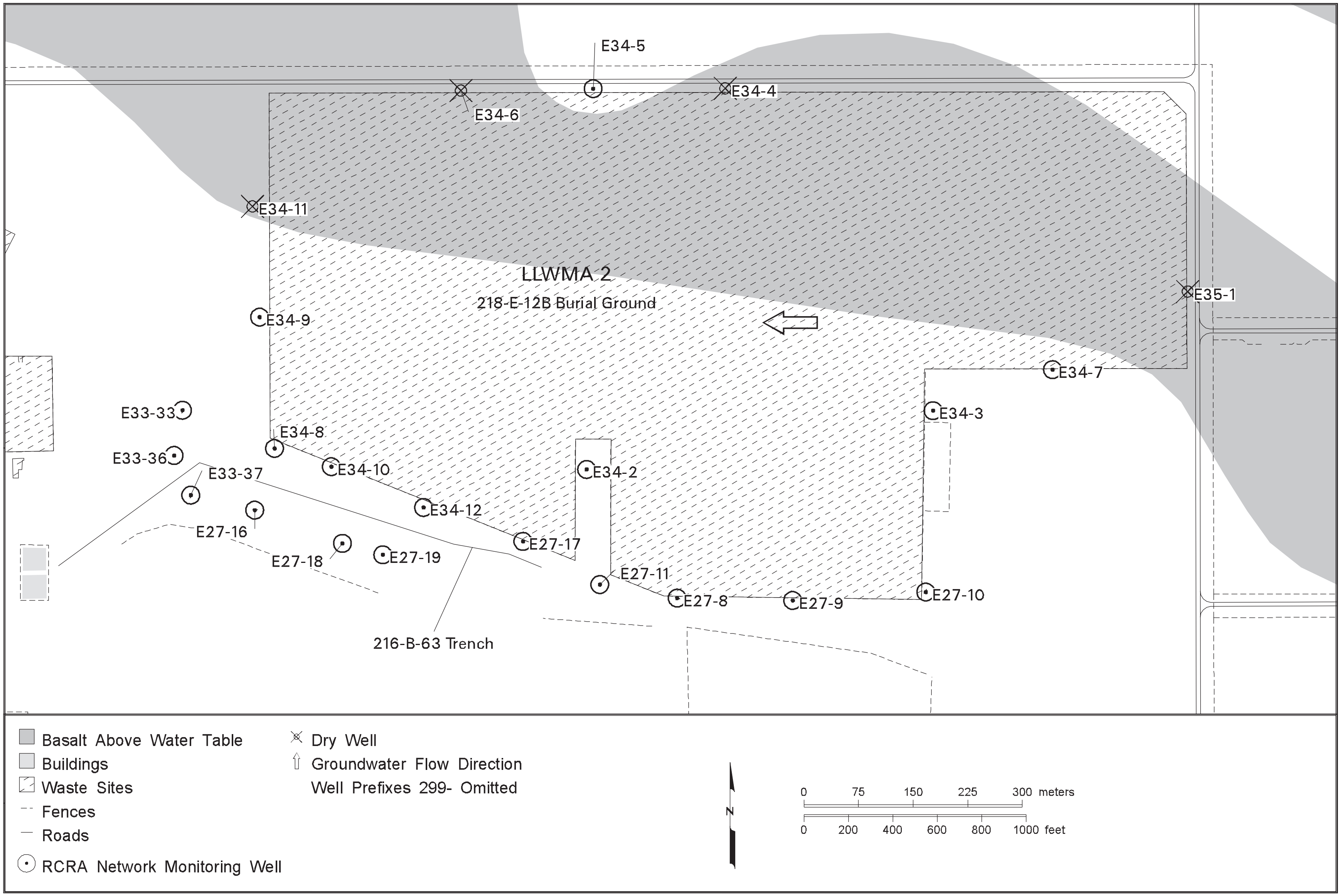
jsc_gwrep02_010 February 19, 2003 12:04 PM

Figure A.4. Groundwater Monitoring Wells at the 216-A-29 Ditch and PUREX Cribs



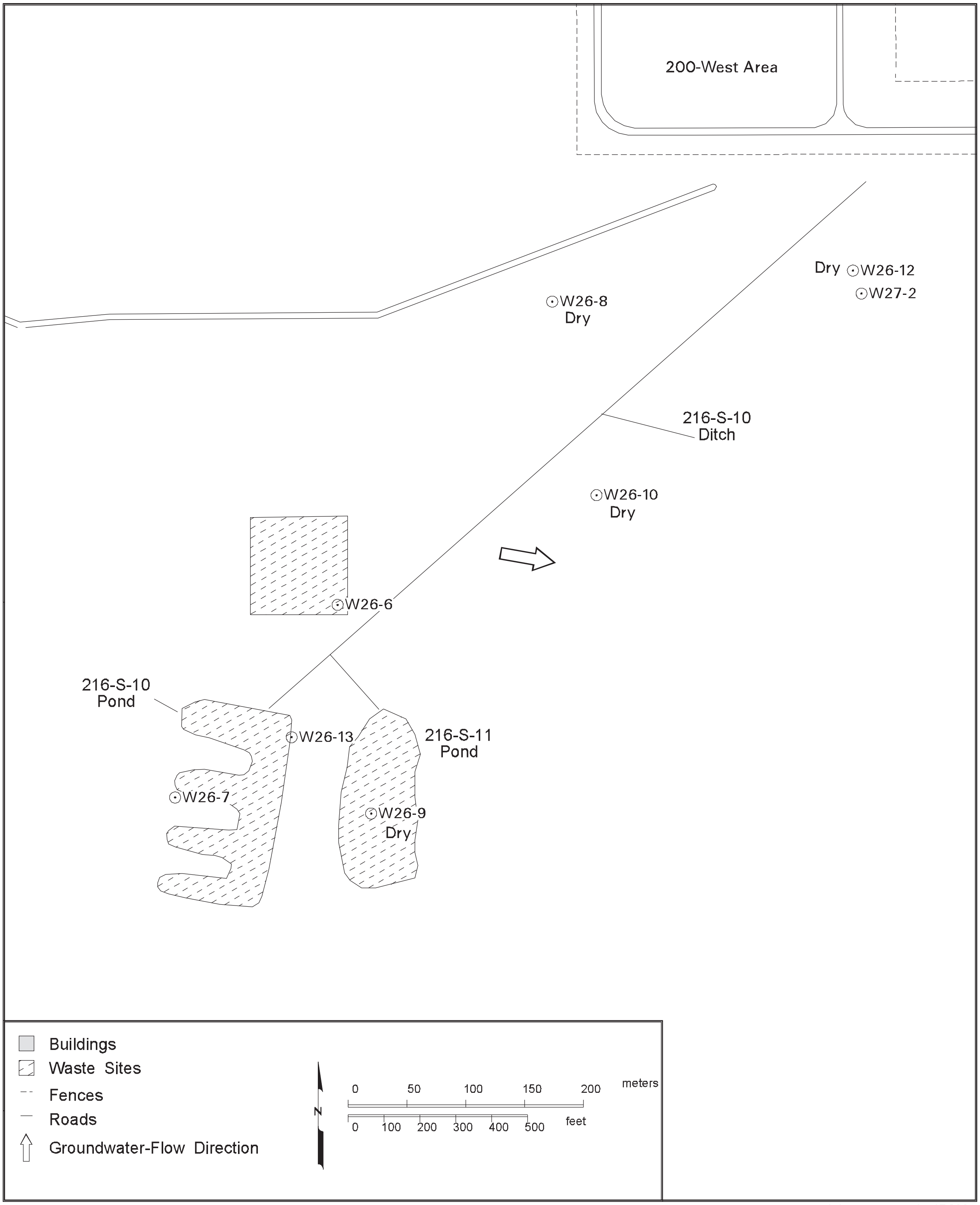
jsc_gwrep02_018 January 08, 2003 4:29 PM

Figure A.5. Groundwater Monitoring Wells at the 216-B-3 Pond and 200 Areas Treated Effluent Disposal Facility



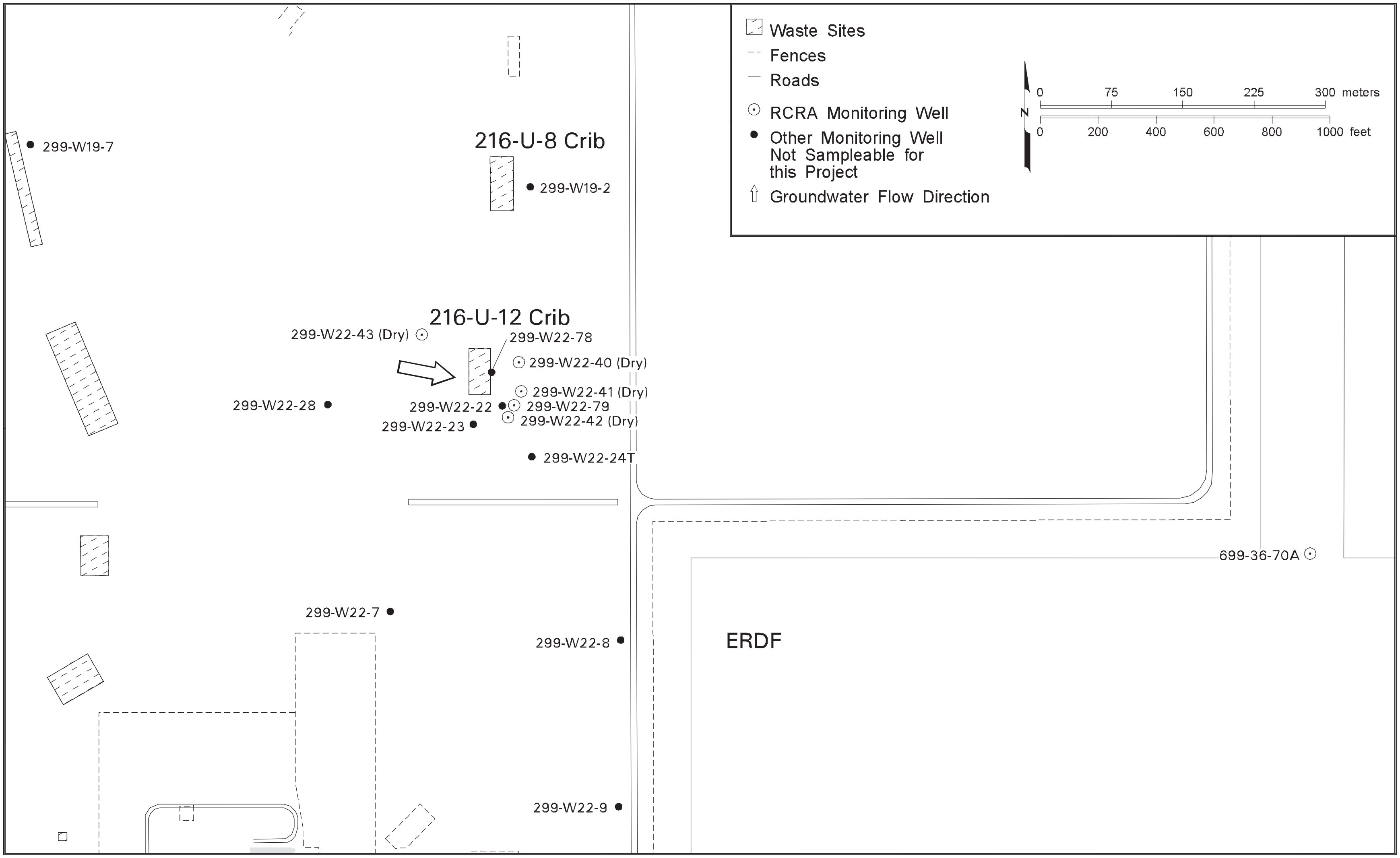
jsc_gwrep02_004 February 18, 2003 11:46 AM

Figure A.6. Groundwater Monitoring Wells at the 216-B-63 Trench and Low-Level Waste Management Area 2



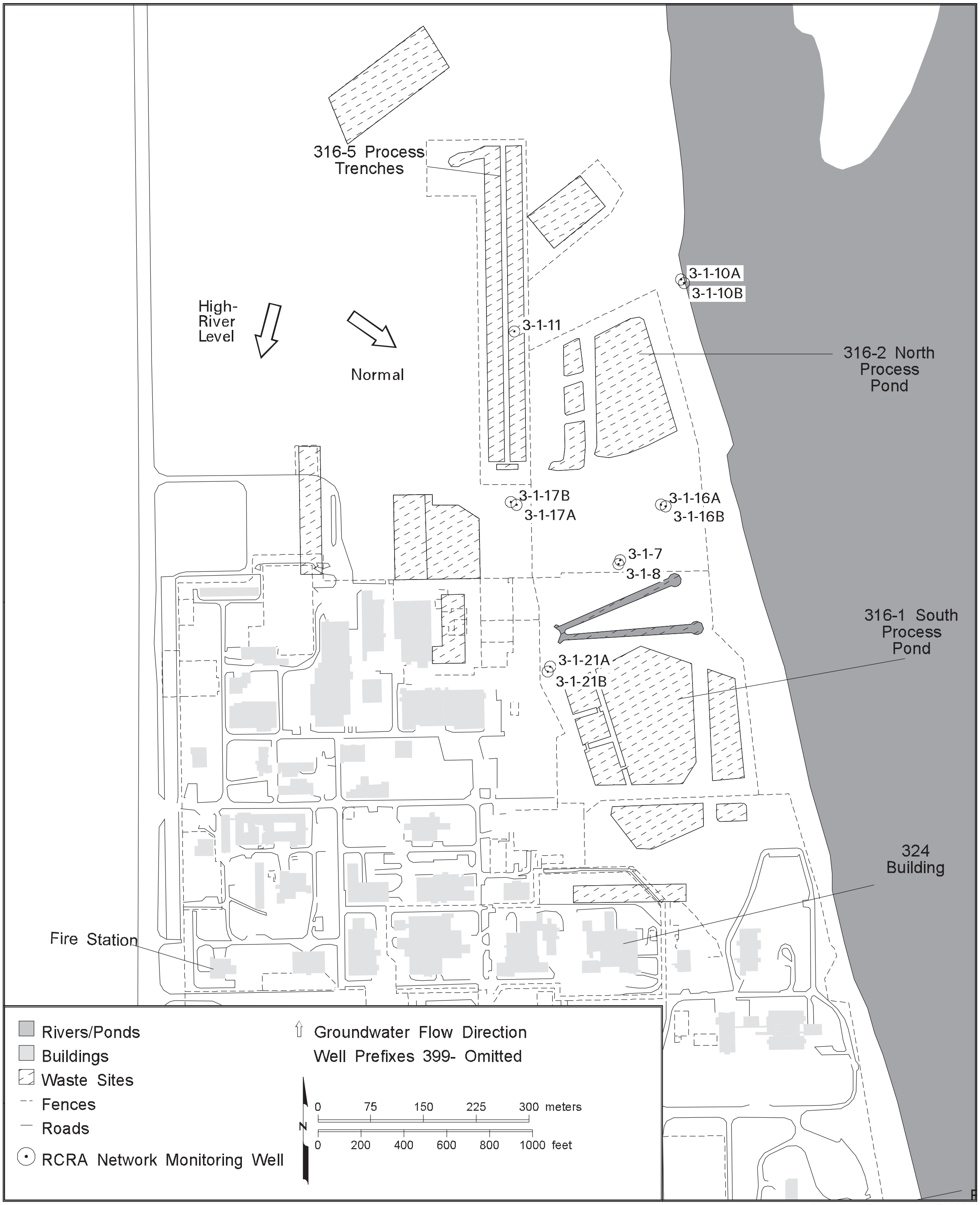
jsc_gwrep02_001 July 22, 2002 12:47 PM

Figure A.7. Groundwater Monitoring Wells at the 216-S-10 Pond and Ditch



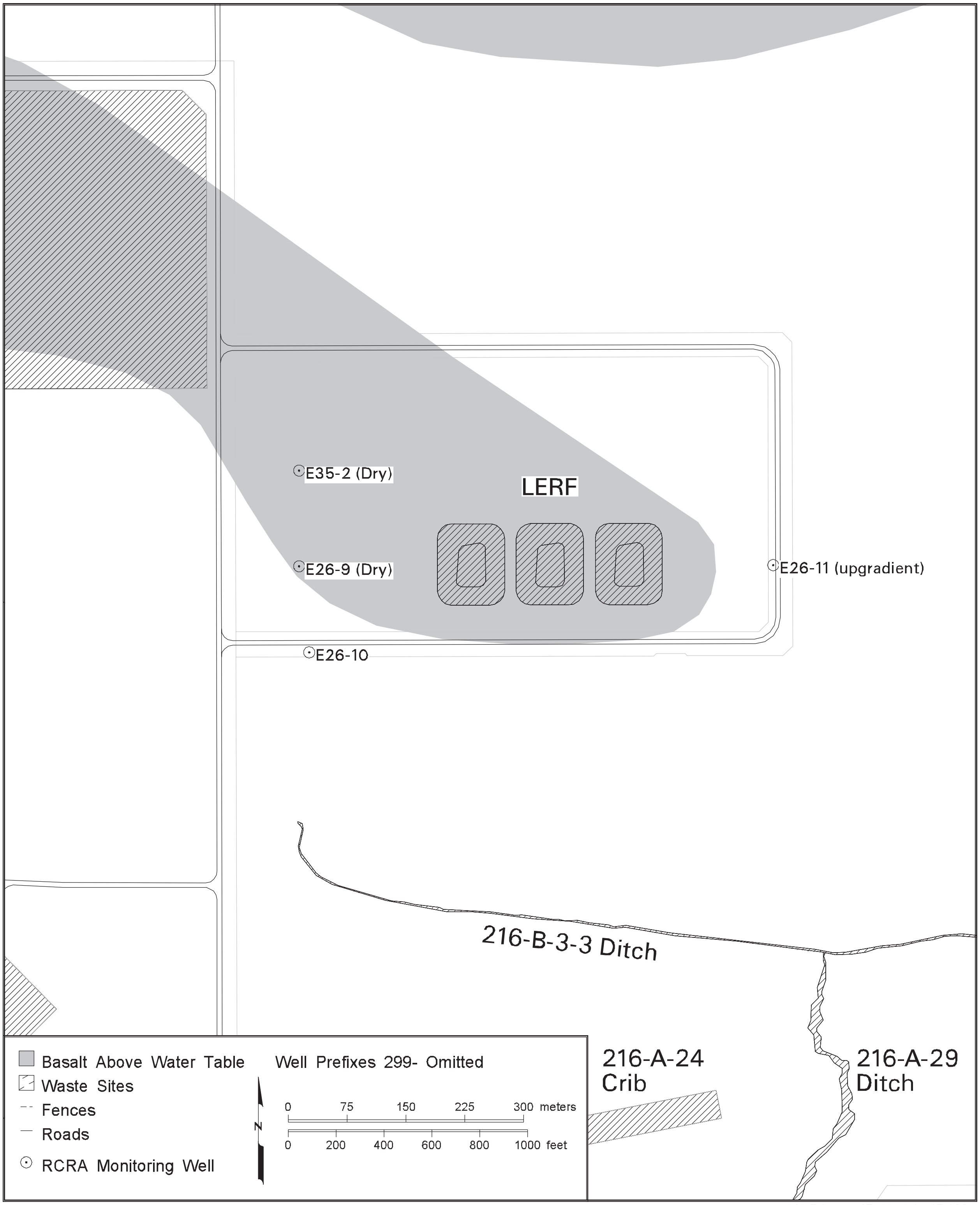
jsc_gwrep02_020 February 17, 2003 12:58 PM

Figure A.8. Groundwater Monitoring Wells at the 216-U-12 Crib



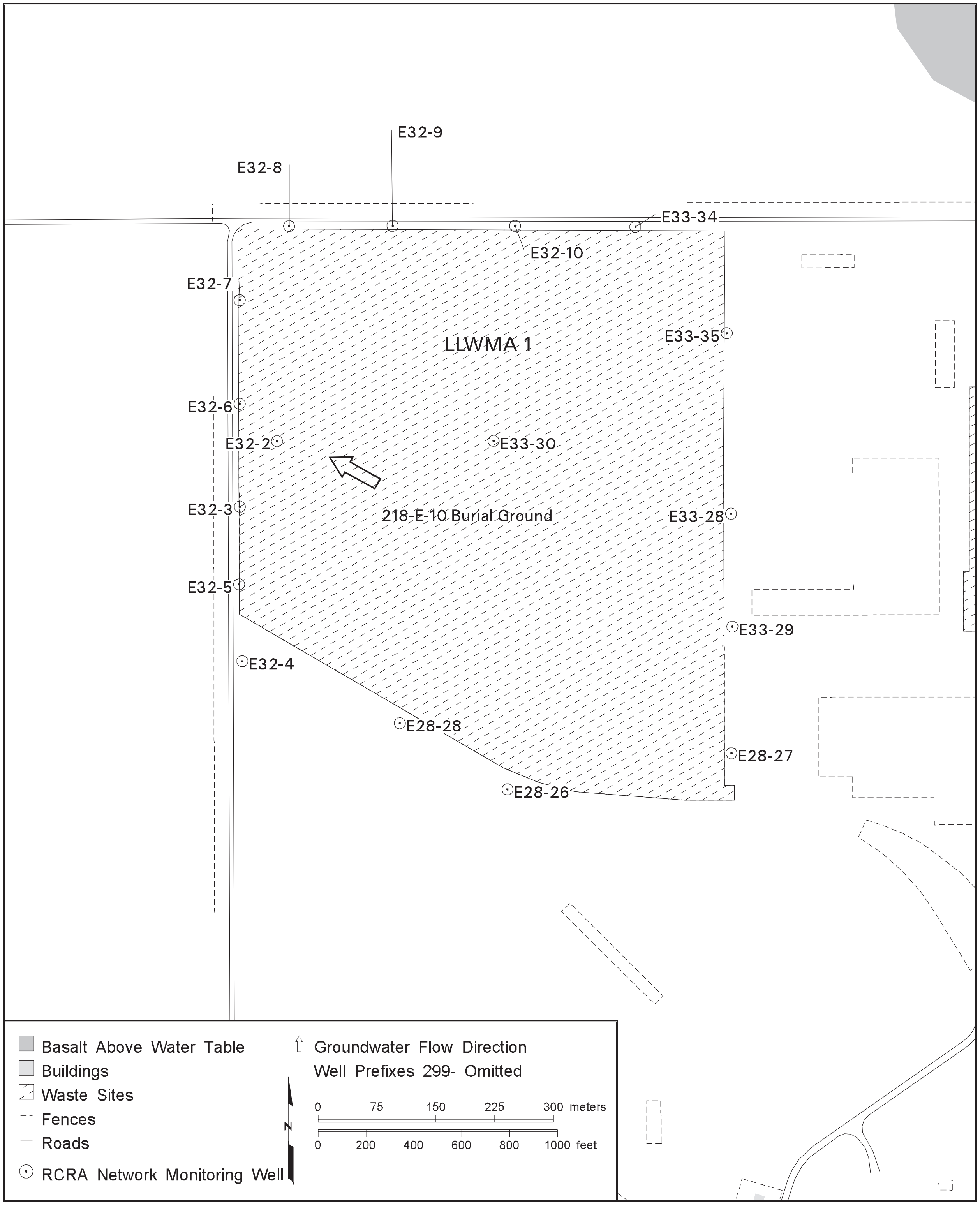
jsc_gwrep02_002 February 17, 2003 10:27 AM

Figure A.9. Groundwater Monitoring Wells at the 316-5 Process Trenches



jsc_gwrep02_012 February 17, 2003 10:47 AM

Figure A.10. Groundwater Monitoring Wells at the Liquid Effluent Retention Facility



jsc_gwrep02_006 February 17, 2003 1:29 PM

Figure A.11. Groundwater Monitoring Wells at Low-Level Waste Management Area 1

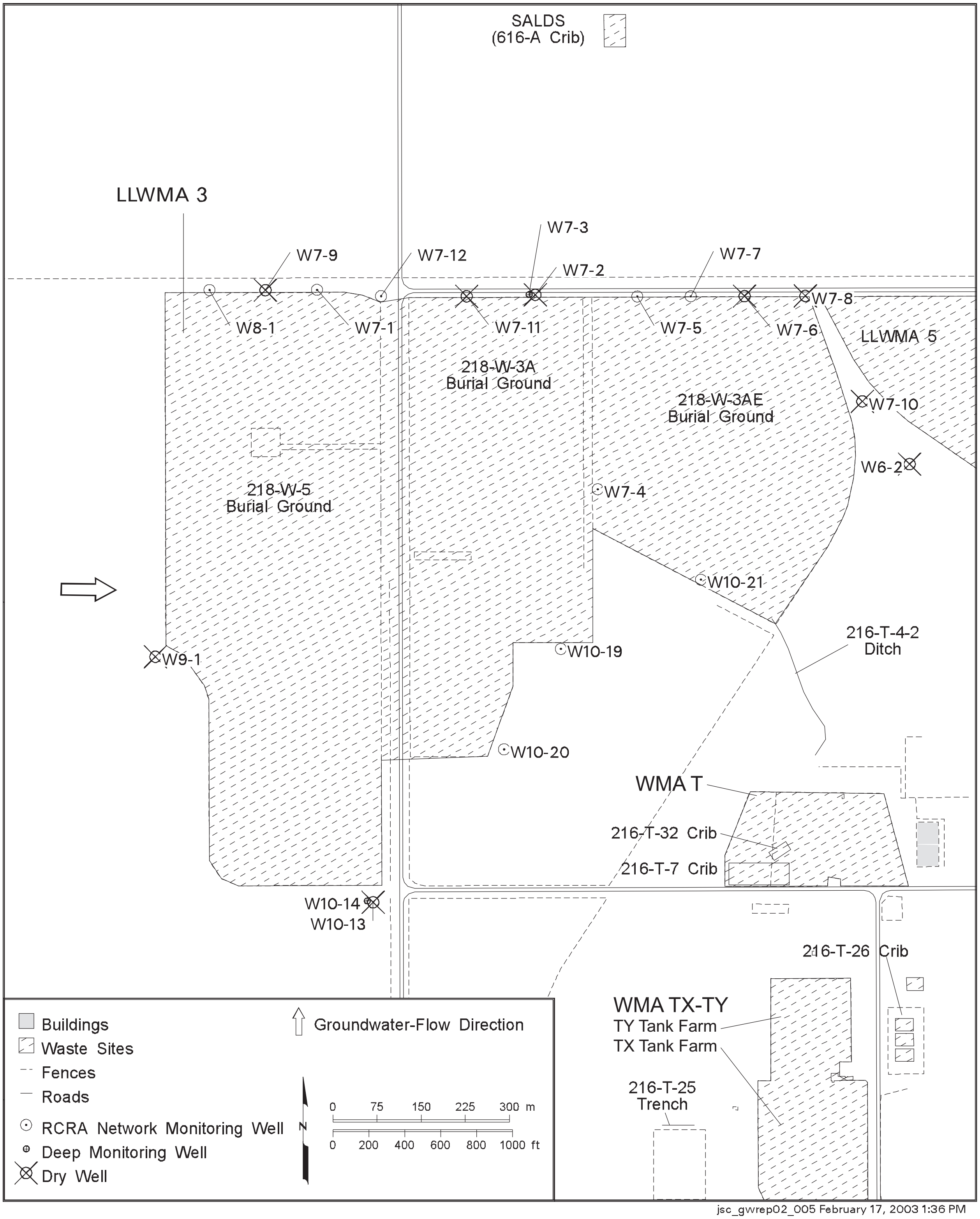
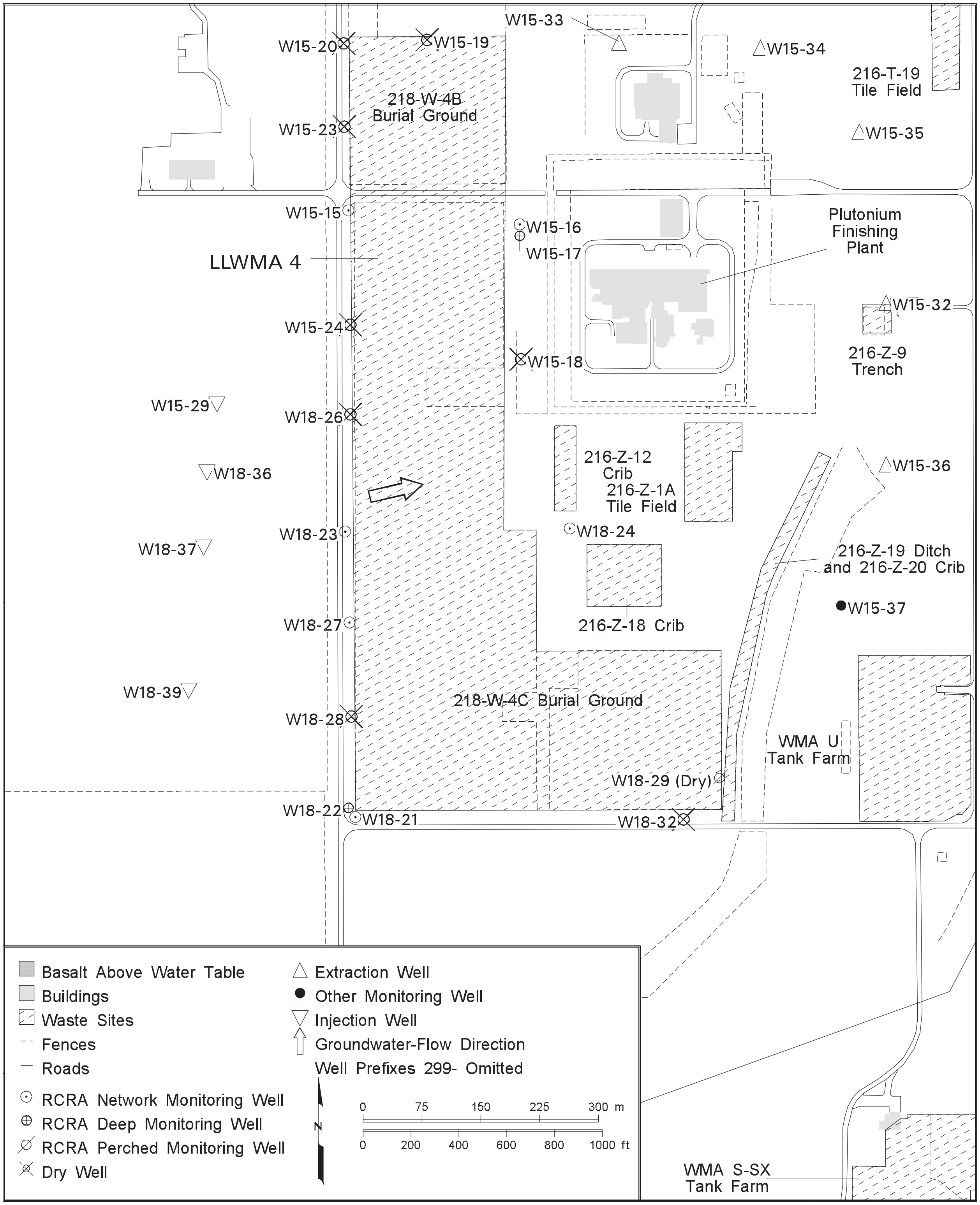
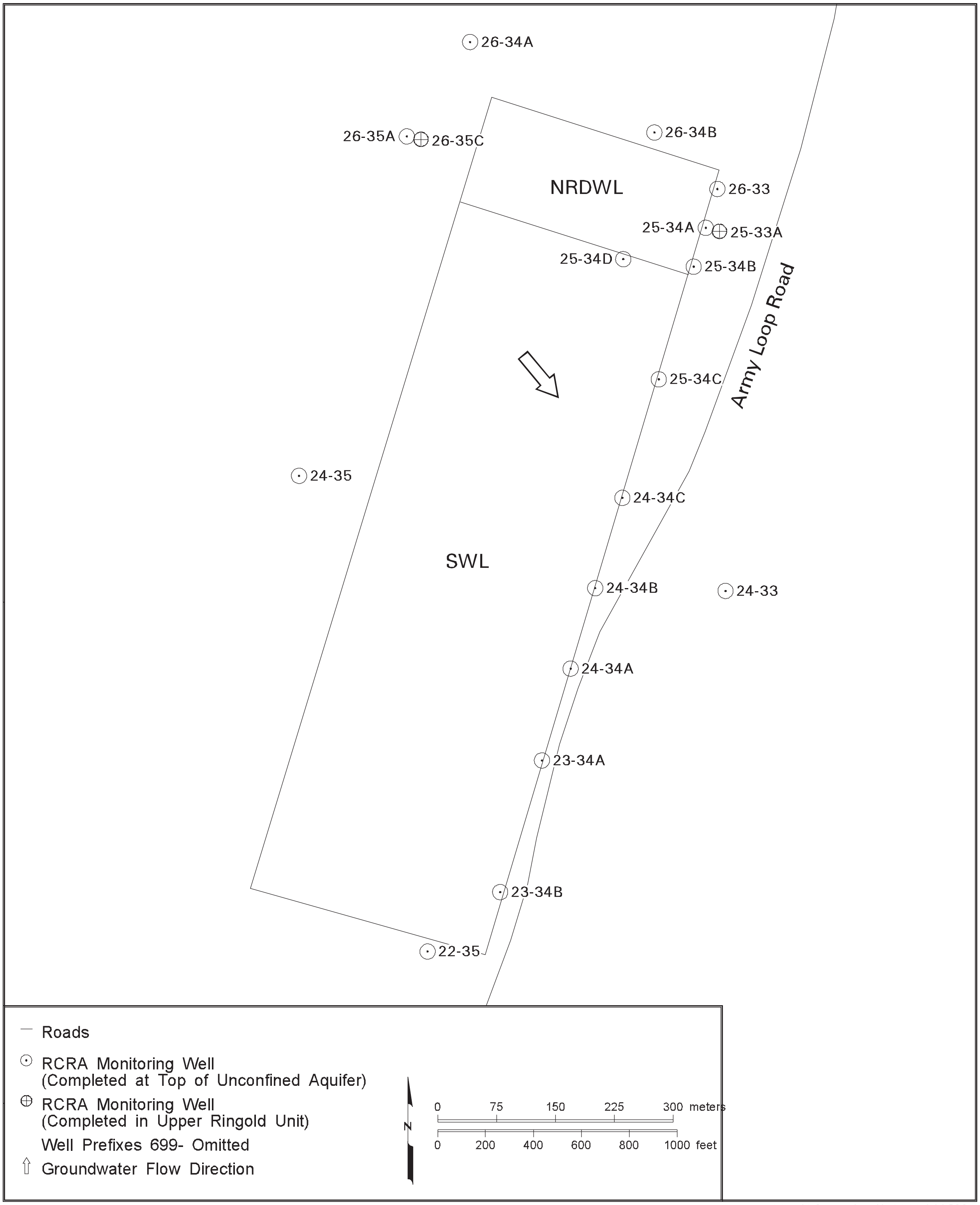


Figure A.12. Groundwater Monitoring Wells at Low-Level Waste Management Area 3



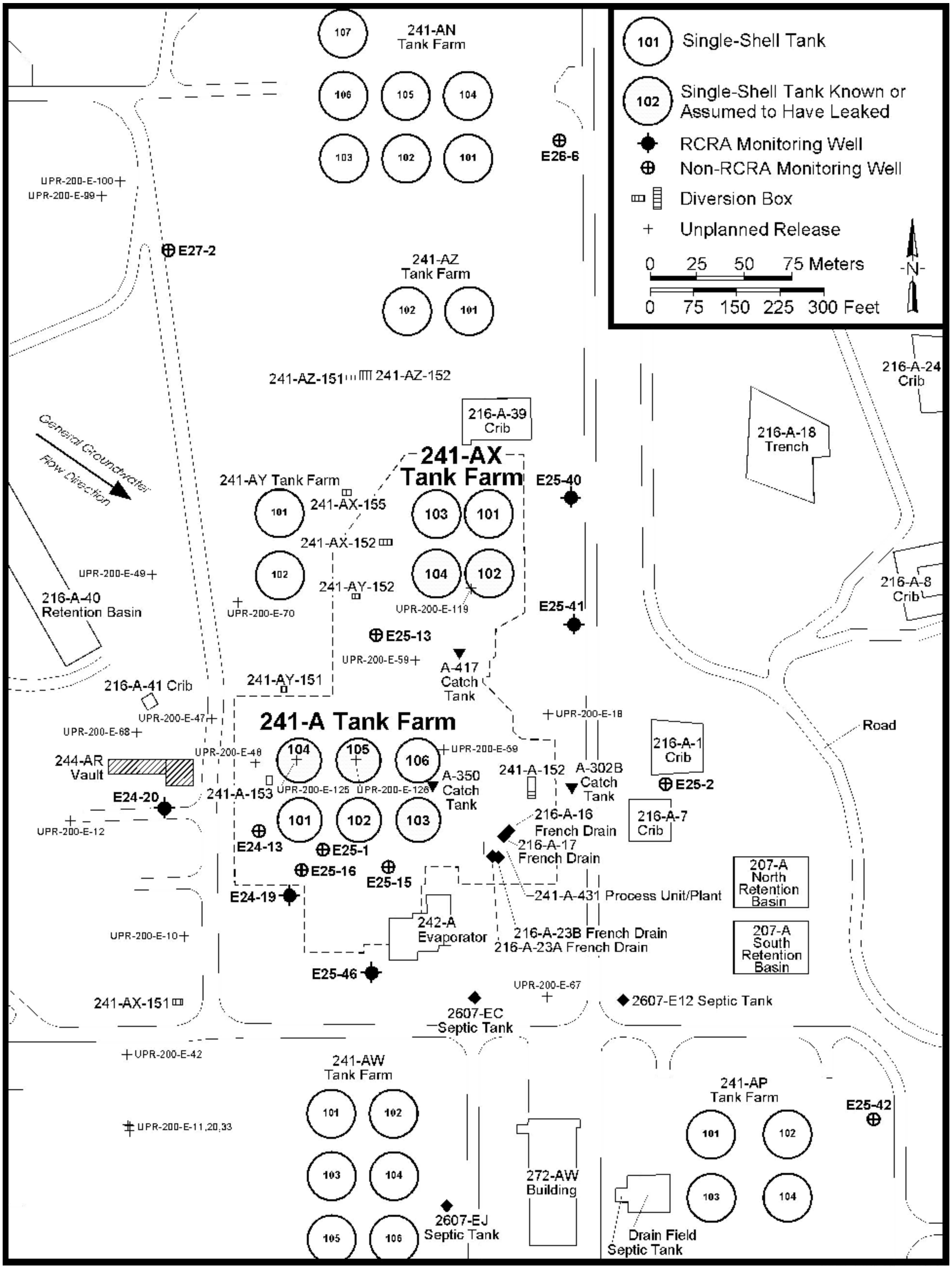
jsc_gwrep02_007 February 17, 2003 1:46 PM

Figure A.13. Groundwater Monitoring Wells at Low-Level Waste Management Area 4



jsc_gwrep02_013 December 11, 2002 1:14 PM

Figure A.14. Groundwater Monitoring Wells at the Nonradioactive Dangerous Waste Landfill and Solid Waste Landfill



2001/DCL/A-AX/011

Figure A.15. Groundwater Monitoring Wells at Waste Management Area A-AX

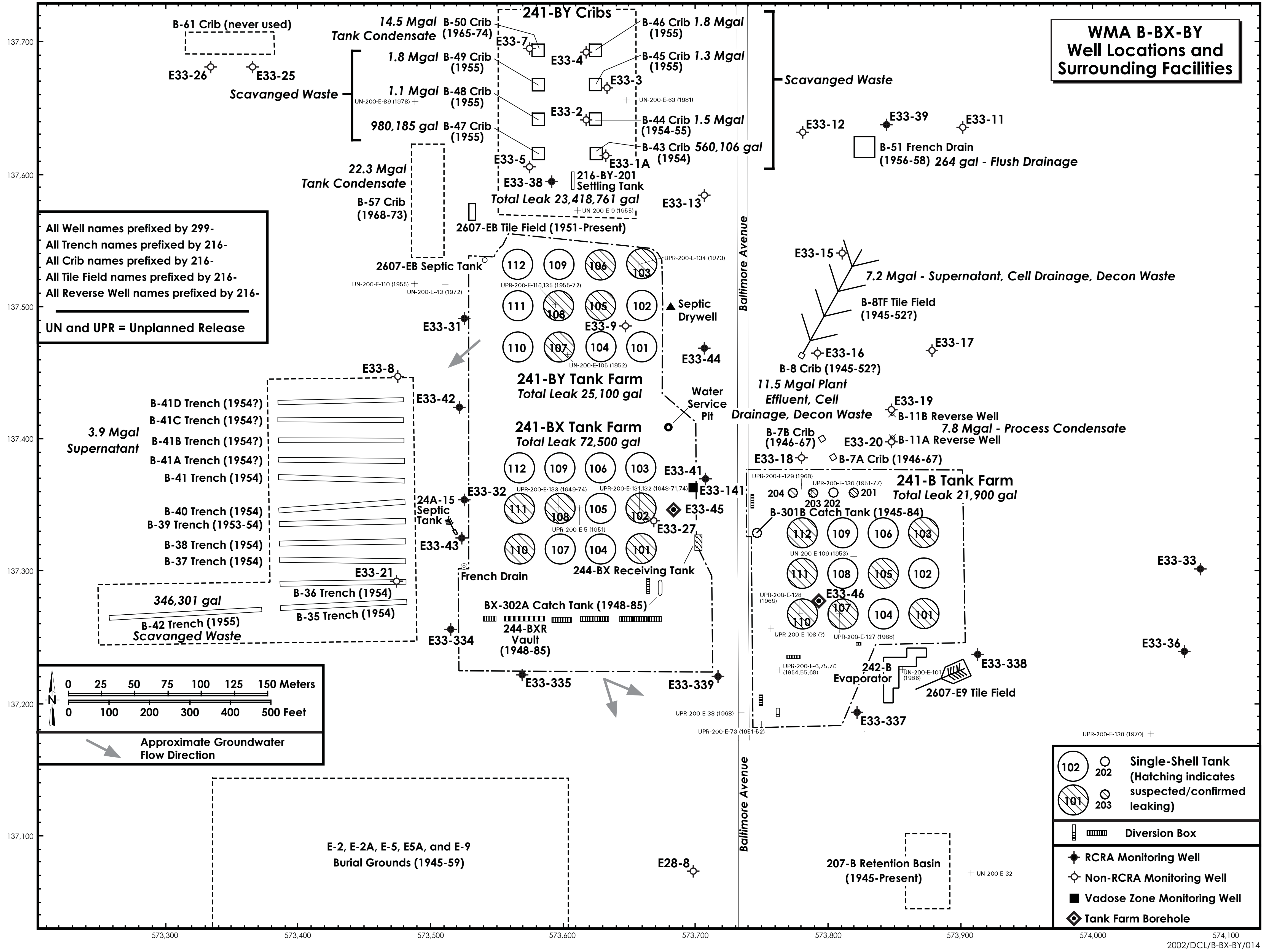
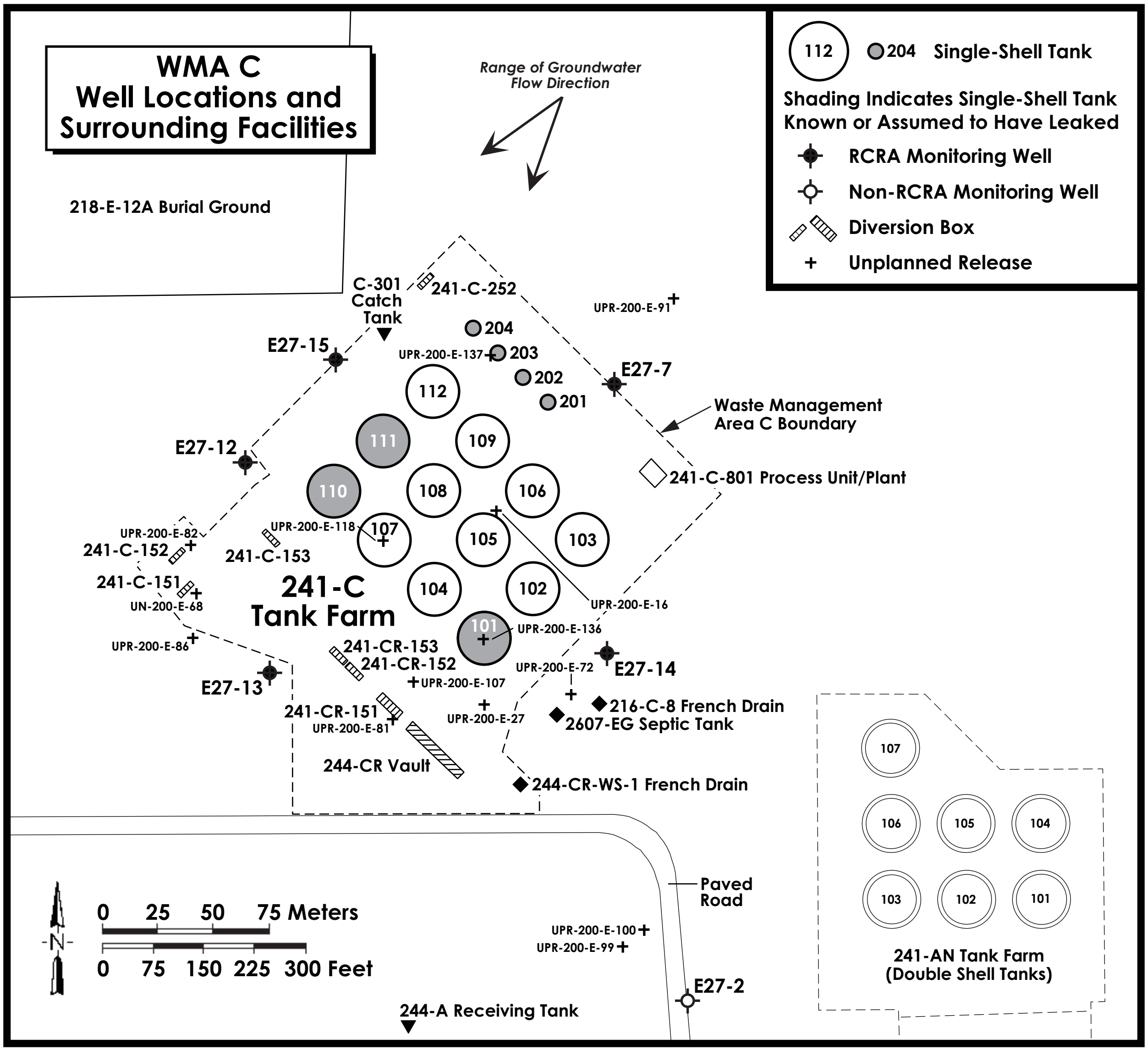
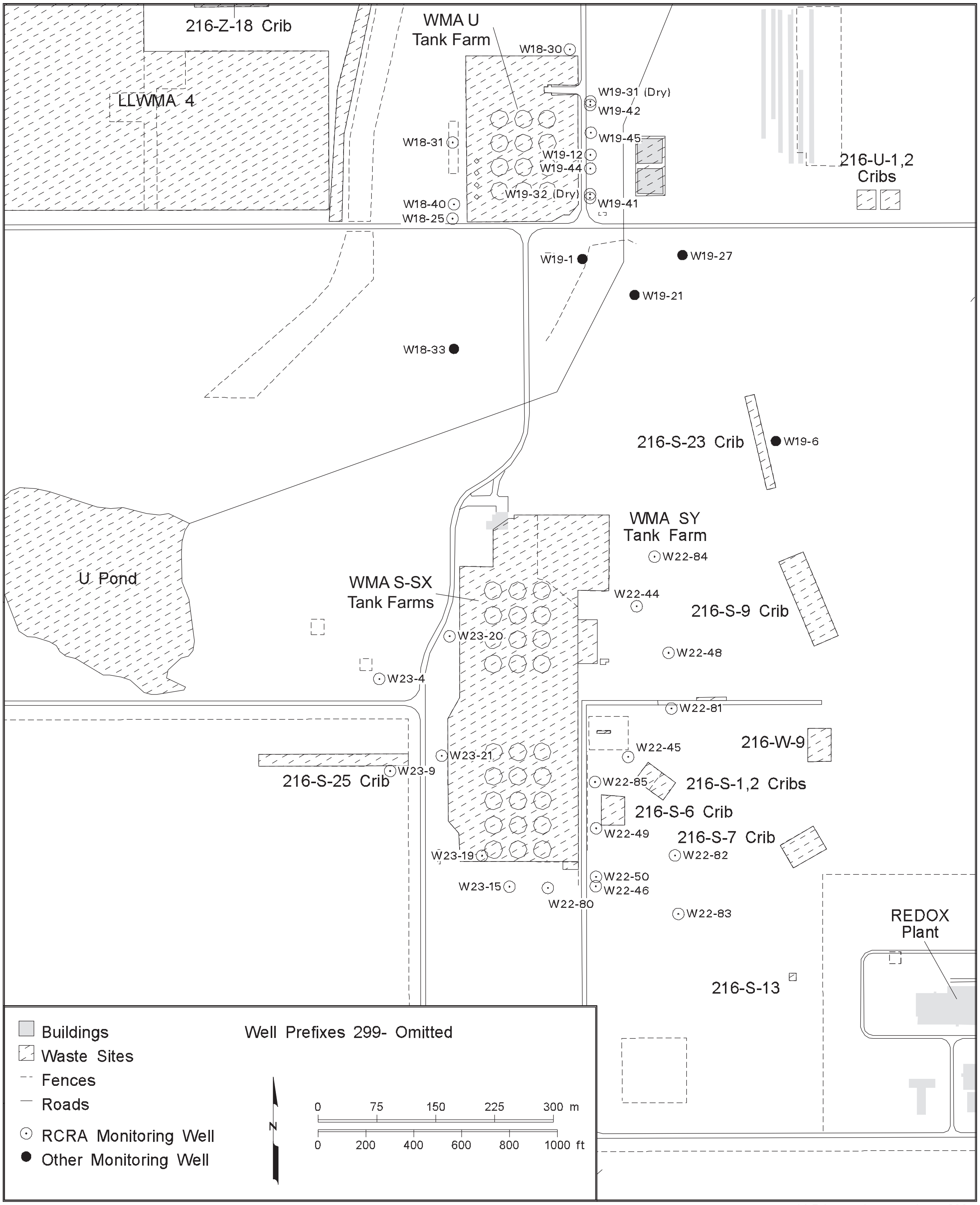


Figure A.16. Groundwater Monitoring Wells at Waste Management Area B-BX-BY



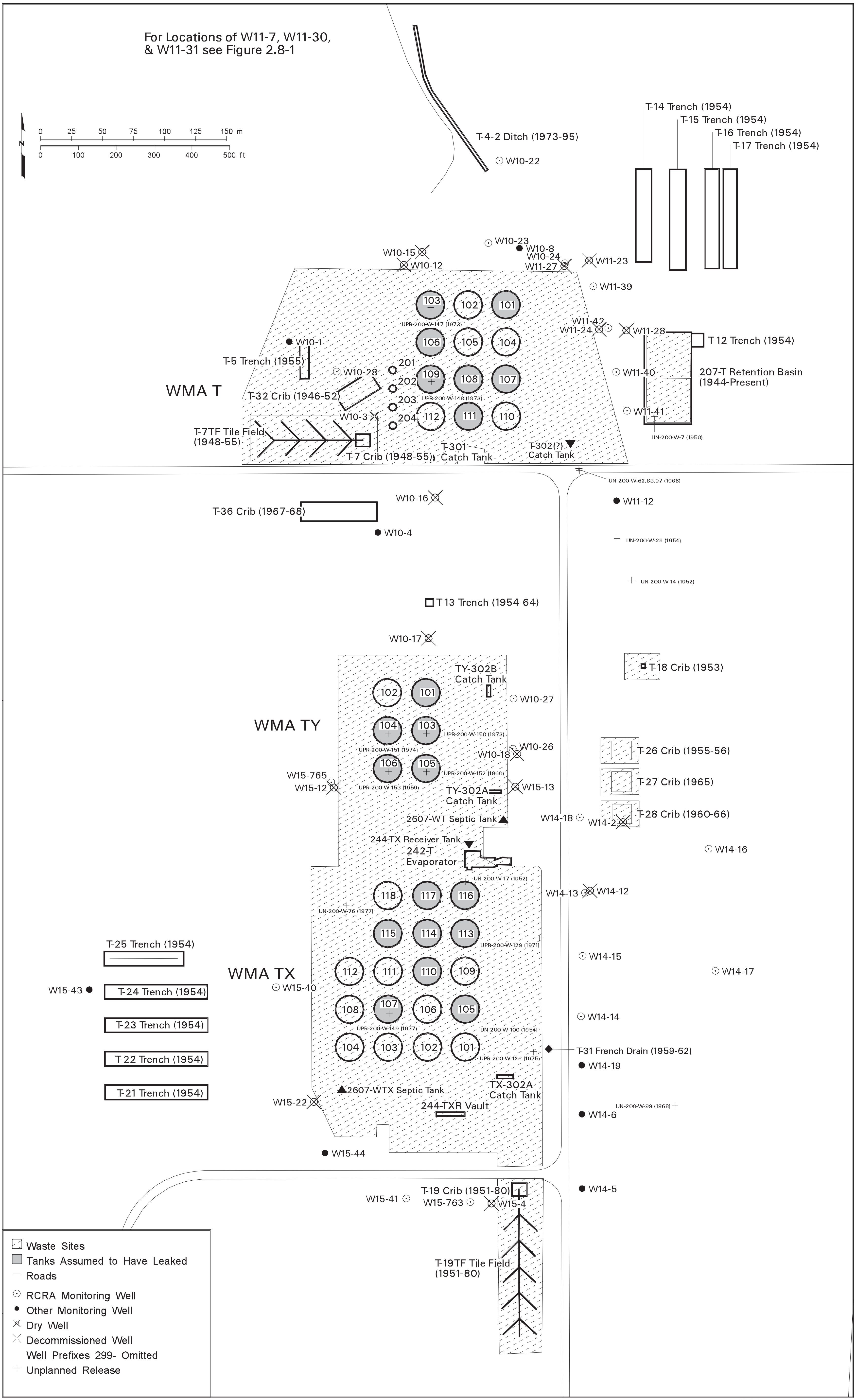
2002/DCL/C/011 (12/16)

Figure A.17. Groundwater Monitoring Wells at Waste Management Area C



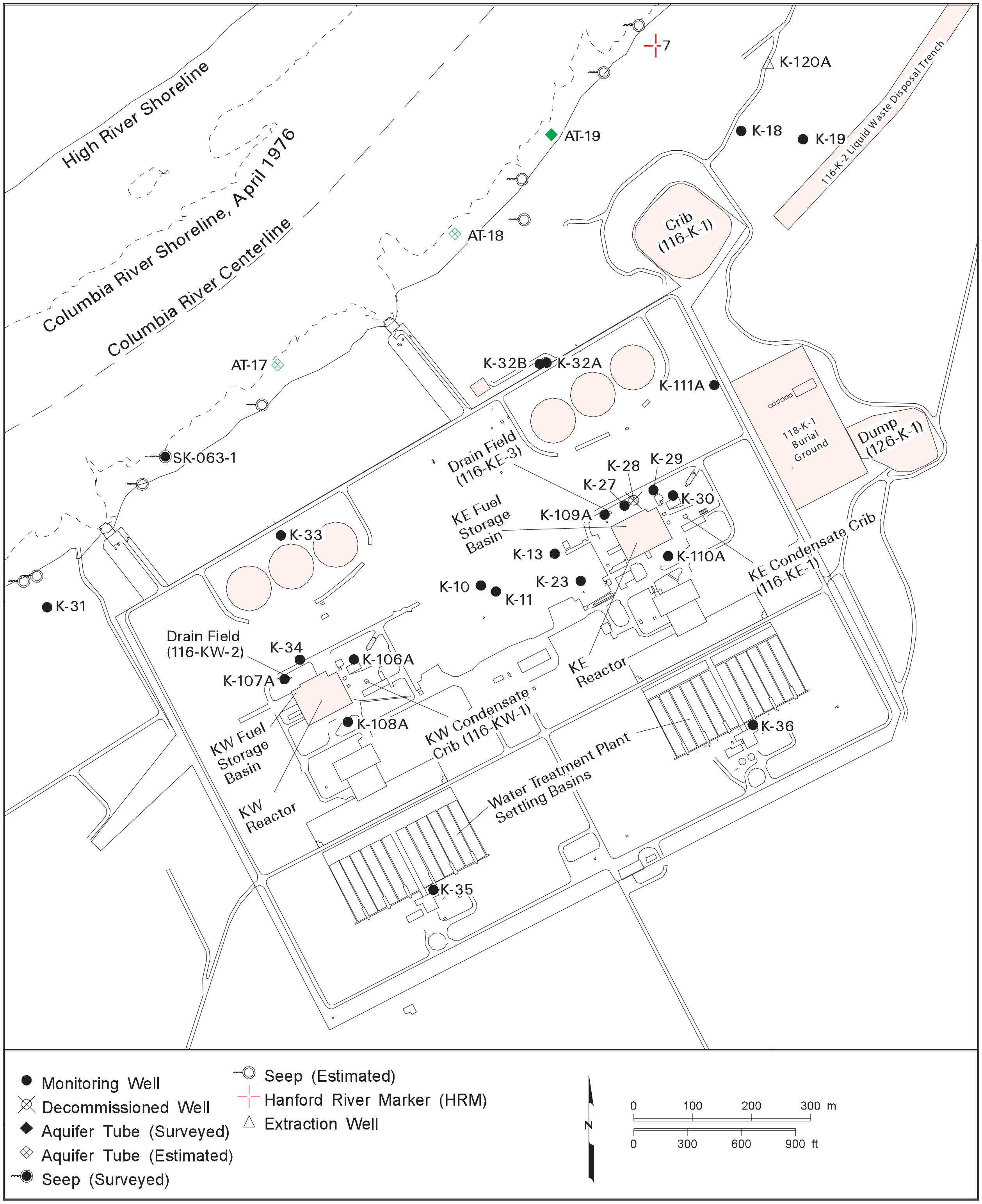
jsc_gwrep02_014 February 19, 2003 12:09 PM

Figure A.18. Groundwater Monitoring Wells at Waste Management Areas S-SX and U



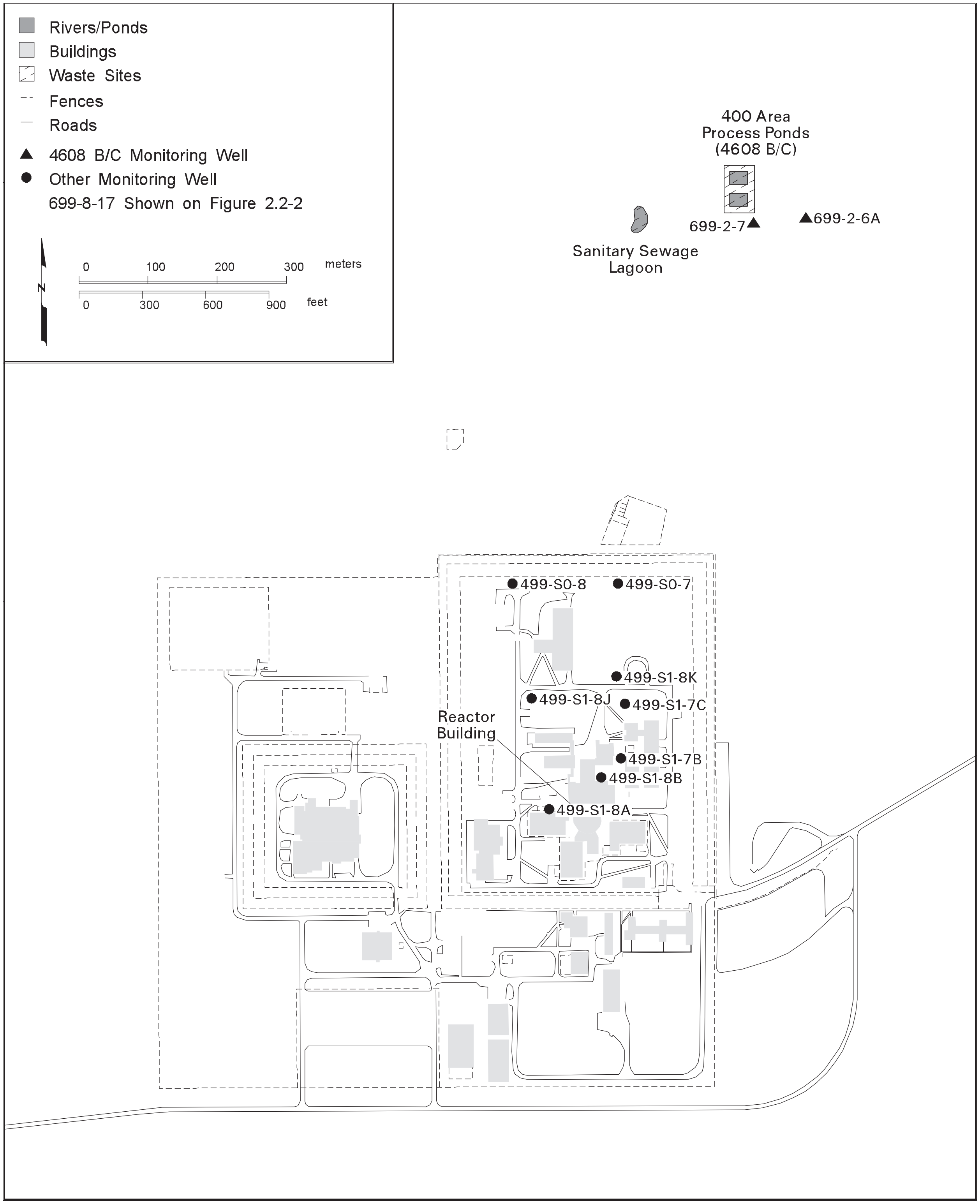
jsc_gwrep02_015 February 19, 2003 12:56 PM

Figure A.19. Groundwater Monitoring Wells at Waste Management Areas T and TX-TY



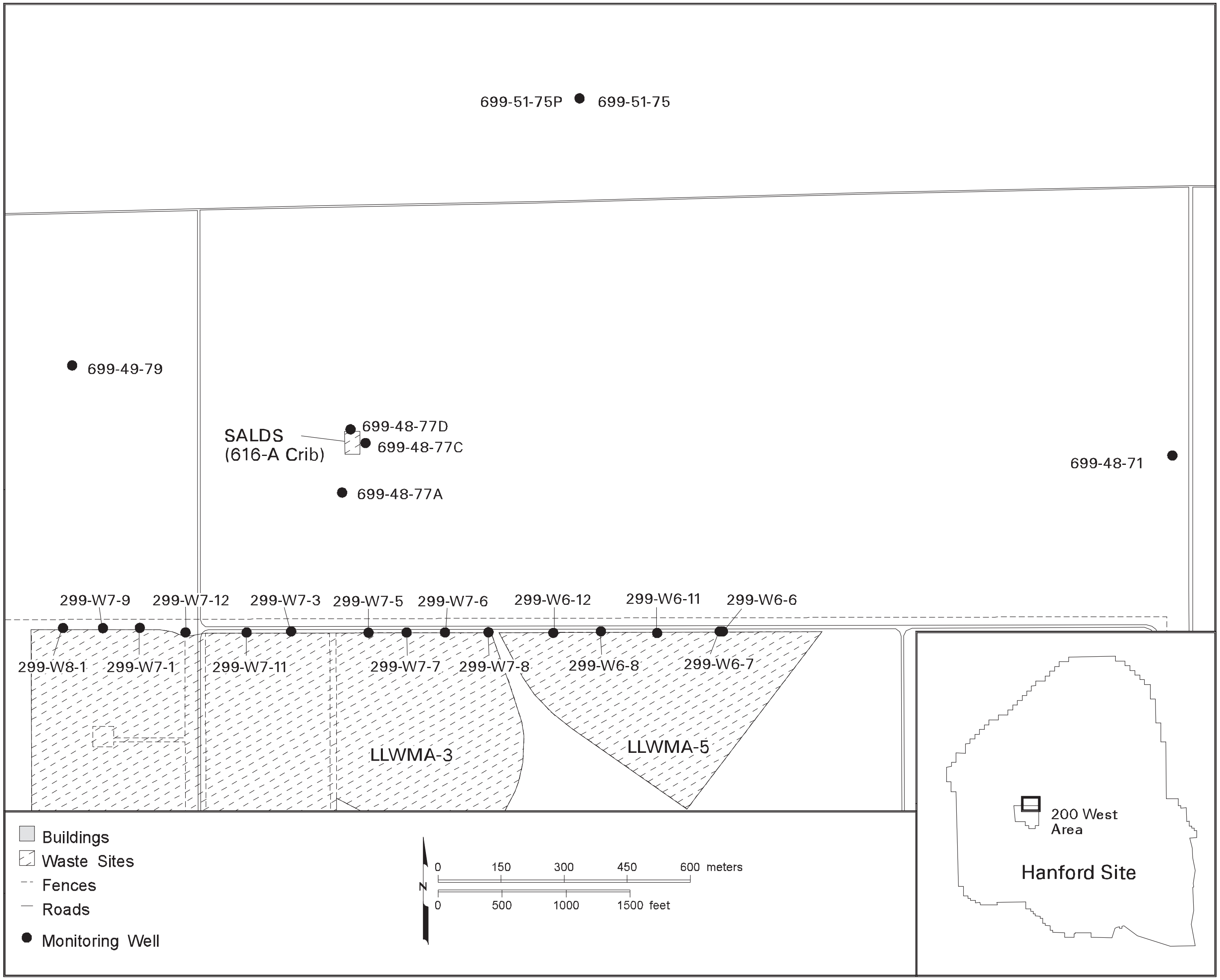
wdw03013/can_pete02_05 August 14, 2002 3:53 PM

Figure A.20. Groundwater Monitoring Wells at the 100-K Basins



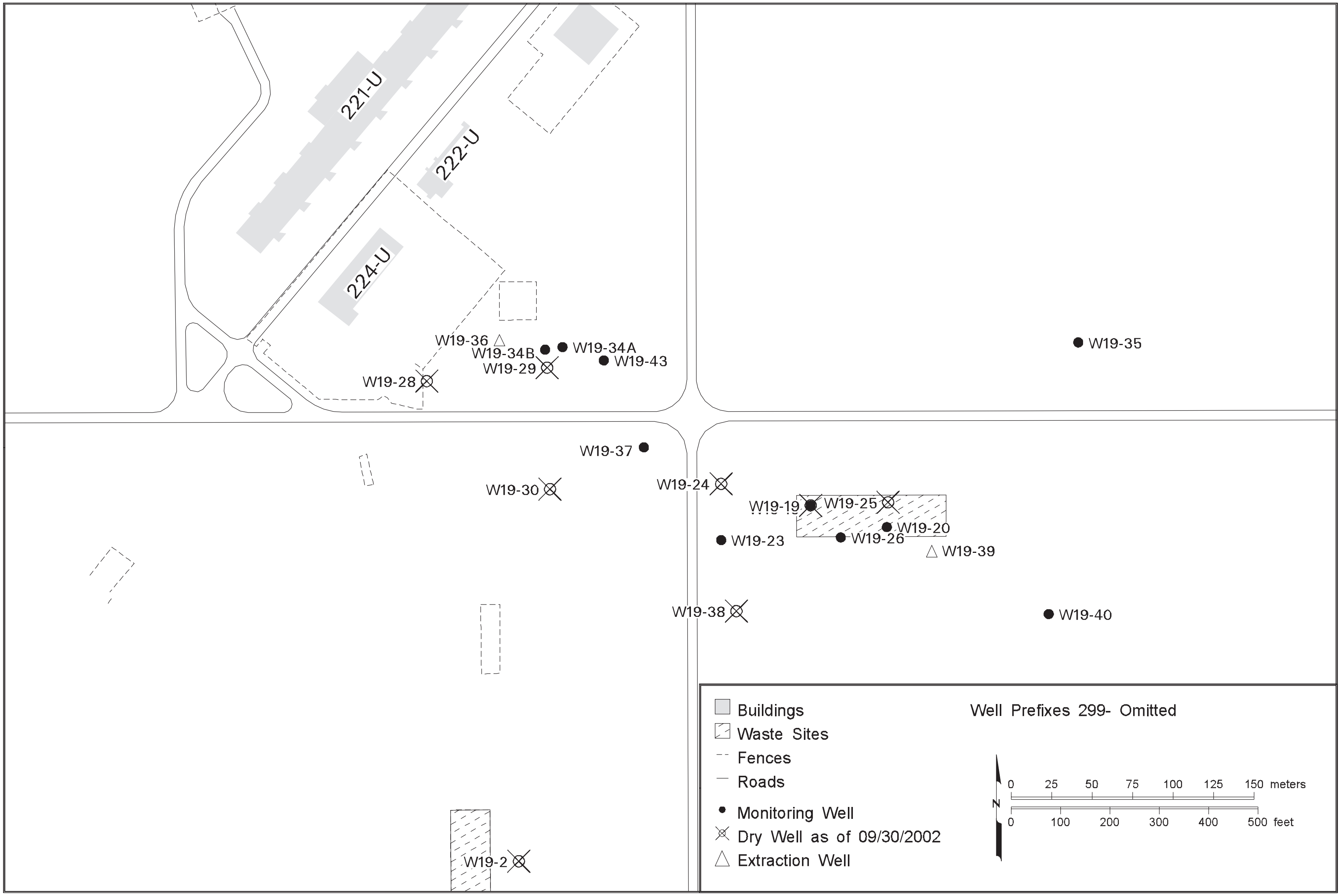
can_gw00_61 February 19, 2001 5:26 PM

Figure A.21. Groundwater Monitoring Wells at the 400 Area Process Ponds



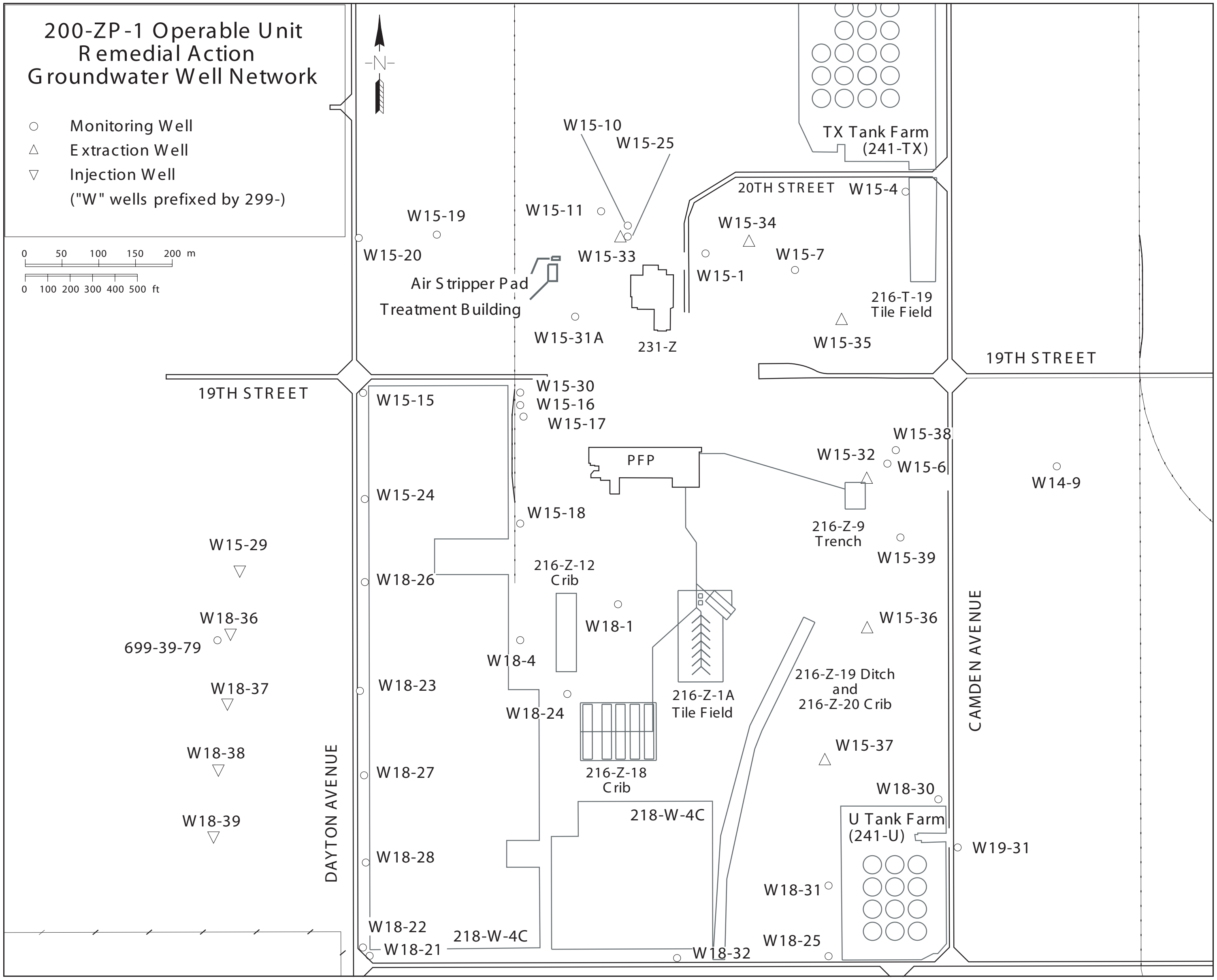
jsc gwrep02 016 February 18, 2003 11:32 AM

Figure A.22. Groundwater Monitoring Wells at the State-Approved Land Disposal Site



jsc_gwrep02_019 February 18, 2003 7:56 AM

Figure A.23. Groundwater Monitoring Wells at the 200-UP-1 Operable Unit



wdw03012

Figure A.24. Groundwater Monitoring Wells at the 200-ZP-1 Operable Unit

Appendix B

Quality Assurance and Quality Control

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Appendix B

Quality Assurance and Quality Control

This appendix presents fiscal year 2002 quality assurance/quality control (QA/QC) information for long-term and interim action groundwater monitoring at the Hanford Site. The phrase "long-term monitoring" refers to monitoring performed to meet the requirements of the *Resource Conservation and Recovery Act* (RCRA) and the *Atomic Energy Act of 1954*. Long-term monitoring also includes monitoring performed at *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA) sites with no groundwater remediation. Pacific Northwest National Laboratory (PNNL) manages long-term monitoring via the Hanford Groundwater Monitoring Project (groundwater project). Interim action monitoring encompasses monitoring at sites with active groundwater remediation under CERCLA. Bechtel Hanford, Inc. managed interim action groundwater monitoring for most of fiscal year 2002 (i.e., through June 30). Bechtel's workscope was transitioned to Fluor Hanford, Inc. on July 1.

The QA/QC practices used by the groundwater project assess and enhance the reliability and validity of field and laboratory measurements conducted to support these programs. Accuracy, precision, and detection are the primary parameters used to assess data quality (Mitchell et al. 1985). Representativeness, completeness, and comparability may also be evaluated for overall quality. These parameters are evaluated through laboratory QC checks (e.g., matrix spikes, laboratory blanks), replicate sampling and analysis, analysis of blind standards and blanks, and interlaboratory comparisons. Acceptance criteria have been established for each of these parameters. When a parameter is outside the criteria, corrective actions are taken to prevent a future occurrence.

The QA/QC practices for RCRA samples are based on guidance from the U.S. Environmental Protection Agency (EPA) (OSWER-9950.1; SW 846). U.S. Department of Energy (DOE) orders and internal requirements provide the guidance for the collection and analysis of samples for other long-term monitoring. The QA/QC practices for the groundwater project are described in the project-specific QA plan. Guidance for interim action monitoring QA/QC practices is provided in project-specific documents (e.g., BHI-00038; DOE/RL-90-08; DOE/RL-91-03; DOE/RL-91-46; DOE/RL-92-76; DOE/RL-96-07; DOE/RL-96-90; DOE/RL-97-36). A glossary of QA/QC terms is provided in PNNL-13080. Additional information about the QA/QC program and fiscal year 2002 data (e.g., results of individual QC samples and/or associated groundwater samples) is available on request.

B.1 Sample Collection and Analysis

C. J. Thompson and D. L. Stewart

Duratek Federal Services, Northwest Operations conducted groundwater sampling for fiscal year 2002. Their tasks included bottle preparation, sample set coordination, field measurements, sample collection, sample shipping, well pumping, and coordination of purgewater containment and disposal. Duratek's statement of work(a) defines quality requirements for sampling activities. Groundwater project staff review all sampling procedures before the procedures are implemented.

Groundwater project staff periodically reviewed sample collection activities performed by nuclear chemical operators from Fluor Hanford, Inc. under the supervision of Duratek Federal Services, Inc. The purpose of the surveillances was to ensure that samples were collected and submitted to the laboratories in accordance with high-quality standards. Ten surveillances were conducted in the following areas: bottle preparation, sample collection, project records related to calibration and certificates of analysis, water-purification system maintenance, measurement of groundwater levels, decontamination of sampling equipment, calibration of field instruments, procedure implementation and control, training, and sample packing, shipping, and storage. A few minor procedural deviations were identified. Corrective actions for these surveillances have been received and accepted. Additionally, a PNNL Health and Safety representative

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(a) SOW-243841-A-B2. 1998. Statement of Work between Pacific Northwest National Laboratory and Duratek Federal Services, Inc., Richland, Washington.

conducted an activities-based self assessment to ensure that sample-collection procedures and practices are adequate to control potential hazards. No safety discrepancies were identified during this assessment.

Severn Trent Laboratories, Incorporated, St. Louis, Missouri (STL St. Louis), performed most routine analyses of hazardous and non-hazardous chemicals for the groundwater project. Lionville Laboratory, Incorporated, Lionville, Pennsylvania (Lionville Laboratory), served as the project's secondary laboratory for chemical analyses of split samples and blind standards. However, Lionville Laboratory performed the majority of chemical analyses for interim action groundwater monitoring. STL St. Louis also analyzed samples from sites with active groundwater remediation.

Severn Trent Laboratories, Incorporated, Richland, Washington (STL Richland) was the primary radiological laboratory for the groundwater project. Eberline Services, Richmond, California, also performed radiological analyses on long-term monitoring samples. The roles of these laboratories were reversed for interim action groundwater monitoring (i.e., Eberline Services served as the primary laboratory, while STL Richland was used as a backup laboratory).

Standard methods from EPA and American Society for Testing and Materials (ASTM) were used for the analysis of chemical constituents. Methods employed for radiological constituents were developed by the analyzing laboratories and are recognized as acceptable within the radiochemical industry. Descriptions of the analytical methods used are provided in PNNL-13080.

B.2 Data Completeness

C. J. Thompson

Data judged to be complete are data that are not suspect, rejected, associated with a missed holding time, out-of-limit field duplicate or field blank, or qualified to indicate laboratory blank contamination. For fiscal year 2002, 88% of the groundwater project data were considered complete. Potentially invalid data were flagged in the database. The percentages of data flagged were 2.0% for field QC problems, 0.5% for exceeded holding times, 0.0% for rejected results, 0.2% for suspect values, and 12.6% for laboratory blank contamination. These values are similar to the percentages observed in fiscal year 2001.

Specific evaluation of completeness for interim action groundwater monitoring was not performed for this report. Completeness issues are primarily assessed as part of site-specific validation activities. No validation activities were performed on interim action groundwater monitoring data in fiscal year 2002.

B.3 Field Quality Control Samples

C. J. Thompson and R. L. Weiss

Field QC samples include field duplicates, split samples, and three types of field blanks. The three types of field blanks are full trip, field transfer, and equipment blanks. Field duplicates are used to assess sampling and measurement precision. Split samples are used to confirm out-of-trend results and for interlaboratory comparisons. Field blanks provide an overall measure of contamination introduced during the sampling and analysis process.

B.3.1 Long-Term Monitoring (Hanford Groundwater Monitoring Project)

The groundwater project's criteria for evaluating the analytical results of field QC samples are as follows:

- field duplicates – Results of field duplicates must have precision within 20%, as measured by the relative percent difference. Only those field duplicates with at least one result greater than five times the method detection limit or minimum detectable activity are evaluated.
- split samples – Results must have a relative percent difference <20%. Only those results that are greater than five times the method detection limit or minimum detectable activity at both laboratories are evaluated.
- field blanks – For most chemical constituents, results above two times the method detection limit are identified as suspected contamination. However, for common laboratory contaminants such as acetone, methylene chloride, 2-butanone, toluene, and phthalate esters, the limit is five times the method detection limit. Results for metals are flagged if they exceed two times the instrument detection limit. For radiological data, blank results are flagged if they are greater than two times the total propagated analytical uncertainty.

If a field blank does not meet the established criteria, it is assumed that there are potential problems with the data for all associated samples. For full-trip and field-transfer blanks, an associated sample is one that was collected on the same day and analyzed by the same method as a full-trip or field-transfer blank. For equipment blanks, an associated sample is one that has all of the following in common with an equipment blank:

- collection date
- collection method/sampling equipment
- analysis method

Data associated with out-of-limit field blanks are flagged with a Q in the database to indicate a potential contamination problem. A Q is also applied to both duplicate results when their precision exceeds the QC limits.

The percentages of acceptable field blank (3,904/4,082 = 96%), split sample (60/62 = 97%), and duplicate (2,316/2,376 = 97%) results evaluated in fiscal year 2002 were high, indicating little problem with contamination and good precision overall.

Tables B.1 through B.4 summarize the field blank and field duplicate results that exceeded QC limits. To assist with their evaluation, the tables are divided into the following categories, where applicable: general chemical parameters, ammonia and anions, metals, volatile organic compounds, semivolatile organic compounds, and radiological parameters. Constituents not listed in the tables had 100% acceptable field blanks and/or field duplicates.

With the exception of semivolatile organic compounds, all classes of constituents had results that were flagged as potentially contaminated because of out-of-limit field blank results. Seventy percent of the out-of-limit blank results were less than quantifiable limits. A few constituents such as chloride, nitrate, sodium, and sulfate had several quantifiable field blank results, but the concentrations were much lower than the levels of these constituents in almost all groundwater samples.

Forty-one percent of the field blank results for total organic carbon exceeded the QC limits. Although the blank concentrations were low (i.e., all results were within a factor of 4 of the method detection limit), the values are of concern for RCRA detection monitoring because total organic carbon is a groundwater contamination indicator parameter. The number of out-of-limit results per quarter decreased throughout the year (91% occurred during the first half of the year), possibly as a result of improved instrument performance. The laboratory had three out-of-limit method-blank results during the year; concentrations were as high as 700 µg/L. All of the elevated method blanks were measured during the first quarter. Overall, the effects of the out-of-limit field blanks are considered minor due to the blanks' low concentrations.

Compared to last year, the number of out-of-limit field blank results for metals increased (5% for fiscal year 2002 versus 2% for fiscal year 2001), but the fiscal year 2002 concentrations were generally lower. Most of the unacceptable results were within a factor of 5 of the instrument detection limits. All of the metals with out-of-limit field blank results had one or more comparable method-blank results, suggesting that the elevated field blank values were caused by false detections or laboratory contamination.

Concentrations of seven volatile organic compounds exceeded the QC limits in one or more field blanks. Methylene chloride was the predominant volatile contaminant, accounting for 70% of the out-of-limit results. Levels of acetone were also out-of-limits in 20 field blanks. Laboratory contamination is the suspected source of these common contaminants, because similar concentrations also were measured in several laboratory method blanks. Trace levels of 2-butanone, carbon disulfide, chloroform, *cis*-1,2-dichloroethene, and trichloroethene also were measured in field blanks. In general, these compounds had low frequencies of detection (i.e., <5%) in field blanks, and the overall impact on the data is minor.

Tritium and uranium were the only radiological constituents with out-of-limit field blank results. Although the blank concentrations were low, they were greater than levels of uranium and tritium in some of the associated groundwater samples. Both constituents also were detected at similar levels in several laboratory method blanks. Beginning with fiscal year 2002, a source of "dead" water (i.e., water containing little or no tritium) was used to prepare full-trip blanks for low-level tritium. As a result, the average blank concentrations and frequencies of detection were significantly reduced compared to previous years.

Comparison of full-trip and equipment blank results suggests that the use of non-dedicated sampling equipment at some wells did not have a significant impact on data quality. Overall, fewer constituents were detected in equipment blanks, and the concentrations of most constituents were lower in equipment blanks. However, only a limited comparison can be made because only 5 equipment blanks were collected compared to 55 full trip blanks. The percentages of out-of-limit results were generally higher in equipment blanks for those constituents detected in both types of blanks.

Duplicate results were flagged for all constituent classes except general chemical parameters and semivolatile organic compounds (see Table B.4). Overall, the relative number of flagged duplicate results was very low (<2.5%), but the percentages of unacceptable results were high for several constituents based on the number of duplicates that met the evaluation criteria. The metals category accounted for approximately half of the out-of-limit results. Most of the metal samples were unfiltered; thus, suspended solids in heterogeneous sample fractions may have caused some of the discrepancies in the metal results. The majority of the out-of-limit duplicate results appear to be anomalous instances of poor precision based on other QC indicators such as the results from the blind standards and laboratory duplicates (discussed in Sections B.4.2 and B.4.3). In several cases, the laboratory was asked to re-analyze or investigate duplicate results with a very high relative percent difference, but the checks did not reveal the source of the problem. Especially poor agreement was observed between a pair of results for the following: fluoride (280 and 4,000 µg/L), hexavalent chromium (2.0 and 74 µg/L), iron (125 and 226 µg/L), nitrogen in nitrate (54,000 and 131,000 µg/L), and zinc (8.3 and 17.5 µg/L). Swapped samples or procedural deviations at the laboratory may have caused the unmatched results.

Three groups of split samples were collected during fiscal year 2002 for the Hanford Groundwater Monitoring Project. The first group consisted of three sample pairs that were collected from wells 199-D4-7, 199-K-27, and 199-H4-4. STL St. Louis and Lionville Laboratory analyzed the samples for anions and metals, and all of the relative percent differences were within the acceptance limits (i.e., less than 20%). The second group included 2 pairs of split samples from well 699-35-66A and 1 pair of samples from wells 699-36-67 and 699-37-68. These samples were analyzed by STL Richland and Eberline Services for iodine-129. Although none of Eberline Services' results were above the quantitation limits, the laboratories demonstrated excellent agreement, with the relative percent difference ranging from 2% to 38%. The final group consisted of five split samples from 200 East Area wells 299-E27-15, 299-E27-7, 299-E33-338, 299-E33-38, and 299-E33-7. STL St. Louis and Lionville Laboratory analyzed these samples for cyanide. Two of the split samples had quantifiable results, and in both cases, the STL St. Louis results were more than twice as high as the Lionville Laboratory (263 and 128 µg/L for well 299-E33-38 and 299 and 125 µg/L for well 299-E33-7). Additional split samples and in-house analyses for cyanide are planned for fiscal year 2003 to investigate these discrepancies.

B.3.2 Interim Action Monitoring

Trained staff collected samples in accordance with approved procedures. In general, field QC samples consisted of field duplicates, splits, equipment blanks, and trip blanks. Field QC data are evaluated as necessary to make decisions that may modify or terminate a remedial action. In fiscal year 2002, no evaluations were necessary for decision-making purposes. At the end of the third quarter, the responsibility for this work was transitioned from Bechtel Hanford, Inc. to Fluor Hanford Inc. No changes in sampling, analysis requirements, analytical services, or reporting formats were made.

Field QC data were examined to monitor laboratory operations and to identify potential problem areas where improvements were necessary. Evaluation criteria were essentially the same as those used for the groundwater project with the following exceptions:

- Field blanks were evaluated based on the number of detections (rather than the groundwater project's approach of using two times the detection limit as an acceptance criterion). Sample-specific detection limits were not captured for interim action monitoring samples, making an identical evaluation impossible.
- The 20% relative percent difference criterion for field duplicate and split sample results was relaxed for sample analytical results near (i.e., typically within five times) nominal method detection limits. This accounts for expected increased analytical error when values are close to detection limits.

For field blank samples, >88% of all results were returned as non-detected. Approximately 70% of the blank results that were detected were common metals (e.g., calcium, iron, manganese, and sodium) measured by the inductively coupled plasma (ICP) method at levels close to analysis procedure detection limits. All detected organic constituents were common laboratory contaminants, and in most cases, detected compounds also were measured at similar levels in the analytical batch blank. Evaluation of other field blank sample results showed no evidence of unexpected or excessive contamination of blanks in the field or by the laboratory. The constituents and levels of contamination found should have no impact on decision making for interim action monitoring. This is comparable, but slightly lower than last year's results (91% non-detect) and still improved over previous years (80% to 85%). Blank detects are summarized in Table B.5.

Field duplicate and split results showed ~5% exceeding the criteria used for evaluation. The percentage of out-of-limit splits was ~2 times higher than the relative number of out-of-limit duplicates. It should be noted that the criteria used to evaluate splits are likely more restrictive than necessary because they are based on similar criteria for laboratory replicate evaluation (i.e., analysis of multiple aliquots from the same sample container by the same laboratory in the same analytical batch).

As noted in previous years, metals analysis by the inductively coupled plasma method accounts for the largest group of results (three-fourths of all) exceeding the criteria. Unlike previous years, no trends between filtered and unfiltered samples were noted; exceeded results appeared to be randomly distributed. Field duplicate evaluations are summarized in Table B.6 and interlaboratory split evaluations are summarized in Table B.7.

This year's interlaboratory splits included volatile organic analyses performed in the field and at the commercial (fixed) laboratories. As noted in previous years, field/fixed splits for carbon tetrachloride >~50 µg/L showed lower levels reported by the fixed laboratory. Differences were smaller than those from previous years, and the majority of the comparisons (>70%) passed as opposed to last year, where 100% of the results did not meet the acceptance criteria. No additional information on potential causes for these differences has been developed.

Previous evaluations noted an apparent non-random variability in interlaboratory splits for analysis of some metals at low levels. This was noted again this year but to a much lesser degree (last year showed improvement as well). At levels below ~50 µg/L, results reported by STL St. Louis were noted greater than Lionville Laboratory only for zinc; the other comparisons showed essentially random distribution.

Overall evaluation indicates no significant issues between procedures and analyses performed by the laboratories providing services to Bechtel Hanford, Inc./Fluor Hanford Inc. The general performance for fiscal year 2002 appeared improved from the previous year.

B.4 Holding Times

D. S. Sklarew

Holding time is the elapsed time period between sample collection and analysis. Samples should be analyzed within recommended holding times to minimize the possibility of changes in constituent concentrations caused by volatilization, decomposition, or other chemical alterations. Samples also are refrigerated to slow potential chemical reactions within the sample matrix. Maximum recommended holding times for constituents frequently analyzed for the groundwater project are listed in Table B.8. Radiological constituents do not have recommended maximum holding times because these constituents are not typically lost under ambient temperatures when appropriate preservatives are used. Results of radionuclide analysis are corrected for decay from sampling date to analysis date.

During fiscal year 2002, recommended holding times were exceeded for 147 out of 5,887 (2.5%) of the groundwater project's non-radiological sample analysis requests. A sample analysis request is defined as a sample that is submitted for analysis by a particular analytical method. In general, the missed holding times should not have a significant impact on the data. Results for samples with missed holding times are flagged with an H in the database. STL St. Louis exceeded the holding times for 144 out of 5,838 (2.5%) sample analysis requests, an improvement from 5.5% exceeded last year. Of these, the constituents with the most missed holding times were anions by ion chromatography (126 samples) and total dissolved solids (6 samples). STL Richland exceeded the holding times for 3 out of 37 (8.1%) coliform samples. Lionville Laboratory did not exceed holding times for the 12 analysis requests that were processed for the groundwater project. This information was discussed with the laboratories to help them identify areas where improvements are needed.

Specific evaluation of adherence to analytical holding times for interim action monitoring was not performed for this report. Analytical holding times are monitored as part of ongoing sample and data management activities throughout the year. However, interim action monitoring data are not flagged for missed holding times. No remediation decisions were affected by missed holding times in fiscal year 2002.

B.5 Laboratory Performance

C. J. Thompson, D. S. Sklarew, and D. L. Stewart

Laboratory performance is measured by several indicators, including nationally-based performance evaluation studies, double-blind standard analyses, laboratory audits, and internal laboratory QA/QC programs. This section provides a detailed discussion of the performance indicators for STL St. Louis and STL Richland. Brief summaries of performance measures for Lionville Laboratory and Eberline Services also are presented throughout this section. The majority of the laboratory's results were within the acceptance limits, indicating good performance overall.

B.5.1 Nationally-Based Performance Evaluation Studies

During fiscal year 2002, Environmental Resources Associates, New York State Department of Health, and DOE conducted nationally-based studies to evaluate laboratory performance for chemical and radiological constituents. STL St. Louis and Lionville Laboratory participated in the EPA sanctioned Water Pollution and Water Supply Performance Evaluation studies conducted by New York State (Environmental Laboratory Approval Program) and Environmental Resources Associates, respectively. STL Richland and Eberline Services took part in DOE's Quality Assessment Program. STL Richland participated in the Environmental Resources Associates' InterLaB RadCheM Proficiency Testing Program. All four laboratories took part in DOE's Mixed Analyte Performance Evaluation Program. Results of those studies related to groundwater monitoring at the Hanford Site are described in this section.

B.5.1.1 Water Pollution and Water Supply Studies

The purpose of water pollution and water supply studies is to evaluate the performance of laboratories in analyzing selected organic and inorganic compounds. Every month, an accredited agency, such as the New York State Department of Health or Environmental Resource Associates, distributes standard water samples to participating laboratories. These samples contain specific organic and inorganic analytes at concentrations unknown to the participating laboratories. After analysis, the laboratories submit results to the accredited agency, which uses regression equations to determine acceptance and warning limits for the study participants. The results of these studies, expressed in this report as a percentage of the results that the accredited agency found acceptable, independently verify the level of laboratory performance.

For the four potable and non-potable water chemistry studies in which STL St. Louis participated this year (NY ELAP 242, 247, and 250[b] and ERA WP-90), the percentage of acceptable results submitted to the Hanford Groundwater Program ranged from 90% to 94% (Table B.9). Of the 37 different constituents with unacceptable results, calcium hardness and cyanide were out of limits in three of the four reports; orthophosphate as P, total iron, and zinc, were out of limits in two of the three reports. The laboratory provided information about possible causes for many of the unacceptable results and suggested corrective actions where appropriate. Overall, the unacceptable results should not have a significant impact on Hanford groundwater samples.

Lionville Laboratory participated in water pollution studies WP-72, 73, 74, 75, 78, 80, 81, 84, and 90 and water supply studies WS-56, 57, 63, 72, January02, and 02-1 this year. For the results submitted to the Hanford Groundwater Program, the percentage of Lionville's acceptable results ranged from 67% to 100% (Table B.10). Of the 35 different constituents with unacceptable results, sulfide was out of limits three times and 1,1,1-trichloroethane, methylene chloride, 1,4-dichlorobenzene, Aroclor 1016/1242, Aroclor 1232, Aroclor 1254, and Aroclor 1260 were out of limits twice. The laboratory provided information about possible causes for a number of the unacceptable results and suggested corrective actions where appropriate. Corrective actions taken last year for cyanide and 2,4-D appear to have resolved those issues, because there were no unacceptable results reported for either constituent this year. Overall, the unacceptable results should not have a significant impact on Hanford groundwater samples.

B.5.1.2 DOE Quality Assessment and Mixed Analyte Performance Evaluation Programs

DOE's Quality Assessment Program evaluates how laboratories perform when they analyze radionuclides in water, air filter, soil, and vegetation samples. This discussion considers only water samples. The program is coordinated by the Environmental Measurements Laboratory in New York. The Environmental Measurements Laboratory provides blind standards that contain specific amounts of one or more radionuclides to participating laboratories. Constituents analyzed can include americium-241, cesium-134, cesium-137, cobalt-60, gross alpha, gross beta, plutonium-238, plutonium-239, strontium-90, tritium, uranium-234, uranium-238, and total uranium. After sample analysis, each

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(b) Letter reports from M. Caruso (Environmental Laboratory Approval Program, State of New York Department of Health, Albany, New York) to W. Deckelmann (Severn Trent Laboratories, St. Louis, Earth City, Missouri). Proficiency Test Reports, ELAP 242, October 25, 2001; ELAP 247, December 17, 2001; and ELAP 250, April 2, 2002.

participating laboratory forwards the results to the Environmental Measurements Laboratory for comparison with known values and with results from other laboratories. The Environmental Measurements Laboratory evaluates the accuracy of the results based on the historical analytical capabilities for the individual analyte/matrix pairs. Using a cumulative normalized distribution, acceptable performance yields results between the 15th and 85th percentiles. Acceptable with warning results are between the 5th and 15th percentile and between the 85th and 95th percentile. Not acceptable results include the outer 10% (<5th percentile or >95th percentile) of historical data (EML-617).

For the one study conducted this year, QAP56 (EML-617), the percentage of STL Richland's acceptable results was 91% (Table B.11). The one unacceptable result was for cesium-134. Two constituents (18%) had results that were evaluated as acceptable with warning (see Table B.11).

The percentage of Eberline Services' results that was acceptable was 100% (Table B.12). One constituent had a result that was evaluated as acceptable with warning (see Table B.12).

DOE's Mixed Analyte Performance Evaluation Program examines laboratory performance in the analysis of soil and water samples containing metals, volatile and semivolatile organic compounds, and radionuclides. This report considers only water samples. The program is conducted at the Radiological and Environmental Sciences Laboratory in Idaho Falls, Idaho, and is similar in operation to DOE's Quality Assessment Program discussed above. DOE evaluates the accuracy of the Mixed Analyte Performance Evaluation Program results for radiological and inorganic samples by determining if they fall within a 30% bias of the reference value.

All fiscal year 2002 results (MAPEP-01-W9) for inorganics and organics from STL St. Louis were acceptable, although one was acceptable with warning (see Table B.11). Only one result from STL Richland, plutonium-238, was not acceptable (see Table B.11). All results for Eberline Services and Lionville Laboratory were acceptable (see Table B.12).

B.5.1.3 InterLaB RadCheM Proficiency Testing Program Studies

The purpose of the InterLaB RadCheM Proficiency Testing Program, conducted by Environmental Resources Associates, is to evaluate the performance of laboratories in analyzing selected radionuclides. The program provides blind standards that contain specific amounts of one or more radionuclides in a water matrix to participating laboratories. Environmental Resources Associates standards were prepared for the following radionuclides/parameters: barium-133, cesium-134, cesium-137, cobalt-60, gross alpha, gross beta, iodine-131, radium-226, radium-228, strontium-89, strontium-90, tritium, uranium, and zinc-65. After sample analysis, the results were forwarded to Environmental Resources Associates for comparison with known values and with results from other laboratories. Environmental Resources Associates bases its control limits on the EPA's National Standards for Water Proficiency Testing Studies Criteria Document (NERL-Ci-0045).

In the 6 studies in which STL Richland participated this year (RAD-45, 46, 47, 48, 49, 50), 53 constituents were analyzed. Of these, 51 (96%) were acceptable. The unacceptable results were for gross beta and cesium-134 (see Table B.11). Six of the results were evaluated as acceptable with warning, viz., barium-133, cesium-134, gross alpha, tritium, and uranium (twice) (see Table B.11).

Eberline Services does not participate in the Environmental Resources Associates program.

B.5.2 Double-Blind Standard Evaluation

The groundwater project forwarded blind QC standards to STL Richland and St. Louis, Lionville Laboratory, and Eberline Services during fiscal year 2002. Blind spiked standards were generally prepared in triplicate and submitted to the laboratories to check the accuracy and precision of analyses. For most constituents, the standards were prepared in a groundwater matrix from a background well. One cyanide standard from the second quarter and standards for antimony and cadmium were prepared in organic free, deionized water. In all cases, the standards were submitted to the laboratories in double-blind fashion (i.e., the standards were disguised as regular groundwater samples). After analysis, the laboratory's results were compared with the spiked concentrations, and a set of control limits were used to determine if the data were acceptable. Generally, if a result was out of limits, the data were reviewed for errors. In situations where several results for the same method were unacceptable, the results were discussed with the laboratory, potential problems were investigated, and corrective actions were taken if appropriate.

Tables B.13 and B.14 list the number and types of blind standards used in fiscal year 2002 along with the control limits for each constituent. Overall, 95% of the blind spike determinations were acceptable. This is significantly higher than the percentage from the previous year (83%). A total of twelve results were out of limits for STL Richland and St. Louis. Lionville Laboratory and Eberline Services demonstrated excellent performance; none of their results were outside the acceptance limits.

Table B.15 lists the blind-standard spike concentrations and the average results for STL Richland and St. Louis. One or more individual results (not listed separately in Table B.15) were unacceptably low for gross alpha and total organic halides. Similarly, one or more results were biased high for fluoride and total organic carbon.

Most of STL St. Louis' results for total organic carbon were biased high, but only one was outside the acceptance limits. Typical recoveries ranged from 105% to 120%. A similar tendency was observed in last year's blind standard results. The standard with the out-of-limit recovery (129%) was spiked at the lowest level (1,010 µg/L, which is approximately equal to the laboratory's practical quantitation limit).

Seven of twenty-eight results for total organic halides from STL St. Louis were out of limits. One of the unacceptable results was for a standard spiked with 2,4,6-trichlorophenol. The low-biased concentration associated with this sample appears to have been an anomalous instance of poor accuracy, because three replicates of the standard had acceptable results. The remaining out-of-limit results were for standards spiked with volatile organic compounds. PNNL staff performed in-house analyses on splits of the volatile standards and confirmed that the standards were spiked at the proper concentrations. Consequently, the reason for the low bias appears to be volatilization or weak retention of the volatile analytes on the charcoal cartridges used in the analysis. The laboratory investigated the out-of-limit results but was unable to determine the source of error. Low-biased total organic halide results are of concern because of the potential for not detecting halogenated organics at RCRA sites. However, even with a 50% negative bias, detection should occur at concentrations well below the limit of quantitation (discussed in Section B.5).

Three of STL St. Louis' second quarter results for fluoride appeared to be biased high by ~40%. The results, however, agreed well with an in-house analysis of the fluoride standards. Consequently, PNNL staff believe the fluoride standards were inadvertently spiked at higher levels than anticipated. Fluoride recoveries for the other three quarters were acceptable.

During fiscal year 2001, some special blind standards containing low concentrations of cadmium and some other metals were submitted to STL St. Louis to evaluate the laboratory's trace-ICP capability. As a result of some low recoveries for cadmium, additional standards containing cadmium and antimony were submitted to the laboratory in the second quarter of fiscal year 2002. All of the results were acceptable, suggesting that the previous problems were caused by instability of the standards.

In general, STL Richland's performance on radiological blind standards was excellent. All results except one from the fourth quarter were within the QC limits. The out-of-limit result was for gross alpha. Since the other fourth quarter results for gross alpha were acceptable, the low recovery appears to have been caused by a procedural error at the laboratory.

Table B.16 provides a detailed summary of Lionville Laboratory's and Eberline Services' blind standard results. All of the two laboratories' results for total organic carbon and gross beta were acceptable for the second year in a row.

Bechtel Hanford, Inc. sent no blind standards as part of interim action monitoring to the commercial laboratories in fiscal year 2002. The great similarity of matrices between the long-term and interim action monitoring samples and common use of the same laboratories make additional analysis of blind standards redundant.

B.5.3 Laboratory Internal QA/QC Programs

STL Richland, STL St. Louis, Eberline Services, and Lionville Laboratory maintain internal QA/QC programs that generate data on analytical performance by analyzing method blanks, laboratory control samples, matrix spikes and matrix spike duplicates, matrix duplicates, and surrogates (see PNNL-13080 for definitions of these terms). This information provides a way to assess laboratory performance and the suitability of a method for a particular sample matrix. Currently, laboratory QC data are not used for in-house validation of individual sample results unless the lab is experiencing unusual performance problems with an analytical method. An assessment of the laboratory QC data for fiscal year 2002 is summarized in this section. STL data are discussed in detail first. Table B.17 provides a summary of the STL QC data by listing the percentage of QC results that were out of limits for each analyte category and QC parameter. Additional details are presented in Tables B.18 through B.21. Constituents not listed in these tables did not exceed STL's QC limits. A brief summary of Lionville Laboratory and Eberline Services data is presented at the end of the section.

Most of this year's laboratory QC results were within acceptance limits, suggesting that the analyses were in control and reliable data were generated. Nevertheless, several parameters had unacceptable results, and some were significantly out-of-limits. For method blanks, significantly out-of-limits means some results were greater than twice the QC limit. For laboratory control samples, matrix spikes, and duplicates, significantly out-of-limits means the results were outside the range of the QC limits plus or minus more than 10 percentage points (e.g., if the QC limits are 80% to 120%, significantly out-of-limits would mean <70% or >130%). Results that were significantly out-of-limits are noted in Tables B.18 through B.21.

Evaluation of results for method blanks was based on the frequency of detection above the blank QC limits. In general, these limits are two times the method detection limit for chemical constituents and two times the total propagated error for radiochemistry parameters. For common laboratory contaminants such as 2-butanone, acetone, methylene chloride, phthalate esters, and toluene, the QC limit is five times the method detection limit.

Table B.18 summarizes method blank results from STL Richland and St. Louis. The ammonia and anions and metals categories had the greatest percentages of method blank results exceeding the QC limits. The following parameters had >10% of method blank results outside the QC limits: acetone, aluminum, beryllium, chloride, copper, iron, methylene chloride, sodium, specific conductance, sulfate, and zinc. The out-of-limit method blank results for conductance are not a significant problem because the values are much lower than the levels measured in Hanford Site groundwater. Similarly, the highest method blank result for chloride (0.14 mg/L) is lower than the chloride levels measured in Hanford groundwater. The percentage of out-of-limit method blanks for total organic carbon and for cyanide decreased significantly over that from last year.

Table B.19 summarizes results for the laboratory control samples from STL Richland and St. Louis. Only volatile organic compounds had >1% of their measurements outside the QC limits - 2-butanone, 4-methyl-2-pentanone, acetone, chloromethane, *trans*-1,3-dichloropropene, vinyl chloride, Aroclor-1016, Aroclor-1260, oil and grease, and uranium-235 had >10% of laboratory control samples outside of QC limits. In most of these cases, the number of QC samples analyzed was limited (<10).

Table B.20 summarizes results for the matrix spikes and matrix spike duplicates from STL Richland and St. Louis. The semivolatile organics category had the greatest percentage of matrix spikes/spike duplicates exceeding the QC limits. Fewer than 4% of the matrix spikes or matrix spike duplicates for general chemistry parameters, ammonia and anions, metals, volatile organic compounds, and radiochemistry parameters were out of limits. This represents a significant decrease compared to last year's results for ammonia and anions and radiochemistry parameters. Table B.20 indicates which constituents had >10% of matrix spikes/spike duplicates out of limits.

Matrix duplicates were evaluated by comparing the relative percent difference to the QC limit for results that were five times greater than the method detection limit or the minimum detectable activity. Table B.21 lists the constituents that exceeded the relative percent difference limits. All analyte categories had fewer than 3% of their measurements outside the QC limits. Individual constituents with >10% of matrix duplicates out of limits may be found in Table B.21. The percentage of out-of-limit results for cyanide decreased significantly from last year (from 20% to 0%).

Surrogate data included eight compounds each for volatile organics and for semivolatile organics. For volatile organic compounds, 2.3% of the surrogate results were outside of QC limits; the corresponding percentage for semivolatile organic surrogates was 3.9%.

QC data for Eberline Services and Lionville Laboratory were limited for fiscal year 2002 because these laboratories did not analyze many samples for the groundwater project. Lionville Laboratory analyzed method blanks, laboratory control samples, matrix spikes, and matrix duplicates for total organic carbon and cyanide. All of the QC data were within limits; however, insufficient sample size was available for matrix spike and duplicate analyses for cyanide. Eberline Services QC data were limited to gross beta. All of the QC data were within limits.

B.5.3.1 Issue Resolution

Issue resolution forms are documents that are used to record and resolve problems encountered with sample receipt, sample analysis, missed hold times, and data reporting (e.g., broken bottles or QC problems). The laboratories generate the forms and forward them to the groundwater project as soon as possible after a potential problem is identified. The forms provide a means for the project to give direction to the laboratory on resolution with the issues. The documentation is intended to identify occurrences, deficiencies, and/or issues that may potentially have an adverse effect on data integrity. Table B.22 indicates the specific issues identified during fiscal year 2002 and the number of times these occurred. The number of issues identified by the laboratories was small compared to the total number of analytical requests submitted (~10,800, consisting of ~15,000 bottles). The frequencies of the individual issues increased in some categories prior to receipt at the laboratory, decreased in others after receipt at the laboratory, and remained the same as last year for other categories. The number of hold time issues was primarily related to either shipping problems or delays caused by the need for radiological screens prior to shipment.

B.5.3.2 Laboratory Audits/Assessments

Laboratory activities are regularly assessed by surveillance and auditing processes to ensure that quality problems are prevented and/or detected. Regular assessment supports continuous process improvement.

Assessments of STL Richland and St. Louis were conducted January 22 to January 25, 2002, and April 23 to 26, 2002, respectively. Representatives from Bechtel Hanford, Inc. and PNNL conducted both audits. The purpose of the assessments was to evaluate the continued support of analytical services to Hanford Site contractors as specified in the statement of work between Flour Hanford, Inc. and Severn Trent Laboratories.(c)

The assessment scope for these audits was based on the analytical and QA requirements for both groundwater and multi-media samples as specified in the statement of work. The primary areas of focus for the STL Richland laboratory were personnel training, procedure compliance, sample receipt and tracking, instrument operation and calibration, equipment maintenance, instrumentation records and logbooks, implementation of Severn Trent Laboratories' QA Management Plan in accordance with Hanford Analytical Services Quality Assurance Document (HASQARD, Volumes 1 and 4, DOE/RL-96-68) and the implementation of corrective actions for deficiencies identified in previous audits.

For the laboratory audit at STL St. Louis, emphasis was placed on the implementation of Severn Trent Laboratories' QA program in accordance with the requirements of HASQARD, compliance to laboratory specific administrative and technical operating procedures, and verification of the corrective actions initiated in response to the previous audits. The specific areas reviewed included STL St. Louis personnel training, procedure compliance, sample receipt and tracking, instrument operation and calibration, equipment maintenance, instrument records and logbooks, software control, and STL QA Management Plan.

One finding and six observations were noted in the assessment of STL Richland, and thirteen findings and eleven observations were identified during the assessment of STL St. Louis. Although there is an increase in the number of findings and observations from last year's audits, the technical quality of data has not been affected. The findings and observations related to deficiencies in the following specific programmatic areas: document control, quality improvement, work processes, sample receipt, procedure development and review, control charting practices, preventative maintenance, calibration, and non-compliance to HASQARD in the areas of trending surveillances, process for changes to records, identification of qualifications and responsibilities of assessors, and lack of procedures or incomplete procedures for some work processes. Corrective-action responses to the assessment findings and observations have been evaluated. The STL Richland laboratory has addressed all finding and observations, and the audit findings have been closed. STL St. Louis has addressed all findings and observations, including 2001 audit findings and observations.

Quality and technical representatives from Bechtel Hanford, Inc. conducted assessments of Eberline Services, Inc., Richmond, California Laboratory and its subcontractor, Lionville Laboratory, on June 18 through 20, 2002, and May 21 through May 24, 2002, respectively. The scope of these audits focused on the analytical and QA requirements for sample analyses as specified in the Flour Hanford Contract 630, and associated statement of work SOW 93-0003, Rev. 6, *Environmental and Waste Characterization Analytical Services*, with these laboratories. The primary focus of these audits was the implementation of Eberline/Richmond's and Lionville's QA Programs and compliance to their operating procedures to meet the requirements specified in the statement of work and verification of the implementation of corrective actions associated with previous audits.

One finding and ten observations were noted during the audit of Eberline Services/Richmond. The finding related to non-compliance to the statement of work for sending Performance Evaluation results to the buyer. The observations were related to procedural incompleteness, documentation of data review, management of electronic data changes, and implementation of the internal audit process. All corrective-action responses have been addressed by the laboratory and were found acceptable.

Four findings and seven observations were noted for Lionville Laboratory. These findings and observations dealt with procedural non-compliance, incomplete or insufficient procedures, and non-compliance to the QA requirements in HASQARD. Closure of the audit findings for 2002 and all previous audits is complete.

(c) RFSH-SOW-93-0003, Rev. 6. 1999. *Environmental and Waste Characterization of Analytical Services*. Statement of Work between Fluor Daniel Hanford, Inc. and Severn Trent Laboratories, Richland, Washington.

Members of the DOE-sponsored Environmental Management Consolidated Assessment Program also conducted audits of STL St. Louis, Eberline Services, Lionville Laboratory, and STL Richland. The dates for these assessments were May 29 to 31, 2002, July 8 to 9, 2002, August 27 to 29, 2002, and September 17 to 19, 2002, respectively. The goal of the Environmental Management Consolidated Assessment Program is to design and implement a program to consolidate site audits of commercial and DOE environmental laboratories providing services to DOE Environmental Management. The specific audit objectives were to assess the ability of the laboratories to produce data of acceptable and documented quality through analytical operations that follow approved and technically sound methods and to handle DOE samples and associated waste in a manner that is protective of human health and the environment.

The focus of the Environmental Management Consolidated Assessment Program audits included the following functional areas: general laboratory practices and quality management, data quality for inorganics and wet chemistry, data quality of organic chemistry, data quality of radiochemistry analysis, laboratory information management and electronic data deliverables, and hazardous and radioactive material management. Additionally, corrective action implementation of past audit findings were verified.

STL St. Louis had eleven findings and fourteen observations in the following areas: incomplete or lack of procedures, procedural non-compliance, implementation of the preventative maintenance program, instrument calibration, records storage and management, and incomplete documentation for the handling of hazardous and radioactive materials. Fourteen findings from the previous audit were closed, and the remaining five were incorporated into this year's audit.

STL Richland had one finding and fifteen observations, of which six were corrected during the audit. The finding was related to insufficient procedure for the gas proportional counter voltages. All previous findings with the exception of the bioassay findings of last year's audit were closed.

Eberline Services, Inc. had one finding and six observations, while Lionville Laboratory had five findings and ten observations. These findings and observations related to lack of standard operating procedures or procedural non-compliance. Some of the areas noted were: insufficient documentation of standards, insufficient monitoring of the nanopure system, lack of an annual review of the Radiological Control Program, and no formalized plan for computer hardware maintenance. Findings from the previous audits were closed out for both Eberline Services, Inc. and Lionville Laboratory.

In addition to many of the past audit findings being closed, several proficiencies for all laboratories were noted in each audit this year, indicating that the laboratories are improving their processes and continuing to provide quality analytical services. Continued assessments of the laboratories are planned for the upcoming year to further evaluate performance and to ensure those corrective actions for the past findings and observations have been implemented.

B.6 Limit of Detection, Limit of Quantitation, and Method Detection Limit

C. J. Chou, D. S. Sklarew, and C. J. Thompson

Detection and quantitation limits are essential to evaluate data quality and usefulness because they provide the limits of a method's measurement. The detection limit is the lower limit at which a measurement can be differentiated from background. The quantitation limit is the lower limit where a measurement becomes quantifiably meaningful. The limit of detection, limit of quantitation, and method detection limit are useful for evaluating groundwater data.

The limit of detection is defined as the lowest concentration level statistically different from a blank (Currie 1988). The concentration at which an analyte can be detected depends on the variability of the blank response. For the purpose of this discussion, the blank is taken to be a method blank.

In general, the limit of detection is calculated as the mean concentration in the blank plus three standard deviations of that concentration (EPA/540/P-87/001, OSWER 9355.0-14). The blank-corrected limit of detection is simply three times the blank standard deviation. At three standard deviations from the blank mean, the false-positive and the false-negative error rates are each ~7% (Miller and Miller 1988). A false-positive error is an instance when an analyte is declared present but is, in fact, absent. A false-negative error is an instance when an analyte is declared absent but is, in fact, present.

The limit of detection for a radionuclide is typically computed from the counting error associated with each reported result (e.g., EPA 520/1-80-012) and represents instrumental or background conditions at the time of analysis. In contrast, the limit of detection and limit of quantitation for the radionuclides shown in Table B.23 are based on variabilities that result from both counting errors and uncertainties introduced by sample handling. In the latter case, distilled water, submitted as a sample, is processed as if it were an actual sample. Thus, any random cross-contamination of the blank during sample processing will be included in the overall error, and the values shown in Table B.23 are most useful for assessing long-term variability in the overall process.

The limit of quantitation is defined as the level above which quantitative results may be obtained with a specified degree of confidence (Keith 1991). The limit of quantitation is calculated as the blank mean plus 10 standard deviations of the blank (EPA/540/P-87/001, OSWER 9355.0-14). The blank-corrected limit of quantitation is simply 10 times the blank standard deviation. The limit of quantitation is most useful for defining the lower limit of the useful range of concentration measurement technology. When the analyte signal is 10 times larger than the standard deviation of the blank measurements, there is a 95% probability that the true concentration of the analyte is within ±25% of the measured concentration.

The method detection limit is defined as the minimum concentration of a substance that can be measured and reported with a 99% confidence that the analyte concentration is greater than zero. The method detection limit is determined from analysis of a sample in a given matrix containing the analyte (Currie 1988). The method detection limit is 3.14 times the standard deviation of the results of seven replicates of a low-level standard. Note that the method detection limit, as defined above, is based on the variability of the response of low-level standards rather than on the variability of the blank response.

For this report, total organic carbon, total organic halides, and radionuclide field blank data are available for limit of detection and limit of quantitation determinations. The field blanks are QC samples that are introduced into a process to monitor the performance of the system. The use of field blanks to calculate the limit of detection and the limit of quantitation is preferred over the use of laboratory blanks because field blanks include error contributions from sample preparation and handling, in addition to analytical uncertainties. Methods to calculate the limit of detection and the limit of quantitation are described in detail in Appendix A of DOE/RL-91-03. The results of the limit of detection and limit of quantitation determinations are listed in Table B.23.

Because of the lack of blank data for other constituents of concern, it was necessary to calculate approximate limit of detection and limit of quantitation values by using variability information obtained from low-level standards. The data from the low-level standards are obtained from laboratory method detection limit studies. If low-level standards are used, the variability of the difference between the sample and blank response is increased by a factor of 2 (Currie 1988, p. 84). The formulas are summarized below:

where s = standard deviation from the seven replicates of the low-level standard.

The results of limit of detection, limit of quantitation, and method detection limit calculations for most non-radiological constituents of concern (besides total organic carbon and total organic halides) are listed in Table B.24.

$$\mathrm{MDL} = 3.14 \times s$$

$$\begin{aligned}\mathrm{LOD} &= 3 \times \left(\sqrt{2} \times s\right)\\ &= 4.24 \times s\end{aligned}$$

$$\begin{aligned}\mathrm{LOQ} &= 10 \times \left(\sqrt{2} \times s\right)\\ &= 14.14 \times s\end{aligned}$$

The values in the table apply to STL St. Louis only.

Specific evaluation of detection-limit issues for the interim action groundwater monitoring program was not performed for this report. Detection-limit issues are primarily assessed as part of site-specific validation activities. No validation activities were performed on interim action groundwater monitoring data in fiscal year 2002.

B.7 Conclusions

Overall, assessments of fiscal year 2002 QA/QC information indicate that groundwater monitoring data are reliable and defensible. Sampling was conducted in accordance with reviewed procedures. Few contamination or other sampling-related problems were encountered that affected data integrity. Likewise, laboratory performance was excellent in most respects, based on the large percentages of acceptable field and laboratory QC results. Satisfactory laboratory audits and generally acceptable results in nationally-based performance evaluation studies also demonstrated good laboratory performance. However, the following areas of concern were identified and should be considered when interpreting groundwater monitoring results:

- A few QC samples were probably swapped in the field or at the laboratory based on a small number of unusually high field-blank results and duplicate results with poor precision. The same problem likely occurred for a small number of groundwater samples. Mismatched results for key constituents should be identified during data review.
- Several indicator parameters, anions, metals, volatile organic compounds, and radiological parameters were detected at low levels in field and/or laboratory method blanks. The most significant contaminants were acetone, iron, methylene chloride, sulfate, total organic carbon, total organic halides, and zinc.
- Maximum recommended holding times were exceeded for ~2.5% of groundwater project samples that were analyzed by non-radiological methods. Anions were primarily affected, though the data impacts are considered minor.
- STL St. Louis had several out-of-limit blind-standard results for total organic halides. Most of the results had a low bias, suggesting that groundwater results for total organic halides may also be biased low. STL St. Louis also had performance problems with total organic carbon, and STL Richland had an out-of-limit result for gross alpha.

B.8 References

Atomic Energy Act of 1954, as amended, Ch. 1073, 68 Stat. 919, 42 USC 2011 et seq.

BHI-00038, Rev. 2. 1995. *200-ZP-1 Groundwater Sampling and Analysis Plan/Quality Assurance Plan*. K. M. Singleton, Bechtel Hanford, Inc., Richland, Washington.

Comprehensive Environmental Response, Compensation, and Liability Act. 1980. Public Law 96-510, as amended, 94 Stat. 2767, 42 USC 9601 et seq.

Currie, L. A. (ed.). 1988. "Detection in Analytical Chemistry: Importance, Theory, and Practice." *ACS Symposium Series 361*, American Chemical Society, Washington, D.C., pp. 17, 79-92.

DOE/RL-90-08. 1992. *Remedial Investigation/Feasibility Study Work Plan for the 100-BC-5 Operable Unit, Hanford Site, Richland, Washington*. U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-91-03. 1991. *Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities for 1990*. Prepared by Geosciences Group, Westinghouse Hanford Company, Environmental Division for U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-91-46. 1996. *RCRA Facility Investigation/Corrective Measures Study Work Plan for the 100-NR-2 Operable Unit Hanford Site, Richland, Washington*. U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-92-76. 1994. *Remedial Investigation/Feasibility Study Work Plan for the 200-UP-1 Groundwater Operable Unit, Hanford Site, Richland, Washington*. U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-96-07. 1996. *200-ZP-1 IRM Phase II and III Remedial Design Report*. U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-96-68, Rev. 2. 1998. HASQARD, Volumes 1 and 4. *Hanford Analytical Services Quality Assurance Requirements Documents*. U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-96-90, Draft A. 1996. *Interim Action Monitoring Plan for the 100-HR-3 and 100-KR-4 Operable Units*. Prepared by CH2M HILL Hanford, Inc. for U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-97-36, Rev. 2. 1997. *200-UP-1 Groundwater Remedial Design/Remedial Action Work Plan*. U.S. Department of Energy, Richland Operations Office, Richland, Washington.

EML-617. June 2002. *Semi-Annual Report of the Department of Energy, Office of Environmental Management, Quality Assessment Program*. P. D. Greenlaw and A. Berne, Environmental Measurements Laboratory, U.S. Department of Energy, New York.

EPA 520/1-80-012. 1980. *Upgrading Environmental Radiation Data*. *Health Physics Report HPSR-1*. J. E. Watson, Office of Radiation Programs, U.S. Environmental Protection Agency, Washington, D.C.

EPA/540/P-87/001, OSWER 9355.0-14. 1987. *A Compendium of Superfund Field Operations Methods*. U.S. Environmental Protection Agency, Washington, D.C., pp. 16-3 to 16-5.

EPA-600/4-81-004. 1981. *Environmental Radioactivity Laboratory Intercomparison Studies Program: Fiscal Year 1980-81*. A. B. Jarvis and L. Siu, U.S. Environmental Protection Agency, Las Vegas, Nevada.

Keith, L. H. 1991. *Environmental Sampling and Analysis: A Practical Guide*. Lewis Publishers, CRC Press, Inc., Boca Raton, Florida, pp. 93-115.

MAPEP-01-W9. 2002. *Water Sample MAP-00-9 Performance Report*. U.S. Department of Energy, Mixed Analyte Performance Evaluation Program, Radiological and Environmental Sciences Laboratory, Idaho Falls, Idaho.

Miller, J. C., and J. N. Miller. 1988. *Statistics for Analytical Chemistry*, Second Edition. Ellis Horwood Limited, Chichester, England, pp. 115-116.

Mitchell, W. J., R. C. Rhodes, and F. F. McElroy. 1985. "Determination of Measurement Data Quality and Establishment of Achievable Goals for Environmental Measurements." *Quality Assurance for Environmental Measurements*, ASTM STP 867.

NERL-Ci-0045. 1998. *National Standards for Water Proficiency Testing Studies Criteria Document*. U.S. Environmental Protection Agency, Washington, D.C.

OSWER-9950.1. 1986. *Resource Conservation and Recovery Act (RCRA) Groundwater Monitoring Technical Enforcement Guidance Document (TEGD)*. U.S. Environmental Protection Agency, Washington, D.C.

PNNL-13080. 1999. *Hanford Site Groundwater: Setting, Sources and Methods*. M. J. Hartman (ed.), Pacific Northwest National Laboratory, Richland, Washington.

Resource Conservation and Recovery Act. 1976. Public Law 94 580, as amended, 90 Stat 2795, 42 USC 6901 et seq.

SW-846. 1986. *Test Methods for Evaluating Solid Wastes: Physical/Chemical Methods*, 3rd ed. Office of Solid Waste and Emergency Response, U.S. Environmental Protection Agency, Washington, D.C.

Table B.1. Long-Term Monitoring Full Trip Blanks Exceeding Quality Control Limits

Constituent	Number Out of Limits	Number of Analyses	Percent Out of Limits	Range of QC Limits[(a)]	Range of Out-of-Limit Results
General Chemical Parameters					
Alkalinity	2	29	6.9	3,360 - 8,086 µg/L	104,000 - 130,000 µg/L
Total organic carbon	21	53	39.6	240 - 286 µg/L	260 - 540 µg/L
Ammonia and Anions					
Chloride	7	40	17.5	20 - 58.2 µg/L	62 - 150 µg/L
Fluoride	1	40	2.5	12 - 62 µg/L	83 µg/L
Nitrogen in nitrate	2	40	5.0	4 - 8.8 µg/L	9.3 - 50 µg/L
Sulfate	5	40	12.5	58 - 74.8 µg/L	180 - 1,400 µg/L
Metals					
Aluminum	2	35	5.7	21.6 - 83.6 µg/L	28.8 - 103 µg/L
Beryllium	3	35	8.6	0.34 - 1 µg/L	0.79 - 1.7 µg/L
Cadmium	1	35	2.9	0.4 - 5.6 µg/L	0.76 µg/L
Chromium	2	35	5.7	0.66 - 2.8 µg/L	1 - 2 µg/L
Cobalt	1	35	2.9	2.6 - 3.2 µg/L	3.3 µg/L
Copper	1	35	2.9	5.6 - 15.4 µg/L	7.6 µg/L
Iron	3	35	8.6	18.8 - 31.2 µg/L	19.6 - 73.6 µg/L
Manganese	2	35	5.7	1.8 µg/L	1.8 - 3 µg/L
Nickel	1	35	2.9	3.2 - 4.2 µg/L	7.3 µg/L
Silver	4	35	11.4	0.96 - 13.8 µg/L	1.5 - 5.3 µg/L
Sodium	9	35	25.7	166.2 - 280 µg/L	183 - 1,770 µg/L
Vanadium	3	35	8.6	3.8 - 6.8 µg/L	8.5 - 15.3 µg/L
Zinc	3	35	8.6	4.8 - 6.2 µg/L	6.3 - 13.9 µg/L
Volatile Organic Compounds					
Acetone	3	17	17.6	1.5 - 3.3 µg/L	1.8 - 4 µg/L
Carbon disulfide	1	17	5.9	0.58 - 0.86 µg/L	0.92 µg/L
Methylene chloride	6	18	33.3	1.2 - 11.9 µg/L	1.3 - 3.2 µg/L
Trichloroethene	1	19	5.3	0.32 - 0.58 µg/L	2.7 µg/L
Radiological Parameters					
Tritium	3	37	8.1	6.2 - 520 pCi/L[(b)]	14.2 - 17.9 pCi/L
Uranium	6	18	33.3	0.00082 - 0.03 µg/L[(b)]	0.00986 - 0.0653 µg/L

(a) Because method detection limits may change throughout the year, the limits are presented as a range. However, each result was evaluated according to the method detection limit in effect at the time the sample was analyzed.

(b) The limit for radiological analyses is determined by the sample-specific total propagated uncertainty.

Table B.2. Long-Term Monitoring Field Transfer Blanks Exceeding Quality Control Limits

Constituent	Number Out of Limits	Number of Analyses	Percent Out of Limits	Range of QC Limits[(a)] (µg/L)	Range of Out-of-Limit Results (µg/L)
2-Butanone	1	87	1.1	0.58 - 0.78	0.95
Acetone	16	87	18.4	1.5 - 3.3	1.6 - 14
Chloroform	1	87	1.1	0.14 - 0.42	21
cis-1,2-Dichloroethlene	1	87	1.1	0.12 - 0.48	0.9
Methylene chloride	57	87	65.5	1.2 - 1.5	1.3 - 15
Trichloroethene	1	87	1.1	0.32 - 0.58	0.72

(a) Because method detection limits may change throughout the year, the limits are presented as a range. However, each result was evaluated according to the method detection limit in effect at the time the sample was analyzed.

Table B.3. Long-Term Monitoring Equipment Blanks Exceeding Quality Control Limits

Constituent	Number Out of Limits	Number of Analyses	Percent Out of Limits	Range of QC Limits[a] (µg/L)	Range of Out-of-Limit Results (µg/L)
General Chemical Parameters					
Total organic carbon	1	1	100.0	240	330
Ammonia and Anions					
Chloride	1	5	20.0	20 - 58.2	240
Metals					
Chromium	1	3	33.3	0.66	0.98
Sodium	1	3	33.3	166.2	1,620
Zinc	1	3	33.3	6.2	7.9
Volatile Organic Compounds					
Acetone	1	2	50.0	1.5	2
Trichloroethene	1	2	50.0	0.58	2.6
Radiological Parameters					
Uranium	1	1	100.0	0.008[b]	0.0168

(a) Because method detection limits may change throughout the year, the limits are presented as a range. However, each result was evaluated according to the method detection limit in effect at the time the sample was analyzed.

(b) The limit for radiological analyses is determined by the sample-specific total propagated uncertainty.

Table B.4. Long-Term Monitoring Field Duplicates Exceeding Quality Control Limits

Constituent	Total Number of Duplicates	Number of Duplicates Evaluated[(a)]	Number Out of Limits	Percent Out of Limits	Range of Relative Percent Differences[(b)]
General Chemical Parameters					
Bromide	3	1	1	100.0	147.4
Chloride	53	53	1	1.9	41.6
Fluoride	53	53	5	9.4	23.0 - 173.8
Nitrogen in nitrate	53	52	3	5.8	24.4 - 83.2
Nitrogen in nitrite	53	2	1	50.0	35.7
Sulfate	65	65	1	1.5	24.5
Beryllium	53	1	1	100.0	23.4
Cadmium	67	1	1	100.0	156.9
Chromium	67	37	4	10.8	22.2 - 37.0
Copper	53	4	4	100.0	91.4 - 165.9
Hexavalent chromium	8	7	1	14.3	189.5
Iron	53	14	7	50.0	26.0 - 143.1
Lead	19	1	1	100.0	50.5
Manganese	53	15	2	13.3	23.3 - 181.7
Potassium	53	25	4	16.0	21.5 - 119.7
Zinc	53	17	6	35.3	26.7 - 158.2
Acetone	23	5	5	100.0	28.6 - 161.1
Carbon tetrachloride	24	6	1	16.7	32.1
Gross alpha	27	4	1	25.0	32.7
Gross beta	30	19	4	21.1	20.9 - 32.1
Iodine-129	14	5	1	20.0	20.5
Technetium-99	27	20	3	15.0	21.6 - 31.6
Tritium	40	29	3	10.3	21.1 - 115.6
Uranium	19	18	1	5.6	22.6
Uranium-235	2	1	1	100.0	48.3

(a) Duplicates with both results less than five times the method detection limit or minimum detectable activity were excluded from the evaluation.

(b) In cases where a non-detected result was compared with a measured value, the method detection limit or minimum detectable activity was used for the non-detected concentration.

Table B.5. Interim Action Monitoring Field Blank Detections

Constituent	Number of Detects	Number of Analyses	Percent Out of Limits	RDL[a] (µg/L)	Range of Detected Results (µg/L)
General Chemical Parameters					
Alkalinity	1	1	100.0	5,000	1,300
Oil and grease	1	1	100.0	2,000	980
Ammonia and Anions					
Chloride	5	10	50.0	200	280 - 350
Metals					
Aluminum	7	14	50.0	200	20 - 107
Barium	9	18	50.0	200	0.19 - 0.47
Beryllium	5	14	35.7	5	0.11 - 0.38
Cadmium	1	14	7.1	5	5.8
Calcium	9	14	64.3	5,000	9.7 - 55
Cobalt	1	14	7.1	50	0.81
Copper	2	14	14.3	25	12.6 - 2.1
Chromium	1	18	5.6	10	5.4
Hexavalent chromium	2	8	25.0	10	5 - 49
Iron	5	14	35.7	100	9.7 - 32
Magnesium	7	14	50.0	5,000	8.1 - 25
Manganese	3	14	21.4	15	0.21 - 0.78
Potassium	4	14	28.6	5,000	19 - 100
Sodium	13	14	92.9	5,000	34 - 139
Strontium	7	14	50.0	50	0.14 - 0.26
Tin	2	4	50.0	100	4.3
Vanadium	1	18	5.6	50	0.72
Zinc	11	18	61.1	20	0.4 - 7.9
Volatile Organic Compounds					
Acetone	5	17	29.4	20	3 - 6.6
Methylene chloride	16	17	94.1	5	2 - 23
Toluene	1	17	5.9	5	0.56
Total petroleum hydrocarbons	1	1	100.0	500	2,599
Radiological Parameters					
Uranium	1	2	50.0	1	0.033

(a) Contractually defined required detection limit.

Table B.6. Interim Action Monitoring Field Duplicates Exceeding Quality Control Limits

Constituent	Total Number of Duplicates	Number of Duplicates Evaluated[(a)]	Number Out of Limits	Percent Out of Limits	Range of Relative Percent Differences
		Ammonia and Anions			
Phosphate	12	1	1	100.0	23
		Metals			
Aluminum	16	5	2	40.0	37 - 89
Iron	16	9	3	33.3	57 - 102
Manganese	16	10	1	10.0	64
Zinc	18	14	5	35.7	26 - 135
		Radiological Parameters			
Uranium	8	8	1	12.5	23

(a) Duplicates with both results less than five times the method detection limit or minimum detectable activity were excluded from the evaluation.

Table B.7. Interim Action Monitoring Interlaboratory Splits Exceeding Quality Control Limits

Constituent	Total Number of Splits	Number of Splits Evaluated[(a)]	Number Out of Limits	Percent Out of Limits	Range of Relative Percent Differences
		Metals			
Aluminum	11	4	3	75.0	30 - 135
Chromium	11	9	1	11.1	22
Iron	11	4	3	75.0	21 - 115
Nickel	11	2	1	50.0	167
Manganese	11	3	1	33.3	24
Potassium	11	11	5	45.5	22 - 53
Strontium	11	33	3	9.1	21 - 24
Vanadium	11	6	3	50.0	79 - 171
Zinc	11	5	3	60.0	32 - 69
		Radiological Parameters			
Carbon-14	1	1	1	100.0	65
Technetium-99	3	3	1	33.3	24
		Fixed Laboratory-Field Analyses			
Hexavalent chromium	40	33	2	6.1	25 - 52
Carbon tetrachloride	7	6	2	33.3	23 - 24
Chlorform	7	2	1	50.0	33

(a) Split sample pairs with both results less than five times the method detection limit or minimum detectable activity were excluded from the evaluation.

Table B.8. Hanford Groundwater Monitoring Project Maximum Recommended Holding Times

Method	Constituent	Holding Time
8010/8020/8260 (SW-846)	Volatile organics	14 days
8270 (SW-846)	Semivolatile organics	7 days before extraction; 40 days after extraction
8080 (SW-846)	Pesticides	7 days before extraction; 40 days after extraction
8080 (SW-846)	Polychlorinated biphenyls	7 days before extraction; 40 days after extraction
8040 (SW-846)	Phenols	7 days before extraction; 40 days after extraction
6010 (SW-846)	Inductively coupled plasma metals	6 months
7060 (SW-846)	Arsenic	6 months
7421 (SW-846)	Lead	6 months
7470 (SW-846)	Mercury	28 days
7740 (SW-846)	Selenium	6 months
7841 (SW-846)	Thallium	6 months
9012 (SW-846)	Cyanide	14 days
9020 (SW-846)	Total organic halides	28 days
9060 (SW-846)	Total organic carbon	28 days
9131 (SW-846)	Coliform	1 day
120.1 (EPA-600/4-81-004	Conductivity	28 days
160.1 (EPA-600/4-81-004)	Total dissolved solids	7 days
300.0 (EPA-600/4-81-004)	Bromide	28 days
300.0 (EPA-600/4-81-004)	Chloride	28 days
300.0 (EPA-600/4-81-004)	Fluoride	28 days
300.0 (EPA-600/4-81-004)	Nitrate	48 hours
300.0 (EPA-600/4-81-004)	Nitrite	48 hours
300.0 (EPA-600/4-81-004)	Phosphate	48 hours
300.0 (EPA-600/4-81-004)	Sulfate	28 days
310.1 (EPA-600/4-81-004)	Alkalinity	14 days
410.4 (EPA-600/4-81-004)	Chemical oxygen demand	28 days

Table B.9. Summary of Severn Trent-St. Louis Water Pollution Performance Evaluation Studies

Accreditation Laboratory	NY ELAP 242 April 2001 Acceptable Results/ Total	NY ELAP 247 October 2001 Acceptable Results/ Total	NY ELAP 250 January 2002 Acceptable Results/ Total	WP-90 September 2002 Acceptable Results/ Total
New York Environmental Laboratory Approval Program	63/67[a]	81/87[b]	149/158[c]	
Environmental Resource Associates				215/239[d]

(a) Unacceptable results were for calcium (hardness), iron, silver, and m-xylene.
(b) Unacceptable results were for calcium hardness, cyanide, iron, thallium, zinc, and *cis*-1,2-dichloroethene.
(c) Unacceptable results were for pH, cyanide, orthophosphate (as P), total phosphorus, aluminum, mercury, selenium, zinc, and PCB 1221.
(d) Unacceptable results were for alkalinity, settleable solids, calcium hardness, chloride, cyanide, orthophosphate (as P), sulfide, cobalt, magnesium, manganese, potassium, sodium, α-BHC, 4,4'-DDT, heptachlor, heptachlor epoxide, 4-chloro-3-methylphenol, 2,4-dichlorophenol, 4,6-dinitro-2-methylphenol, 2-nitrophenol, pentachlorophenol, 2,4,5-trichlorophenol, total phenolics, and grease and oil.

Table B.10. Summary of Lionville Laboratory Water Pollution (WP) and Water Supply (WS) Performance Evaluation Studies

Water Pollution Studies[a]	Date	Acceptable Results/Total	Water Supply Studies[a]	Date	Acceptable Results/Total
WP-72	March 2001	191/194[b]	WS-56	May 2001	5/7[c]
WP-73	April 2001	1/1	WS-57	June 2001	11/11
WP-74	May 2001	2/2	WS-63	January 2002	2/2
WP-75	June 2001	124/129[d]	WS-72	September 2002	134/136[e]
WP-78	September 2001	273/285[f]	WS02-1	April 2002	5/5
WP-80	November 2001	8/12[g]	WSJan02	January 2002	181/192[h]
WP-81	December 2001	14/15[i]			
WP-84	April 2002	222/225[j]			
WP-90	September 2002	218/219[k]			

(a) Environmental Resources Associates is the accreditation laboratory for all the water pollution and water supply studies except WS02-1 (RTC Laboratory Proficiency Testing Program) and WSJan02 (Analytical Products Group Proficiency Testing Program).
(b) Unacceptable results were for ammonia (as N), total residual chlorine, and 2,4,5-T.
(c) Unacceptable results were for 2,4-DB and dichlorodifluoromethane.
(d) Unacceptable results were for sulfide, 1,1,1-trichloroethane, and phenanthrene.
(e) Unacceptable results were for chloride and ortophosphate (as P).
(f) Unacceptable results were for 1,2-dichlorobenzene, 1,3-dichlorobenzene, 1,4-dichlorobenzene, 1,2,4-trichlorobenzene, hexachlorobutadiene, methylene chloride, fluoranthene, pyrene, Aroclor 1016/1242, and Aroclor 1254.
(g) Unacceptable results were for Aroclor 1232 and Aroclor 1260.
(h) Unacceptable results were for conductivity, calcium hardness, 1,4-dichlorobenzene, 1,1,2,2-tetrachloroethane, bromoform, chlorobenzene, MTBE, sec-butylbenzene, tert-butylbenzene, vinyl chloride, and 2,4,5-TP.
(i) Unacceptable result was for sulfide.
(j) Unacceptable results were for CBOD, bis(2-chloroethoxy)methane, and total petroleum hydrocarbons.
(k) Unacceptable result was for methylene chloride.

Table B.11. Summary of Severn Trent Interlaboratory Performance, Fiscal Year 2002

Radionuclides	Number of Results Reported for Each	Number Within Acceptable Control Limits
DOE Quality Assessment Program (QAP56) Environmental Measurements Laboratory		
Americium-241, cesium-137, cobalt-60, gross alpha, gross beta, plutonium-238, plutonium-239, strontium-90, tritium, uranium	1	1[a,b]
Cesium-134	1	0[a]
DOE Mixed Analyte Performance Evaluation Program (MAPEP-01-W9) Radiological and Environmental Sciences Laboratory		
Americium-241, cesium-134, cesium-137, cobalt-57, cobalt-60, manganese-54, nickel-63, plutonium-239/240, strontium-90, uranium-234/233, uranium-238, zinc-65	1	1[c]
Plutonium-238	1	0[c]
Antimony, arsenic, barium, beryllium, cadmium, chromium, copper, lead, nickel, selenium, silver, thallium, vanadium, zinc; 1,3-dichlorobenzene, hexachloroethane, nitrobenzene, 2,4-dimethylphenol, 2-4-dichlorophenol, 1,2,4-trichlorobenzene, naphthalene, hexachlorobutadiene, 2,6-dichlorophenol,2,6-dinitrotoluene, hexachlorobenzene, anthracene, 1,2-dinitrobenzene, pentachlorobenzene, fluoranthene, pyrene, benzo(a)anthracene	1	1[d,e]
ERA InterLaB RadCheM Proficiency Testing Program Environmental Resource Associates		
Cesium-137, cobalt-60, gross alpha	5	5[f,g]
Cesium-134, gross beta	5	4[f,g]
Radium-226, radium-228, strontium-89 strontium-90, uranium	4	4[f,g]
Barium-133, zinc-65	3	3[f,g]
Iodine-131, tritium	1	1[f,g]

(a) Control limits from EML-617.
(b) One result each for americium-241 and total uranium was acceptable but outside warning limits.
(c) Results from STL Richland.
(d) Results from STL St. Louis.
(e) One result for 1,2-dinitrobenzene was acceptable but outside warning limits.
(f) Control limits from National Standards for Water Proficiency Testing Studies Criteria Document.
(g) Two results for uranium and one result each for barium-133, cesium-134, gross alpha, and tritium were acceptable but outside warning limits.

Table B.12. Summary of Eberline Services and Lionville Laboratory Interlaboratory Performance, Fiscal Year 2002

Radionuclides	Number of Results Reported for Each	Number Within Acceptable Control Limits
DOE Quality Assessment Program (QAP56) Environmental Measurements Laboratory		
Americium-241, cesium-134, cesium-137, cobalt-60, gross alpha, gross beta, plutonium-238, plutonium-239, strontium-90, tritium, uranium-234, uranium-238, uranium	1	1[(a,b)]
DOE Mixed Analyte Performance Evaluation Program (MAPEP-01-W9) Radiological and Environmental Sciences Laboratory		
Americium-241, cesium-134, cesium-137, cobalt-57, cobalt-60, iron-55, manganese-54, nickel-63, plutoniuim-238, plutonium-239/240, strontium-90, uranium-234/233, uranium-238, zinc-65	1	1[(c)]
Antimony, arsenic, barium, beryllium, cadmium, chromium, copper, lead, nickel, selenium, silver, thallium, vanadium, zinc; 1,3-dichlorobenzene, hexachloroethane, nitrobenzene, 2,4-dimethylphenol, 2,4-dichlorophenol, 1,2,4-trichlorobenzene, naphthalene, hexachlorobutadiene, 2,6-dichlorophenol, 2,6-dinitrotoluene, 2,4-dinitrotoluene, diethylphthalate, hexachlorobenzene, anthracene, pentachlorobenzene, fluoranthene, pyrene, benzo(a)anthracene	1	1[(d)]

(a) Results from Eberline Services. Control limits from EML-617.
(b) One result for uranium was acceptable but outside warning limits.
(c) Results from Eberline Services.
(d) Results from Lionville Laboratory.

Table B.13. Summary of Severn Trent Laboratories Double-Blind Spike Determinations

Constituent	Laboratory	Sample Frequency	Number of Results Reported[a]	Number of Results Outside QC Limits[b]	Control Limits[c] (%)
General Chemical Parameters					
Specific conductance	St. Louis	Quarterly	12	0	±25
Total organic carbon (potassium hydrogen phthalate spike)	St. Louis	Quarterly	15	1	±25
Total organic halides (2,4,6-trichlorophenol spike)	St. Louis	Quarterly	14	1	±25
Total organic halides (carbon tetrachloride, chloroform, and trichloroethene spike)	St. Louis	Quarterly	14	6	±25
Anions					
Cyanide	St. Louis	Quarterly	13	0	±25
Fluoride	St. Louis	Quarterly	12	3	±25
Nitrogen in nitrate	St. Louis	Quarterly	12	0	±25
Metals					
Antimony	St. Louis	Annually	3	0	±25
Cadmium	St. Louis	Annually	3	0	±25
Chromium	St. Louis	Annually	3	0	±20
Volatile Organic Compounds					
Carbon tetrachloride	St. Louis	Quarterly	12	0	±25
Chloroform	St. Louis	Quarterly	12	0	±25
Trichloroethene	St. Louis	Quarterly	12	0	±25
Radiological Parameters					
Gross alpha (plutonium-239 spike)	Richland	Quarterly	12	1	±25
Gross beta (strontium-90 spike)	Richland	Quarterly	12	0	±25
Cesium-137	Richland	Annually	3	0	±30
Cobalt-60	Richland	Annually	3	0	±30
Iodine-129	Richland	Semiannually	6	0	±30
Plutonium-239	Richland	Quarterly	12	0	±30
Strontium-90	Richland	Semiannually	6	0	±30
Technetium-99	Richland	Quarterly	12	0	±30
Tritium	Richland	Quarterly	9	0	±30
Uranium-238	Richland	Quarterly	12	0	±30

(a) Blind standards were generally submitted in triplicate or quadruplicate. Tritium standards were not submitted to the laboratory during the third quarter.

(b) Quality control limits are given in the Hanford Groundwater Monitoring Project's QA plan.

(c) Each result must be within the specified percentage of the known value to be acceptable.

QA = Quality assurance.

QC = Quality control.

Table B.14. Summary of Lionville Laboratory, Inc. and Eberline Services Double-Blind Spike Determinations

Constituent	Sample Frequency	Number of Results Reported[a]	Number of Results Outside QC Limits[b]	Control Limits[c] (%)
		General Chemical Parameters		
Total organic carbon (potassium hydrogen phthalate spike)	Quarterly	14	0	±25
		Radiological Parameters		
Gross beta (strontium-90 spike)	Quarterly	12	0	±25

(a) Blind standards were submitted in triplicate or quadruplicate.
(b) Quality control limits are given in the Hanford Groundwater Monitoring Project's QA plan.
(c) Each result must be within the specified percentage of the known value to be acceptable.
QA = Quality assurance.
QC = Quality control.

Table B.15. Double-Blind Standard Results, Severn Trent Laboratories (Richland and St. Louis)

Constituent	Laboratory	Fiscal Year Quarter	Spike Amount	Average Result	Average Recovery (%)	Relative Standard Deviation (%)
General Chemical Parameters (µg/L)						
Specific conductance	St. Louis	First	445	397	89	3
	St. Louis	Second	445	411	92	1
	St. Louis	Third	445	435	98	1
	St. Louis	Fourth	445	424	95	0
Total organic carbon[a]	St. Louis	First	2,500	2,767	111	2
	St. Louis	Second	1,010	1,175	116	8
	St. Louis	Third	1,500	1,700	113	0
	St. Louis	Fourth	2,010	1,875	93	8
Total organic halides[b] (phenol)	St. Louis	First	101	89.3	88	12
	St. Louis	Second	897	852	95	3
	St. Louis	Third	13.3	13.8	103	13
	St. Louis	Fourth	45	50.4	112	4
Total organic halides[c] (volatile organic mixture)	St. Louis	First	111	76.7	69	20
	St. Louis	Second	870	605	705	11
	St. Louis	Third	14	13	93	8
	St. Louis	Fourth	45	36.6	81	16
Ammonia and Anions (µg/L)						
Cyanide	St. Louis	First	101	80.9	80	5
	St. Louis	Second	205	176	86	6
	St. Louis	Third	300	282	94	10
	St. Louis	Fourth	52	50.2	97	10
Fluoride	St. Louis	First	1,000	1,200	120	0
	St. Louis	Second	500	727	145	2
	St. Louis	Third	3,000	3,067	102	2
	St. Louis	Fourth	2,000	1,867	93	3
Nitrogen in nitrate	St. Louis	First	22,590	19,500	86	2
	St. Louis	Second	4,518	4,800	106	0
	St. Louis	Third	45,180	40,970	91	1
	St. Louis	Fourth	45,180	52,270	116	2
Metals (µg/L)						
Antimony	St. Louis	Second	100.3	105	104	1
Cadmium	St. Louis	Second	5.02	4.30	86	2
Chromium	St. Louis	Second	200	208	104	0
Volatile Organic Compounds (µg/L)						
Carbon tetrachloride	St. Louis	First	7	7.03	100	4
	St. Louis	Second	520	460	88	4
	St. Louis	Third	5	4.6	92	6
	St. Louis	Fourth	20	18	90	6
Chloroform	St. Louis	First	110	110	100	0
	St. Louis	Second	230	240	104	0
	St. Louis	Third	5	5.03	101	3
	St. Louis	Fourth	20	18.7	93	3
Trichloroethene	St. Louis	First	7	7.00	100	4
	St. Louis	Second	220	237	108	5
	St. Louis	Third	5.7	5.2	91	3
	St. Louis	Fourth	10	8.87	89	3

Table B.15. (contd)

Constituent	Laboratory	Fiscal Year Quarter	Spike Amount	Average Result	Average Recovery (%)	Relative Standard Deviation (%)
Radiochemical Parameters (pCi/L)						
Cesium-137	Richland	Third	214.2	205	96	1
Cobalt-60	Richland	Third	50.66	59.7	118	4
Gross alpha	Richland	First	20.45	23.5	115	0
	Richland	Second	268.98	269	100	8
	Richland	Third	262.08	208	79	5
	Richland	Fourth	99.18	74.8	75	16
Gross beta[d]	Richland	First	38.41	40.1	104	4
	Richland	Second	30.125	33.1	110	1
	Richland	Third	29.565	28.3	96	4
	Richland	Fourth	116.3275	119	102	2
Iodine-129	Richland	First	30.5	31.7	104	5
	Richland	Third	10.5	10.7	102	6
Plutonium-239	Richland	First	20.45	21.6	106	10
	Richland	Second	1.69	1.45	86	10
	Richland	Third	7.06	7.02	100	8
	Richland	Fourth	2.01	1.86	92	11
Strontium-90	Richland	Second	20.3	21.3	105	1
	Richland	Fourth	98.48	113	115	2
Technetium-99	Richland	First	462.3	463	100	2
	Richland	Second	1,031.8	976	95	2
	Richland	Third	197.1	178	90	17
	Richland	Fourth	101.4	110	109	1
Tritium	Richland	First	20,692.1	20,000	97	2
	Richland	Second	262.5	280	107	2
	Richland	Fourth	261.5	197	75	1
Uranium-238	Richland	First	62.64	67.5	108	1
	Richland	Second	149.91	152	101	5
	Richland	Third	464	452	98	6
	Richland	Fourth	146	144	99	3

(a) Total organic carbon standards were submitted in quadruplicate each quarter.

(b) Total organic halide (phenol) standards were submitted in quadruplicate during the second and third quarters. The standards were submitted in triplicate in the first and fourth quarters.

(c) Total organic halide (volatile) standards were submitted in quadruplicate during the first and fourth quarters. The standards were submitted in triplicate in the second and third quarters.

(d) Assuming strontium-90 and yttrium-90 are in equilibrium, spike amount is strontium-90 + yttrium-90.

Table B.16. Double-Blind Standard Results, Lionville Laboratory and Eberline Services

Constituent	Laboratory	Fiscal Year Quarter	Spike Amount	Average Result	Average Recovery (%)	Relative Standard Deviation (%)
		General Chemical Parameters (µg/L)				
Total organic carbon[a]	Lionville	First	2,500	2,900	116	9
	Lionville	Second	1,010	1,100	109	0
	Lionville	Third	1,500	1,725	115	3
	Lionville	Fourth	2,010	2,150	107	5
		Radiological Parameters (pCi/L)				
Gross beta[b]	Eberline	First	38.41	40.2	105	7
	Eberline	Second	30.125	31.3	104	8
	Eberline	Third	60.01	70.3	117	1
	Eberline	Fourth	116.3275	127	109	7

(a) Total organic carbon standards were submitted in quadruplicate each quarter.

(b) Assuming strontium-90 and yttrium-90 are in equilibrium, spike amount is strontium-90 + yttrium-90.

Table B.17. Percentage of Out-of-Limit Quality Control Results by Category, Severn Trent Laboratories (Richland and St. Louis)

Quality Control Parameter	General Chemistry Parameters	Ammonia and Anions	Metals	Volatile Organic Compounds	Semivolatile Organic Compounds	Radiological Parameters	Total
Method blanks	3.2	8.7	8.2	1.3	0	1.1	4.2
Laboratory control samples	0	0	0	3.8	0.7	0.8	0.9
Matrix spikes	2.8	2.6	0.4	3.4	6.8	2.7	2.1
Matrix duplicates	0.5	0.6	0.1	2.1	1.5	1.5	0.8
Surrogates	--	--	--	2.3	3.9	--	2.6

Table B.18. Method Blank Results, Severn Trent Laboratories (Richland and St. Louis)

Constituent	Percent Out of Limit[a]	Number of Analyses	Concentration Range of Out-of-Limit Results
General Chemistry Parameters			
Total General Chemistry Parameters	3.2	371	--
Conductivity	47.4[b]	19	0.31 - 0.97 µS/cm
Total organic carbon	3.3[b]	91	0.36 - 0.7 mg/L
Ammonia and Anions			
Total Ammonia and Anions	8.7	952	--
Chloride	25.7[b]	175	0.028 - 0.14 mg/L
Fluoride	5.1[b]	175	0.071 - 0.099 mg/L
Nitrogen in ammonia	7.1	14	41.6 µg/L
Nitrogen in nitrate	3.4[b]	174	0.012 - 0.039 mg/L
Sulfate	13.1[b]	175	0.09 - 0.39 mg/L
Metals			
Total Metals	8.2	1,686	--
Aluminum	32.9[b]	85	41.7 - 437 µg/L
Barium	1.2	86	0.05 µg/L
Beryllium	20.0[b]	85	0.39 - 2.6 µg/L
Cadmium	10.0[b]	90	0.63 - 2.3 µg/L
Calcium	9.5	84	168 - 418 µg/L
Chromium	2.2[b]	90	2.6 - 2.8 µg/L
Copper	11.6[b]	86	3.6 - 13.1 µg/L
Iron	17.6[b]	85	31.8 - 278 µg/L
Magnesium	9.4[b]	85	136 - 637 µg/L
Manganese	8.2[b]	85	1.2 - 2.7 µg/L
Nickel	3.5[b]	86	3.6 - 9.3 µg/L
Potassium	1.2	84	1,970 µg/L
Sodium	15.5[b]	84	224 - 1,290 µg/L
Strontium	1.2	85	2.3 µg/L
Vanadium	3.5	85	4.5 - 16.5 µg/L
Zinc	14.1[b]	85	2.8 - 8.7 µg/L
Volatile Organic Compounds			
Total Volatile Organic Compounds	1.3	1,833	--
1,2-dichloroethane	2.7[b]	75	0.75 - 0.83 µg/L
Acetone[c]	12.5[b]	72	1.6 - 12 µg/L
Chloroform	2.6	77	0.54 - 0.55 µg/L
Methylene chloride[c]	13.5[b]	74	1.4 - 3.6 µg/L
Semivolatile Organic Compounds			
Total Semivolatile Organic Compounds	0.0	588	--
Radiochemistry Parameters			
Total Radiochemistry Parameters	1.1	942	--
Tritium	4.0[b]	149	12.7 - 25.3 pCi/L
Uranium	7.5[b]	53	0.0198 - 0.294 pCi/L

(a) Quality control limits are twice the method detection limit.
(b) One or more results were "significantly out of limits" as defined in the text.
(c) Quality control limits are five times the method detection limit.

Table B.19. Laboratory Control Samples, Severn Trent Laboratories (Richland and St. Louis)

Constituent	Percent Out of Limit	Number of Analyses
General Chemistry Parameters		
Total General Chemical Parameters	0.0	369
Ammonia and Anions		
Total Ammonia and Anions	0.0	951
Metals		
Total Metals	0.0	1,661
Volatile Organic Compounds		
Total Volatile Organic Compounds	3.8	860
1,1,1-trichloroethane	2.9	35
2-butanone	17.1[a]	35
4-methyl-2-pentanone	11.4[a]	35
Acetone	25.7[a]	35
Benzene	1.2[a]	82
Carbon tetrachloride	5.3	38
Chloromethane	20.0[a]	5
Methylene chloride	5.7	35
Toluene	1.2[a]	82
trans-1,3-dichloropropene	20.0	5
Trichloroethene	1.2[a]	81
Vinyl chloride	10.8[a]	37
Semivolatile Organic Compounds		
Total Semivolatile Organic Compounds	0.7	446
Aroclor-1016	14.3[a]	7
Aroclor-1260	14.3[a]	7
Oil and grease	20.0[a]	5
Radiochemistry Parameters		
Total Radiochemical Parameters	0.8	652
Cobalt-60	2.2	46
Tritium	1.4	146
Uranium	1.8[a]	56
Uranium-235	12.5[a]	8

(a) One or more results were “significantly out of limits” as defined in the text.

Table B.20. Matrix Spikes and Matrix Spike Duplicates, Severn Trent Laboratories (Richland and St. Louis)

Constituent	Percent Out of Limit	Number of Analyses
General Chemistry Parameters		
Total General Chemistry Parameters	2.8	145
Total organic carbon	1.3	78
Total organic halides	4.5(a)	66
Ammonia and Anions		
Total Ammonia and Anions	2.6	352
Bromide	9.1	11
Chloride	1.7	58
Cyanide	14.8(a)	27
Nitrogen in nitrate	3.4	58
Nitrogen in nitrite	1.7	58
Metals		
Total Metals	0.4	3,159
Cadmium	1.2(a)	170
Copper	0.6(a)	158
Lead	12.3(a)	57
Silver	1.9(a)	158
Sodium	0.6(a)	158
Volatile Organic Compounds		
Total Volatile Organic Compounds	3.4	841
1,1,2-Trichloroethane	3.1	32
1,1-Dichloroethene	3.1	32
1,2-Dichloroethane	2.8	36
1,2-Dichloropropane	50.0	2
2-Butanone	3.1	32
4-Methyl-2-pentanone	3.1	32
Benzene	2.0	101
Bromoform	50.0	2
Carbon tetrachloride	5.6(a)	36
Chloroform	2.6	38
cis-1,3-Dichloropropene	50.0	2
Ethylbenzene	10.0(a)	10
Methylene chloride	31.3(a)	32
Vinyl chloride	13.9(a)	36
Semivolatile Organic Compounds		
Total Semivolatile Organic Compounds	6.8	777
2,4,5-Trichlorophenol	7.1(a)	42
2,4,6-Trichlorophenol	7.1(a)	42
2,4-Dichlorophenol	6.8(a)	44
2,4-Dimethylphenol	7.1(a)	42
2,4-Dinitrophenol	9.5(a)	42
2,6-Dichlorophenol	7.1(a)	42
2-Chlorophenol	7.0(a)	43
2-Methylphenol	6.8(a)	44
2-Nitrophenol	7.0(a)	43
2-secButyl-4,6-dinitrophenol	7.1(a)	42
3-+4-Methylphenol	7.1(a)	42
4,6-Dinitro-2-methylphenol	7.1(a)	42
4-Chloro-3-methylphenol	6.8(a)	44
4-Nitrophenol	6.8(a)	44
Aroclor-1016	12.5(a)	8
Aroclor-1260	25.0(a)	8
Pentachlorophenol	6.5(a)	46
Phenol	4.4	45
TPH diesel	20.0	10
Radiochemistry Parameters		
Total Radiochemistry Parameters	2.7	111
Uranium	5.9(a)	51

(a) One or more results were “significantly out of limits” as defined in the text.

Table B.21. Matrix Duplicates, Severn Trent Laboratories (Richland and St. Louis)

Constituent	Percent Out of Limit	Number of Analyses
General Chemistry Parameters		
Total General Chemistry Parameters	0.5	367
Alkalinity	1.1[a]	88
Total organic carbon	0.6[a]	165
Ammonia and Anions		
Total Ammonia and Anions	0.6	1,260
Chloride	0.4[a]	231
Fluoride	0.9	231
Nitrogen in nitrate	1.3[a]	230
Nitrogen in nitrite	0.4	231
Sulfate	0.4	237
Metals		
Total Metals	0.1	1,598
Copper	1.3[a]	79
Lead	3.6	28
Volatile Organic Compounds		
Total Volatile Organic Compounds	2.1	474
2-Butanone	5.3[a]	19
4-Methyl-2-pentanone	10.5[a]	19
Acetone	10.5	19
Bromomethane	100.0[a]	1
Methylene chloride	10.5	19
Toulene	1.9	54
Trichloroethene	1.9	53
Semivolatile Organic Compounds		
Total Semivolatile Organic Compounds	1.5	459
2-Methylphenol	4.0	25
2-Nitrophenol	4.0	25
4-Methylphenol	100.0	1
4-Nitrophenol	4.0[a]	25
Oil and grease	22.2[a]	9
Phenol	3.8[a]	26
Radiochemistry Parameters		
Total Radiochemistry Parameters	1.5	853
Gross alpha	5.4[a]	56
Gross beta	1.7	59
Iodine-129	6.7[a]	45
Technetium-99	1.7	60
Uranium	2.0	51
Uranium-234	12.5	8
Uranium-235	12.5[a]	8
Uranium-238	25.0[a]	8

(a) One or more results were “significantly out of limits” as defined in the text.

Table B.22. Summary of Issue Resolution Forms Received from Severn Trent Laboratories (Richland and St. Louis) for Fiscal Year 2002

Issue Category	Number of Occurrences Prior to Receipt at the Laboratory	After Receipt at the Laboratory
Hold time missed	190	90
Broken bottles	9	
Missing samples	0	
Temperature deviation	16	
pH variance	38	
Bottle size/type (insufficient volume)	16	
Chain of custody forms incomplete	18	
Laboratory QC out of limits		103
Analytical preparation deviations		7
Method failures/discontinued analyses		12

Table B.23. Summary of Analytical Laboratory Detection/Quantitation Limits Determined from Field Blanks Data, Severn Trent Laboratories (Richland and St. Louis)

Period(a)	Number of Samples	Mean	Standard Deviation	Limit of Detection	Limit of Quantitation
Constituent: Total Organic Carbon (µg/L)					
02/13/01 - 11/08/01	25(b)	273.87	125.85	380(c)	1,260(c)
05/08/01 - 02/13/02	33(b)	276.89	120.18	360	1,200
07/16/01 - 05/06/02	41(b)	264.82	113.85	340	1,140
08/22/01 - 09/13/02	49(b)	221.45	108.64	330	1,090
Summary	49(b)	221.45	108.64	330	1,090
Constituent: Total Organic Halides (µg/L)					
02/13/01 - 11/08/01	31	0.88	1.81	5.4(c)	18.1(c)
05/08/01 - 02/12/02	36(b)	0.83	1.70	5.1	17.0
07/16/01 - 05/06/02	40(b)	0.83	1.63	4.9	16.3
08/22/01 - 09/13/02	47(b)	0.77	1.61	4.8	16.1
Summary	47(b)	0.77	1.61	4.8	16.1
Constituent: Antimony-125 (pCi/L)					
11/08/01 - 06/05/02	9	0.52	2.94	8.81(c)	29.36(c)
Constituent: Cesium-134 (pCi/L)					
11/08/01 - 06/05/02	9	0.26	0.38	1.13(c)	3.77(c)
Constituent: Cesium-137 (pCi/L)					
11/08/01 - 06/05/02	9	0.28	1.44	4.31(c)	14.36(c)
Constituent: Cobalt-60 (pCi/L)					
11/08/01 - 06/05/02	9	-0.09	1.42	4.27(c)	14.23(c)
Constituent: Europium-154 (pCi/L)					
11/08/01 - 06/05/02	9	-0.3	2.6	7.81(c)	26.02(c)
Constituent: Gross Alpha (pCi/L)					
10/05/01 - 12/10/01	7	0.21	0.49	1.46(c)	4.88(c)
01/02/02 - 03/20/02	5	0.03	0.10	0.30	0.99
04/04/02 - 09/27/02	8	0.03	0.17	0.51	1.69
Summary	20	0.09	0.31	0.94	3.13
Constituent: Gross Beta (pCi/L)					
10/05/01 - 12/10/01	10	0.62	0.52	1.57(c)	5.25(c)
01/02/02 - 03/20/02	6	0.96	0.51	1.52	5.08
04/04/02 - 09/27/02	11	0.91	1.22	3.67	12.22
Summary	27	0.81	0.88	2.65	8.83
Constituent: Iodine-129 (pCi/L)					
10/05/01 - 09/27/02	10	0.00	0.09	0.26(c)	0.85(c)
Constituent: Potassium-40 (pCi/L)					
11/08/01 - 06/05/02	9	-23	21	63(c)	210(c)
Constituent: Ruthenium-106 (pCi/L)					
11/08/01 - 06/05/02	9	-1.7	11.76	35.3(c)	117.6(c)
Constituent: Strontium-90 (pCi/L)					
10/10/01 - 04/04/02	8	0.05	0.13	0.38(c)	1.28(c)

Table B.23. (contd)

Period	Number of Samples	Mean	Standard Deviation	Limit of Detection	Limit of Quantitation
		Constituent: Technetium-99 (pCi/L)			
10/05/01 - 12/10/01	9	1.38	3.16	9.5(c)	31.6(c)
01/02/02 - 03/20/02	6	3.53	3.52	10.6	35.2
05/03/02 - 06/11/02	5	1.62	2.23	6.7	22.3
07/31/02 - 09/19/02	5	2.05	3.21	9.6	32.1
Summary	25	2.01	3.11	9.3	31.1
		Constituent: Tritium (pCi/L)			
10/05/01 - 12/18/01	13	52.3	151.3	454(c)	1,513(b)
01/02/02 - 03/26/02	10	61.1	86.8	260	868
04/04/02 - 06/11/02	6	139.8	80.1	240	801
08/07/02 - 09/27/02	5	53.8	104.7	314	1,047
Summary	34	70.5	118.1	354	1,181
		Constituent: Tritium – Low-Level Method (pCi/L)			
12/12/01 - 09/27/02	6	10.9	6.5	19(c)	65(c)
		Constituent: Uranium (µg/L)			
10/05/01 - 12/18/01	7	0.0269	0.0269	0.108(d)	0.296(d)
01/02/02 - 03/18/02	4	0.0136	0.0174	0.066	0.188
04/11/02 - 06/11/02	4	0.0079	0.0033	0.018	0.041
07/31/02 - 09/19/02	3	0.0066	0.0033	0.016	0.039
Summary	18	0.016	0.0195	0.075	0.211

(a) Time period covered for total organic carbon and total organic halides is a moving average of four quarters.
(b) Excluded outliers.
(c) Limit of detection (blank corrected) equals 3 times the blank standard deviation; limit of quantitation (blank corrected) equals 10 times the blank standard deviation. Numbers are rounded.
(d) Limit of detection equals the mean blank concentration plus 3 standard deviations; limit of quantitation equals the mean blank concentration plus 10 standard deviations. Numbers are rounded.

Table B.24. Summary of Detection and Quantitation Limits, Severn Trent Laboratory (St. Louis)

Method	Constituent	Initial MDL[a] (μg/L)	Initial LOD (μg/L)	Initial LOQ (μg/L)	Ending Values, Effective Date	Ending MDL[a] (μg/L)	Ending LOD (μg/L)	Ending LOQ (μg/L)
General Chemical Parameters								
EPA-600/4-81-004, 120.1	Conductivity[b]	0.147	0.198	0.662	02/07/02	0.147	0.198	0.662
EPA-600/4-81-004, 160.1	Total dissolved solids	4,228	5,709	19,039	11/20/01	4,392	5,931	19,778
EPA-600/4-81-004, 310.1	Alkalinity	1,680	2,269	7,565	01/30/02	4,043	5,459	18,206
EPA-600/4-81-004, 410.4	Chemical oxygen demand[c]	3,940	5,320	17,743	08/29/02	4,800	6,482	21,615
EPA-600/4-81-004, 413.1	Oil and grease	699	944	3,148	03/22/02	915	1,236	4,120
Ammonia and Anions								
EPA-600/4-81-004, 300.0	Bromide	10	13.5	45.0	02/06/02	18.3	24.7	82.4
EPA-600/4-81-004, 300.0	Chloride	10	13.5	45.0	02/06/02	29.1	39.3	131.0
EPA-600/4-81-004, 300.0	Fluoride	6	8.1	27.0	02/06/02	31	41.9	139.6
EPA-600/4-81-004, 300.0	Nitrogen in nitrate	2	2.7	9.0	02/06/02	4.4	5.9	19.8
EPA-600/4-81-004, 300.0	Nitrogen in nitrite	2	2.7	9.0	02/06/02	10.9	14.7	49.1
EPA-600/4-81-004, 300.0	Phosphate	35	47.3	157.6	02/06/02	79	106.7	355.8
EPA-600/4-81-004, 300.0	Sulfate	29	39	130.6	02/06/02	37.4	50.5	168.4
EPA-600/4-81-004, 350.1	Nitrogen in ammonia	12.878	17.4	58.0	02/01/02	11.935	16.1	53.7
SW-846, 9012	Cyanide	2.51	3.4	11.3	02/12/02	4.654	6.3	21.0
Metals								
SW-846, 6010	Aluminum[d]	41.8	56.4	188.2	01/23/02	20.3	27.4	91.4
SW-846, 6010	Antimony[d]	24.7	33.4	111.2	01/23/02	16	21.6	72.1
SW-846, 6010	Barium[d]	3.9	5.3	17.6	01/23/02	6.5	8.8	29.3
SW-846, 6010	Beryllium[d]	0.5	0.7	2.3	01/23/02	0.17	0.2	0.8
SW-846, 6010	Cadmium[d]	2.8	3.8	12.6	01/23/02	2	2.7	9.0
SW-846, 6010	Calcium[d]	122.5	165.4	551.6	01/23/02	148	199.8	666.5
SW-846, 6010	Chromium[d]	4.6	6.2	20.7	01/23/02	2	2.7	9.0
SW-846, 6010	Cobalt[d]	4.3	5.8	19.4	01/23/02	4	5.4	18.0
SW-846, 6010	Copper[d]	2.8	3.8	12.6	01/23/02	7.7	10.4	34.7
SW-846, 6010	Iron[d]	15.6	21.1	70.2	01/23/02	14.5	19.6	65.3
SW-846, 6010	Lead[d]	71.5	96.5	322.0	01/23/02	9	12.2	40.5
SW-846, 6010	Magnesium[d]	92.2	124.5	415.2	01/23/02	138	186.3	621.4
SW-846, 6010	Manganese[d]	0.9	1.2	4.1	01/23/02	0.79	1.1	3.6
SW-846, 6010	Nickel[d]	15.4	20.8	69.3	01/23/02	12	16.2	54.0
SW-846, 6010	Potassium[d]	1,467.4	1,981.5	6,608.0	01/23/02	1,330	1,796	5,989
SW-846, 6010	Silver[d]	6.9	9.3	31.1	01/23/02	6	8.1	27.0
SW-846, 6010	Sodium[d]	83.1	112.2	374.2	01/23/02	140	189.0	630.4
SW-846, 6010	Strontium (elemental)[d]	1.2	1.6	5.4	01/23/02	1.5	2.0	6.8
SW-846, 6010	Tin[d]	35	47.3	157.6	01/23/02	19.8	26.7	89.2
SW-846, 6010	Vanadium[d]	3.4	4.6	15.3	01/23/02	2.3	3.1	10.4
SW-846, 6010	Zinc[d]	3.1	4.2	14.0	01/23/02	1.3	1.8	5.9

Table B.24. (contd)

Method	Constituent	Initial MDL$^{(a)}$ (µg/L)	Initial LOD (µg/L)	Initial LOQ (µg/L)	Ending Values, Effective Date	Ending MDL$^{(a)}$ (µg/L)	Ending LOD (µg/L)	Ending LOQ (µg/L)
SW-846, 7060	Arsenic	1.38	1.9	6.2				
SW-846, 7131	Cadmium	0.2	0.3	0.9				
SW-846, 7191	Chromium	0.3	0.4	1.4				
SW-846, 7421	Lead	1.01	1.4	4.5				
SW-846, 7470	Mercury	0.011	0.015	0.050	02/28/02	0.012	0.016	0.054
SW-846, 7740	Selenium	1.22	1.6	5.5				
SW-846, 7841	Thallium	1.77	2.4	8.0				
			Volatile Organic Compounds					
SW-846, 8010	1,1,1-Trichloroethane	0.35	0.47	1.58	02/26/02	0.09	0.122	0.405
SW-846, 8010	1,1,2-Trichloroethane	0.19	0.26	0.86	02/26/02	0.2	0.270	0.901
SW-846, 8010	1,1-Dichloroethane	0.36	0.49	1.62	02/26/02	0.23	0.311	1.036
SW-846, 8010	1,2-Dichloroethane	0.34	0.46	1.53	02/26/02	0.18	0.243	0.811
SW-846, 8010	1,4-Dichlorobenzene	0.1	0.14	0.45	02/26/02	None		
SW-846, 8010	Carbon tetrachloride	0.32	0.43	1.44	02/26/02	0.16	0.216	0.721
SW-846, 8010	Chloroform	0.38	0.51	1.71	02/26/02	0.12	0.162	0.540
SW-846, 8010	*cis*-1,2-Dichloroethylene	0.33	0.45	1.49	02/26/02	0.14	0.189	0.630
SW-846, 8010	Methylene chloride	2.38	3.21	10.72	02/26/02	0.12	0.162	0.540
SW-846, 8010	Tetrachloroethylene	0.15	0.20	0.68	02/26/02	0.17	0.230	0.766
SW-846, 8010	*trans*-1,2-Dichloroethylene	0.43	0.58	1.94	02/26/02	0.14	0.189	0.630
SW-846, 8010	Trichloroethylene	0.26	0.35	1.17	02/26/02	0.21	0.284	0.946
SW-846, 8010	Vinyl chloride	0.25	0.34	1.13	02/26/02	0.21	0.284	0.946
SW-846, 8020	1,4-Dichlorobenzene	0.33	0.45	1.49	02/26/02	0.04	0.054	0.180
SW-846, 8020	Benzene	0.25	0.34	1.13	02/26/02	0.04	0.054	0.180
SW-846, 8020	Ethylbenzene	0.12	0.16	0.54	02/26/02	0.05	0.068	0.225
SW-846, 8020	Toluene	0.21	0.28	0.95	02/26/02	0.05	0.068	0.225
SW-846, 8020	Xylenes (total)	0.33	0.45	1.49	02/26/02	0.05	0.068	0.225
SW-846, 8260	1,1,1,2-Tetrachloroethane	0.21	0.28	0.95	08/05/02	0.04	0.05	0.18
SW-846, 8260	1,1,1-Trichloroethane	0.31	0.42	1.40	08/05/02	0.17	0.23	0.77
SW-846, 8260	1,1,2,2-Tetrachloroethane	0.32	0.43	1.44	08/05/02	0.17	0.23	0.77
SW-846, 8260	1,1,2-Trichloroethane	0.27	0.36	1.22	08/05/02	0.05	0.07	0.23
SW-846, 8260	1,1-Dichloroethane	0.25	0.34	1.13	08/05/02	0.2	0.27	0.90
SW-846, 8260	1,1-Dichloroethylene	0.39	0.53	1.76	08/05/02	0.16	0.22	0.72
SW-846, 8260	1,2,3-Trichloropropane	0.28	0.38	1.26	08/05/02	0.15	0.20	0.68
SW-846, 8260	1,2-Dibromomethane	0.29	0.39	1.31	08/05/02	0.06	0.08	0.27
SW-846, 8260	1,2-Dichloroethane	0.27	0.36	1.22	08/05/02	0.08	0.11	0.36
SW-846, 8260	1,2-Dichloroethylene (total)	0.45	0.61	2.03	08/05/02	0.17	0.23	0.77
SW-846, 8260	1,2-Dichloropropane	0.2	0.27	0.90	08/05/02	0.24	0.32	1.08

Table B.24. (contd)

Method	Constituent	Initial MDL[(a)] (µg/L)	Initial LOD (µg/L)	Initial LOQ (µg/L)	Ending Values, Effective Date	Ending MDL[(a)] (µg/L)	Ending LOD (µg/L)	Ending LOQ (µg/L)
SW-846, 8260	1,4-Dichlorobenzene	0.25	0.34	1.13	08/05/02	0.11	0.15	0.50
SW-846, 8260	1,4-Dioxane	--	--	--	08/05/02	11.1	14.99	49.99
SW-846, 8260	1-Butanol	4.92	6.64	22.16	08/05/02	4.57	6.17	20.58
SW-846, 8260	2-Butanone	0.39	0.53	1.76	08/05/02	0.29	0.39	1.31
SW-846, 8260	2-Hexanone	0.28	0.38	1.26	08/05/02	0.14	0.19	0.63
SW-846, 8260	4-Methyl-2-pentanone	0.42	0.57	1.89	08/05/02	0.35	0.47	1.58
SW-846, 8260	Acetone	0.3	0.41	1.35	08/05/02	0.66	0.89	2.97
SW-846, 8260	Acetonitrile	2.32	3.13	10.45	08/05/02	2.7	3.65	12.16
SW-846, 8260	Acrolein	1.83	2.47	8.24	08/05/02	2.13	2.88	9.59
SW-846, 8260	Benzene	0.23	0.31	1.04	08/05/02	0.07	0.09	0.32
SW-846, 8260	Bromodichloromethane	0.22	0.30	0.99	08/05/02	0.18	0.24	0.81
SW-846, 8260	Bromoform	0.32	0.43	1.44	08/05/02	0.2	0.27	0.90
SW-846, 8260	Bromomethane	0.52	0.70	2.34	08/05/02	0.61	0.82	2.75
SW-846, 8260	Carbon disulfide	0.29	0.39	1.31	08/05/02	0.43	0.58	1.94
SW-846, 8260	Carbon tetrachloride	0.33	0.45	1.49	08/05/02	0.15	0.20	0.68
SW-846, 8260	Chlorobenzene	0.24	0.32	1.08	08/05/02	0.08	0.11	0.36
SW-846, 8260	Chloroethane	0.39	0.53	1.76	08/05/02	0.32	0.43	1.44
SW-846, 8260	Chloroform	0.21	0.28	0.95	08/05/02	0.07	0.09	0.32
SW-846, 8260	Chloromethane	0.18	0.24	0.81	08/05/02	0.2	0.27	0.90
SW-846, 8260	*cis*-1,2-Dichloroethylene	0.24	0.32	1.08	08/05/02	0.06	0.08	0.27
SW-846, 8260	*cis*-1,3-Dichloropropene	0.25	0.34	1.13	08/05/02	0.24	0.32	1.08
SW-846, 8260	Dichlorodifluoromethane	0.45	0.61	2.03	08/05/02	0.32	0.43	1.44
SW-846, 8260	Ethyl cyanide	2	2.70	9.01				
SW-846, 8260	Ethylbenzene	0.24	0.32	1.08	08/05/02	0.14	0.19	0.63
SW-846, 8260	Methylene chloride	0.24	0.32	1.08	08/05/02	0.3	0.41	1.35
SW-846, 8260	Styrene	0.24	0.32	1.08	08/05/02	0.07	0.09	0.32
SW-846, 8260	Tetrachloroethylene	0.36	0.49	1.62	08/05/02	0.17	0.23	0.77
SW-846, 8260	Tetrahydrofuran	2.26	3.05	10.18	08/05/02	1.74	2.35	7.84
SW-846, 8260	Toluene	0.23	0.31	1.04	08/05/02	0.12	0.16	0.54
SW-846, 8260	*trans*-1,2-Dichloroethylene	0.23	0.31	1.04	08/05/02	0.17	0.23	0.77
SW-846, 8260	*trans*-1,3-Dichloropropene	0.22	0.30	0.99	08/05/02	0.05	0.07	0.23
SW-846, 8260	Trichloroethene	0.29	0.39	1.31	08/05/02	0.16	0.22	0.72
SW-846, 8260	Vinyl acetate	0.24	0.32	1.08	08/05/02	0.2	0.27	0.90
SW-846, 8260	Vinyl chloride	0.32	0.43	1.44	08/05/02	0.25	0.34	1.13
SW-846, 8260	Xylenes (total)	0.66	0.89	2.97	08/05/02	0.28	0.38	1.26
SW-846, 8260	1,4-Dichlorobenzene	0.929	1.25	4.18	11/20/01	2.55	3.44	11.48
WTPH_Gasoline	TPH, gasoline fraction	0.05	0.07	0.23				

Table B.24. (contd)

Method	Constituent	Initial MDL$^{(a)}$ (µg/L)	Initial LOD (µg/L)	Initial LOQ (µg/L)	Ending Values, Effective Date	Ending MDL$^{(a)}$ (µg/L)	Ending LOD (µg/L)	Ending LOQ (µg/L)
				Semivolatile Organic Compounds				
SW-846, 8015	TPH, diesel function	92.3	124.6	415.6	11/20/01	5	6.75	22.52
SW-846, 8040	2,3,4,6-Tetrachlorophenol	2.64	3.56	11.89	03/20/02	3.73	5.04	16.80
SW-846, 8040	2,4,5-Trichlorophenol	2.9	3.92	13.06	03/20/02	2.91	3.93	13.10
SW-846, 8040	2,4,6-Trichlorophenol	4.71	6.36	21.21	03/20/02	2.65	3.58	11.93
SW-846, 8040	2,4-Dichlorophenol	3.08	4.16	13.87	03/20/02	2.9	3.92	13.06
SW-846, 8040	2,4-Dimethylphenol	2.52	3.40	11.35	03/20/02	3.75	5.06	16.89
SW-846, 8040	2,4-Dinitrophenol	1.88	2.54	8.47	03/20/02	3.45	4.66	15.54
SW-846, 8040	2,6-Dichlorophenol	3.3	4.46	14.86	03/20/02	2.66	3.59	11.98
SW-846, 8040	2-Chlorophenol	3.16	4.27	14.23	03/20/02	2.65	3.58	11.93
SW-846, 8040	2-Methylphenol (cresol, o-)	2.94	3.97	13.24	03/20/02	2.79	3.77	12.56
SW-846, 8040	2-Nitrophenol	3.1	4.19	13.96	03/20/02	2.65	3.58	11.93
SW-846, 8040	2-secButyl-4,6-dinitrophenol (DNBP)	2.2	2.97	9.91	03/20/02	1.43	1.93	6.64
SW-846, 8040	3,4-Methyl phenol	3.54	4.78	15.94				
SW-846, 8040	4,6-Dinitro-2-methyl phenol	2.15	2.90	9.68	03/20/02	4.02	5.43	18.10
SW-846, 8040	4-Chloro-3-methylphenol	2.56	3.46	11.53	03/20/02	2.78	3.75	12.52
SW-846, 8040	4-Nitrophenol	1.62	2.19	7.30	03/20/02	2.81	3.79	12.65
SW-846, 8040	Pentachlorophenol	2.24	3.02	10.09	03/20/02	2.5	3.38	11.26
SW-846, 8040	Phenol	1.69	2.28	7.61	03/20/02	3	4.05	13.51
SW-846, 8082	Aroclor-1016	0.68	0.918	3.062	02/08/02	0.22	0.30	0.99
SW-846, 8082	Aroclor-1221	0.68	0.918	3.062	02/08/02	0.22	0.30	0.99
SW-846, 8082	Aroclor-1232	0.68	0.918	3.062	02/08/02	0.49	0.66	2.21
SW-846, 8082	Aroclor-1242	0.68	0.918	3.062	02/08/02	0.2	0.27	0.90
SW-846, 8082	Aroclor-1248	0.68	0.918	3.062	02/08/02	0.14	0.19	0.63
SW-846, 8082	Aroclor-1254	0.5	0.675	2.252	02/08/02	0.38	0.51	1.71
SW-846, 8082	Aroclor-1260	0.5	0.675	2.252	02/08/02	0.19	0.26	0.86
SW-846, 8270	1,2,4,5-Tetrachlorobenzene	1.98	2.67	8.92	11/20/01	1.98	2.67	8.92
SW-846, 8270	1,2,4-Trichlorobenzene	0.973	1.31	4.38	11/20/01	2.55	3.44	11.48
SW-846, 8270	1,2-Dichlorobenzene	0.894	1.21	4.03	11/20/01	2.58	3.48	11.62
SW-846, 8270	1,3-Dichlorobenzene	0.9	1.22	4.05	11/20/01	2.5	3.38	11.26
SW-846, 8270	2,2'-Oxybis(1-chloropropane)	1.178	1.59	5.30	11/20/01	2.75	3.71	12.38
SW-846, 8270	2,4,5-Trichlorophenol	0.776	1.05	3.49	11/20/01	1.98	2.67	8.92
SW-846, 8270	2,4,6-Trichlorophenol	0.663	0.90	2.99	11/20/01	1.73	2.34	7.79
SW-846, 8270	2,4-Dichlorophenol	1.005	1.36	4.53	11/20/01	1.7	2.30	7.66
SW-846, 8270	2,4-Dimethylphenol	0.968	1.31	4.36	11/20/01	2.73	3.69	12.29
SW-846, 8270	2,4-Dinitrophenol	0.969	1.31	4.36	11/20/01	1.26	1.70	5.67
SW-846, 8270	2,4-Dinitrotoluene	0.675	0.91	3.04	11/20/01	2.15	2.90	9.68
SW-846, 8270	2,6-Dinitrotoluene	0.709	0.96	3.19	11/20/01	1.85	2.50	8.33

Table B.24. (contd)

Method	Constituent	Initial MDL[(a)] (μg/L)	Initial LOD (μg/L)	Initial LOQ (μg/L)	Ending Values, Effective Date	Ending MDL[(a)] (μg/L)	Ending LOD (μg/L)	Ending LOQ (μg/L)
SW-846, 8270	2-Chloronaphthalene	0.979	1.32	4.41	11/20/01	2.56	3.46	11.53
SW-846, 8270	2-Chlorophenol	1.118	1.51	5.03	11/20/01	1.45	1.96	6.53
SW-846, 8270	2-Methylnaphthalene	0.996	1.34	4.49	11/20/01	2.36	3.19	10.63
SW-846, 8270	2-Methylphenol (cresol, o-)	0.996	1.34	4.49	11/20/01	1.24	1.67	5.58
SW-846, 8270	2-Nitroaniline	0.587	0.79	2.64	11/20/01	2.45	3.31	11.03
SW-846, 8270	2-Nitrophenol	1.176	1.59	5.30	11/20/01	2	2.70	9.01
SW-846, 8270	3,3'-Dichlorobenzidine	0.549	0.74	2.47	11/20/01	1.3	1.76	5.85
SW-846, 8270	3-Nitroaniline	0.499	0.67	2.25	11/20/01	1.42	1.92	6.39
SW-846, 8270	4,6-Dinitro-2 methyl phenol	1.74	2.35	7.84	11/20/01	1.38	1.86	6.21
SW-846, 8270	4-Bromophenylphenyl ether	0.776	1.05	3.49	11/20/01	3.06	4.13	13.78
SW-846, 8270	4-Chloro-3-methylphenol	0.835	1.13	3.76	11/20/01	1.49	2.01	6.71
SW-846, 8270	4-Chloroaniline	0.883	1.19	3.98	11/20/01	1.63	2.20	7.34
SW-846, 8270	4-Chlorophenylphenyl ether	1.024	1.38	4.61	11/20/01	2.69	3.63	12.11
SW-846, 8270	4-Methylphenol (cresol, p-)	0.767	1.04	3.45	11/20/01	1.51	2.04	6.80
SW-846, 8270	4-Nitroaniline	0.866	1.17	3.90	11/20/01	1.44	1.94	6.48
SW-846, 8270	4-Nitrophenol	0.478	0.65	2.15	11/20/01	0.63	0.85	2.84
SW-846, 8270	Acenaphthene	0.869	1.17	3.91	11/20/01	2.47	3.34	11.12
SW-846, 8270	Acenaphthylene	0.98	1.32	4.41	11/20/01	2.35	3.17	10.58
SW-846, 8270	Aniline	7.763	10.48	34.96	11/20/01	1.86	2.51	8.38
SW-846, 8270	Anthracene	0.481	0.65	2.17	11/20/01	2.44	3.29	10.99
SW-846, 8270	Benzo(a)anthracene	0.579	0.78	2.61	11/20/01	2.08	2.81	9.37
SW-846, 8270	Benzo(a)pyrene	0.599	0.81	2.70	11/20/01	1.8	2.43	8.11
SW-846, 8270	Benzo(b)fluoranthene	0.88	1.19	3.96	11/20/01	1.82	2.46	8.20
SW-846, 8270	Benzo(ghi)perylene	0.953	1.29	4.29	11/20/01	1.27	1.71	5.72
SW-846, 8270	Benzo(k)fluoranthene	0.737	1.00	3.32	11/20/01	2.05	2.77	9.23
SW-846, 8270	Benzyl alcohol	1.101	1.49	4.96	11/20/01	1.79	2.42	8.06
SW-846, 8270	Bis(2-Chloroethoxy)methane	1.141	1.54	5.14	11/20/01	2.05	2.77	9.23
SW-846, 8270	Bis(2-chloroethyl) ether	1.121	1.51	5.05	11/20/01	2.69	3.63	12.11
SW-846, 8270	Bis(2-ethylhexyl) phthalate	1.29	1.74	5.81	11/20/01	3.19	4.31	14.37
SW-846, 8270	Butylbenzylphthalate	0.723	0.98	3.26	11/20/01	2.88	3.89	12.97
SW-846, 8270	Chrysene	0.415	0.56	1.87	11/20/01	1.89	2.55	8.51
SW-846, 8270	Di-n-butylphthalate	1.348	1.82	6.07	11/20/01	2.21	2.98	9.95
SW-846, 8270	Di-n-octylphthalate	1.348	1.82	6.07	11/20/01	2.22	3.00	10.00
SW-846, 8270	Dibenz[a,h]anthracene	1.433	1.94	6.45	11/20/01	2.02	2.73	9.10
SW-846, 8270	Dibenzofuran	0.766	1.03	3.45	11/20/01	2.48	3.35	11.17
SW-846, 8270	Diethylphthalate	1.504	2.03	6.77	11/20/01	2.41	3.25	10.85
SW-846, 8270	Dimethyl phthalate	3.039	4.10	13.69	11/20/01	2.09	2.82	9.41

Table B.24. (contd)

Method	Constituent	Initial MDL[(a)] (µg/L)	Initial LOD (µg/L)	Initial LOQ (µg/L)	Ending Values, Effective Date	Ending MDL[(a)] (µg/L)	Ending LOD (µg/L)	Ending LOQ (µg/L)
SW-846, 8270	Fluoranthene	0.602	0.81	2.71	11/20/01	1.78	2.40	8.02
SW-846, 8270	Fluorene	0.723	0.98	3.26	11/20/01	2.55	3.44	11.48
SW-846, 8270	Hexachlorobenzene	0.576	0.78	2.59	11/20/01	3.57	4.82	16.08
SW-846, 8270	Hexachlorobutadiene	0.907	1.22	4.08	11/20/01	2.01	2.71	9.05
SW-846, 8270	Hexachlorocyclopentadiene	0.906	1.22	4.08	11/20/01	2.11	2.85	9.50
SW-846, 8270	Hexachloroethane	0.861	1.16	3.88	11/20/01	2.33	3.15	10.49
SW-846, 8270	Indeno(1,2,3-cd)pyrene	0.612	0.83	2.76	11/20/01	1.47	1.98	6.62
SW-846, 8270	Isophorone	0.858	1.16	3.86	11/20/01	0.94	1.27	4.23
SW-846, 8270	N-Nitroso-di-n-dipropylamine	0.905	1.22	4.08	11/20/01	2.49	3.36	11.21
SW-846, 8270	N-Nitrosodimethylamine	0.735	0.99	3.31	11/20/01	1.57	2.12	7.07
SW-846, 8270	N-Nitrosodiphenylamine	0.451	0.61	2.03	11/20/01	1.64	2.21	7.39
SW-846, 8270	Naphthalene	1.093	1.48	4.92	11/20/01	2.64	3.56	11.89
SW-846, 8270	Pentachlorophenol	0.866	1.17	3.90	11/20/01	1.29	1.74	5.81
SW-846, 8270	Phenanthrene	0.457	0.62	2.06	11/20/01	2.5	3.38	11.26
SW-846, 8270	Phenol	0.554	0.75	2.49	11/20/01	0.91	1.23	4.10
SW-846, 8270	Pyrene	0.707	0.95	3.18	11/20/01	2.19	2.96	9.86

(a) MDLs for many constituents changed during the fiscal year. For these constituents, the initial MDL, LOD, and LOQ were in effect until the date the values were updated (ending values, effective date). In cases where the MDL did not change, no ending values are listed.

(b) µMhos/cm.

(c) Between February 11, 2002, and March 28, 2002, a third MDL (value not shown in table) was in effect for this compound.

(d) Two instruments (standard and trace level) were used for samples analyzed by method 6010. MDL values for the standard instrument were included in this table. MDL values for the trace instrument were typically 2 to 10 times lower, but in several cases, the MDL values for the trace instrument were the same as or higher than those reported for the standard instrument.

MDL = Method detection limit.
LOD = Limit of detection.
LOQ = Limit of quantitation.

Appendix C

Wells, Samples, and Analyses

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Appendix C

Wells, Samples, and Analyses

M. J. Hartman

In fiscal year 2002, the Hanford Groundwater Monitoring Project (groundwater project) constructed maps of geographic areas of interest for *Atomic Energy Act of 1954* monitoring (Figure C.1; also see well location maps in main text). These informal areas of interest encompass the operable units monitored under the *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA) and extend to the boundaries of the Hanford Site. Table C.1 lists monitoring wells that have been sampled in the past 5 years in each groundwater interest area. Wells used for monitoring the *Resource Conservation and Recovery Act* (RCRA) or other regulations supplement the surveillance monitoring network and are included in Table C.1. See Appendix A for lists of wells monitored for RCRA and other regulations.

The groundwater monitoring project sampled ~650 wells in fiscal year 2002 (Figure C.2). An additional 300 wells are scheduled for sampling every two or three years. Many of the wells were sampled more than once during the year, resulting in 1,783 sample trips. The samples were analyzed for a variety of constituents, with results entered into the Hanford Environmental Information System. The constituent analyzed most frequently was chromium (total and hexavalent), analyzed in 1,756 samples. Other commonly analyzed constituents include nitrate (1,088 samples) and tritium (914 samples). Figure C.3 illustrates number of analyses for each of eight constituents of concern, divided into groundwater interest areas.

Because of declining water levels caused by reduced volumes of effluent discharged to the ground, 14 wells went dry in fiscal year 2002 (i.e., did not contain enough water to sample, although it was possible to measure water levels in some of the wells). In the past 5 years, 52 wells have gone dry (Table C.2). Some of these dry wells have been replaced by newly drilled or existing wells.

References

Atomic Energy Act of 1954. As amended, Ch. 1073, 68 Stat. 919, 42 USC 2011 et seq.

Comprehensive Environmental Response, Compensation, and Liability Act. 1980. Public Law 96-510, as amended, 94 Stat. 2767, 42 USC 9601 et seq.

Resource Conservation and Recovery Act. 1976. Public Law 94-580, as amended, 90 Stat. 2795, 42 USC 6901 et seq.

Table C.1. Hanford Monitoring Wells by Groundwater Interest Areas for Fiscal Year 2002[(a)]

Well Name	Comment[(b)]
100-BC-5	
01-D	Aquifer tube
01-M	Aquifer tube
02-S	Aquifer tube
03-D	Aquifer tube
04-M	Aquifer tube
04-S	Aquifer tube
05-D	Aquifer tube
05-M	Aquifer tube
05-S	Aquifer tube
06-D	Aquifer tube
06-M	Aquifer tube
07-D	Aquifer tube
11-D	Aquifer tube
12-D	Aquifer tube
13-S	Aquifer tube
14-D	Aquifer tube
14-M	Aquifer tube
199-B2-12	
199-B2-13	
199-B3-1	
199-B3-46	
199-B3-47	
199-B4-1	
199-B4-4	
199-B4-5	
199-B4-7	
199-B4-8	
199-B4-9	
199-B5-1	
199-B5-2	
199-B8-6	
199-B9-2	
199-B9-3	
699-63-58	
699-63-90	
699-64-62	
699-65-72	
699-65-83	
699-66-58	
699-66-64	
699-67-86	
699-71-77	
699-72-73	
699-72-88	
699-72-92	
B8540	Well ID
C3326	Well ID
100-FR-3	
199-F1-2	
199-F5-1	
199-F5-3	
199-F5-4	
199-F5-42	
199-F5-43A	
199-F5-43B	
199-F5-44	
199-F5-45	
199-F5-46	
199-F5-47	
199-F5-48	
199-F5-6	
199-F6-1	
199-F7-1	
199-F7-2	
199-F7-3	
199-F8-2	
199-F8-3	
199-F8-4	
58-M	Aquifer tube
59-S	Aquifer tube
61-D	Aquifer tube
62-M	Aquifer tube
64-D	Aquifer tube
66-M	Aquifer tube
699-58-24	
699-62-43F	
699-64-27	
699-65-50	
699-66-23	
699-71-30	
699-77-36	
699-81-38	
699-83-47	
699-84-35A	
74-S	Aquifer tube
75-D	Aquifer tube
75-M	Aquifer tube
76-M	Aquifer tube
80-D	Aquifer tube
100-HR-3-D	
166-D-1	
166-D-2	
166-D-3	
199-D2-6	
199-D2-8	
199-D3-2	
199-D4-1	
199-D4-10	
199-D4-11	
199-D4-12	
199-D4-13	
199-D4-14	
199-D4-15	
199-D4-19	
199-D4-20	
199-D4-21	
199-D4-22	
199-D4-23	
199-D4-24	
199-D4-25	
199-D4-26	
199-D4-27	
199-D4-28	
199-D4-29	
199-D4-30	
199-D4-31	
199-D4-32	
199-D4-33	
199-D4-34	
199-D4-35	
199-D4-36	
199-D4-37	
199-D4-38	
199-D4-39	
199-D4-4	
199-D4-40	
199-D4-41	
199-D4-42	
199-D4-43	
199-D4-44	
199-D4-45	
199-D4-46	
199-D4-47	
199-D4-48	
199-D4-49	
199-D4-5	
199-D4-50	
199-D4-51	
199-D4-52	
199-D4-53	
199-D4-54	
199-D4-55	

Table C.1. (contd)

Well Name	Comment(b)
199-D4-56	
199-D4-57	
199-D4-58	
199-D4-59	
199-D4-6	
199-D4-60	
199-D4-61	
199-D4-62	
199-D4-63	
199-D4-64	
199-D4-65	
199-D4-66	
199-D4-67	
199-D4-68	
199-D4-69	
199-D4-7	
199-D4-70	
199-D4-71	
199-D4-72	
199-D4-73	
199-D4-74	
199-D4-75	
199-D4-76	
199-D4-77	
199-D4-78	
199-D4-79	
199-D4-8	
199-D4-83	
199-D4-84	
199-D4-85	
199-D4-86	
199-D4-9	
199-D5-12	
199-D5-13	
199-D5-14	
199-D5-15	
199-D5-16	
199-D5-17	
199-D5-18	
199-D5-19	
199-D5-20	
199-D5-22	
199-D5-36	
199-D5-37	
199-D5-38	
199-D5-39	
199-D5-40	
199-D5-41	
199-D5-42	
199-D5-43	
199-D5-44	
199-D8-3	
199-D8-4	
199-D8-5	
199-D8-53	
199-D8-54A	
199-D8-54B	
199-D8-55	
199-D8-6	
199-D8-68	
199-D8-69	
199-D8-70	
199-D8-71	
199-D8-72	
36-D	Aquifer tube
36-S	Aquifer tube
38-D	Aquifer tube
40-S	Aquifer tube
699-93-48A	
699-96-49	
699-97-51A	
B8775	Well ID
B8776	Well ID
B8777	Well ID
B8786	Well ID
DD-06-2	Aquifer tube
DD-06-3	Aquifer tube
DD-10-4	Aquifer tube
DD-12-2	Aquifer tube
DD-15-3	Aquifer tube
DD-15-4	Aquifer tube
DD-17-2	Aquifer tube
DD-17-3	Aquifer tube
DD-39-3	Aquifer tube
DD-41-2	Aquifer tube
DD-41-3	Aquifer tube
DD-41-4	Aquifer tube
DD-42-3	Aquifer tube
DD-42-4	Aquifer tube
DD-43-3	Aquifer tube
DD-44-4	Aquifer tube
DD-49-3	Aquifer tube
DD-50-2	Aquifer tube
DD-50-3	Aquifer tube
100-HR-3-H	
199-H3-1	
199-H3-2A	
199-H3-2C	
199-H4-10	
199-H4-11	
199-H4-12A	
199-H4-12B	
199-H4-12C	
199-H4-13	
199-H4-14	
199-H4-15A	
199-H4-15B	
199-H4-15CP	Piezometer
199-H4-15CQ	Piezometer
199-H4-15CR	Piezometer
199-H4-15CS	Piezometer
199-H4-16	
199-H4-17	
199-H4-18	
199-H4-2	
199-H4-3	
199-H4-4	
199-H4-45	
199-H4-46	
199-H4-47	
199-H4-48	
199-H4-49	
199-H4-5	
199-H4-6	
199-H4-63	
199-H4-64	
199-H4-65	
199-H4-7	
199-H4-8	
199-H4-9	
199-H5-1A	
199-H6-1	
42-D	Aquifer tube
43-D	Aquifer tube
43-M	Aquifer tube
44-D	Aquifer tube
44-M	Aquifer tube
45-D	Aquifer tube
46-D	Aquifer tube
47-D	Aquifer tube
47-M	Aquifer tube

Table C.1. (contd)

Well Name	Comment(b)
48-M	Aquifer tube
48-S	Aquifer tube
49-D	Aquifer tube
49-M	Aquifer tube
49-S	Aquifer tube
50-M	Aquifer tube
51-D	Aquifer tube
51-M	Aquifer tube
52-D	Aquifer tube
54-D	Aquifer tube
55-M	Aquifer tube
55-S	Aquifer tube
58-D	Aquifer tube
699-89-35	
699-91-46A	
699-96-43	
699-97-43	
DH-1451-1	Aquifer tube
100-KR-4	
15-M	Aquifer tube
17-D	Aquifer tube
18-S	Aquifer tube
199-K-106A	
199-K-107A	
199-K-108A	
199-K-109A	
199-K-11	
199-K-110A	
199-K-111A	
199-K-112A	
199-K-113A	
199-K-114A	
199-K-115A	
199-K-116A	
199-K-117A	
199-K-119A	
199-K-120A	
199-K-125A	
199-K-126	
199-K-127	
199-K-18	
199-K-19	
199-K-20	
199-K-21	
199-K-22	
199-K-23	
199-K-27	
199-K-28	
199-K-29	
199-K-30	
199-K-31	
199-K-32A	
199-K-32B	
199-K-33	
199-K-34	
199-K-35	
199-K-36	
199-K-37	
19-D	Aquifer tube
21-M	Aquifer tube
22-D	Aquifer tube
22-M	Aquifer tube
23-D	Aquifer tube
699-70-68	
699-73-61	
699-78-62	
100-NR-2	
199-N-103A	
199-N-105A	
199-N-106A	
199-N-14	
199-N-16	
199-N-17	
199-N-18	
199-N-19	
199-N-2	
199-N-21	
199-N-26	
199-N-27	
199-N-28	
199-N-3	
199-N-32	
199-N-33	
199-N-34	
199-N-41	
199-N-46	
199-N-47	
199-N-48	
199-N-5	
199-N-50	
199-N-51	
199-N-52	
199-N-54	
199-N-56	
199-N-57	
199-N-59	
199-N-64	
199-N-67	
199-N-69	
199-N-70	
199-N-71	
199-N-72	
199-N-73	
199-N-74	
199-N-75	
199-N-76	
199-N-77	
199-N-80	
199-N-81	
199-N-8T	
199-N-92A	
199-N-96A	
199-N-99A	
25-D	Aquifer tube
26-D	Aquifer tube
26-M	Aquifer tube
26-S	Aquifer tube
699-81-58	
699-84-62A	
699-87-55	
DK-04-2	Aquifer tube
1100-EM-1	
09N28E04G01	
1199-33-18B	
1199-39-15	
1199-39-16D	
1199-39-16E	
1199-40-15	
1199-40-16B	
1199-40-16C	
3099-42-16	
3099-47-18B	
399-5-2	
699-ATH	
699-ORV-1	
699-S12-29	
699-S19-11	
699-S22-E9A	
699-S22-E9C	
699-S24-19P	
699-S24-19Q	

Table C.1. (contd)

Well Name	Comment(b)
699-S27-E12A	
699-S27-E14	
699-S27-E9A	
699-S27-E9B	
699-S27-E9C	
699-S28-E0	
699-S28-E12	
699-S28-E13A	
699-S29-E10A	
699-S29-E11	
699-S29-E12	
699-S29-E13A	
699-S29-E16A	
699-S29-E16B	
699-S29-E16C	
699-S30-E10A	
699-S30-E10B	
699-S30-E11A	
699-S30-E14	
699-S30-E15A	
699-S31-1	
699-S31-E10A	
699-S31-E10B	
699-S31-E10C	
699-S31-E10D	
699-S31-E10E	
699-S31-E11	
699-S31-E8A	
699-S32-E11	
699-S32-E13A	
699-S32-E13B	
699-S34-E10	
699-S34-E15	
699-S36-E13A	
699-S37-E14	
699-S38-E11	
699-S38-E12A	
699-S38-E12B	
699-S40-E13A	
699-S40-E14	
699-S41-E12	
699-S41-E13A	
699-S41-E13B	
699-S41-E13C	
699-S42-E8B	
699-S42-E8C	
699-S43-E12	
699-S8-19	
200-BP-5	
299-E24-8	
299-E26-10	
299-E26-11	
299-E26-8	
299-E26-9	
299-E27-10	
299-E27-11	
299-E27-12	
299-E27-13	
299-E27-14	
299-E27-15	
299-E27-16	
299-E27-17	
299-E27-18	
299-E27-19	
299-E27-7	
299-E27-8	
299-E27-9	
299-E28-13	
299-E28-17	
299-E28-18	
299-E28-2	
299-E28-21	
299-E28-23	
299-E28-24	
299-E28-25	
299-E28-26	
299-E28-27	
299-E28-28	
299-E28-5	
299-E28-6	
299-E28-8	
299-E32-10	
299-E32-2	
299-E32-3	
299-E32-4	
299-E32-5	
299-E32-6	
299-E32-7	
299-E32-8	
299-E32-9	
299-E33-12	
299-E33-13	
299-E33-14	
299-E33-15	
299-E33-16	
299-E33-17	
299-E33-18	
299-E33-20	
299-E33-21	
299-E33-26	
299-E33-28	
299-E33-29	
299-E33-30	
299-E33-31	
299-E33-32	
299-E33-33	
299-E33-334	
299-E33-335	
299-E33-337	
299-E33-338	
299-E33-339	
299-E33-34	
299-E33-35	
299-E33-36	
299-E33-37	
299-E33-38	
299-E33-39	
299-E33-41	
299-E33-42	
299-E33-43	
299-E33-44	
299-E33-45	
299-E33-46	
299-E33-5	
299-E33-7	
299-E33-8	
299-E33-9	
299-E34-10	
299-E34-11	
299-E34-12	
299-E34-2	
299-E34-3	
299-E34-5	
299-E34-7	
299-E34-8	
299-E34-9	
299-E35-2	
699-45-42	
699-49-55A	
699-49-55B	
699-49-57A	
699-49-57B	
699-50-53A	
699-50-53B	

Table C.1. (contd)

Well Name	Comment[(b)]
699-52-46A	
699-52-54	
699-52-57	
699-53-47A	
699-53-47B	
699-53-48A	
699-53-48B	
699-53-55A	
699-53-55B	
699-53-55C	
699-54-34	
699-54-49	
699-55-57	
699-55-60A	
699-56-43	
699-56-53	
699-57-59	
699-59-58	
699-60-60	
699-61-62	
699-61-66	
200-PO-1	
299-E13-14	
299-E13-5	
299-E16-1	
299-E16-2	
299-E17-1	
299-E17-12	
299-E17-13	
299-E17-14	
299-E17-17	
299-E17-18	
299-E17-19	
299-E17-2	
299-E17-21	
299-E17-8	
299-E17-9	
299-E18-1	
299-E23-1	
299-E24-16	
299-E24-18	
299-E24-19	
299-E24-20	
299-E24-4	
299-E24-5	
299-E25-1000	
299-E25-17	
299-E25-18	
299-E25-19	
299-E25-20	
299-E25-22	
299-E25-23	
299-E25-25	
299-E25-26	
299-E25-28	
299-E25-29P	Piezometer
299-E25-29Q	Piezometer
299-E25-3	
299-E25-31	
299-E25-32P	Piezometer
299-E25-32Q	Piezometer
299-E25-34	
299-E25-35	
299-E25-36	
299-E25-37	
299-E25-39	
299-E25-40	
299-E25-41	
299-E25-42	
299-E25-43	
299-E25-44	
299-E25-45	
299-E25-46	
299-E25-47	
299-E25-48	
299-E25-6	
299-E26-12	
299-E26-13	
299-E26-4	
499-S0-7	
499-S0-8	
499-S1-8J	
499-S1-8K	
699-10-54A	
699-1-18	
699-14-38	
699-15-15B	
699-17-5	
699-18-21	
699-19-43	
699-20-20	
699-20-E12O	Piezometer
699-20-E12S	Piezometer
699-20-E5A	
699-21-6	
699-22-35	
699-2-3	
699-23-34A	
699-23-34B	
699-24-1P	
699-24-33	
699-24-34A	
699-24-34B	
699-24-34C	
699-24-35	
699-24-46	
699-25-33A	
699-25-34A	
699-25-34B	
699-25-34C	
699-25-34D	
699-26-15A	
699-26-33	
699-26-34A	
699-26-34B	
699-26-35A	
699-26-35C	
699-2-6A	
699-2-7	
699-27-8	
699-28-40	
699-29-4	
699-31-11	
699-31-31	
699-31-31P	Piezometer
699-32-22A	
699-32-22B	
699-32-43	
699-33-42	
699-33-56	
699-34-41B	
699-34-42	
699-35-9	
699-37-43	
699-37-47A	
699-37-E4	
699-38-15	
699-39-39	
699-40-1	
699-40-33A	
699-40-36	
699-40-39	
699-40-40A	

Table C.1. (contd)

Well Name	Comment[b]
699-41-1A	
699-41-23	
699-41-35	
699-41-40	
699-41-42	
699-42-12A	
699-42-37	
699-42-39A	
699-42-39B	
699-42-40C	
699-42-42B	
699-43-2	
699-43-3	
699-43-40	
699-43-41E	
699-43-41G	
699-43-43	
699-43-44	
699-43-45	
699-44-39B	
699-46-21B	
699-46-4	
699-47-35A	
699-47-5	
699-48-7A	
699-49-13E	
699-50-28B	
699-52-19	
699-8-17	
699-8-25	
699-S12-3	
699-S2-34B	
699-S3-25	
81-S	Aquifer tube
82-S	Aquifer tube
84-D	Aquifer tube
86-D	Aquifer tube
200-UP-1	
299-W15-37	
299-W18-15	
299-W18-21	
299-W18-22	
299-W18-25	
299-W18-30	
299-W18-31	
299-W18-32	
299-W18-33	
299-W18-40	
299-W19-12	
299-W19-14	
299-W19-15	
299-W19-16	
299-W19-17	
299-W19-18	
299-W19-20	
299-W19-23	
299-W19-24	
299-W19-26	
299-W19-28	
299-W19-29	
299-W19-3	
299-W19-30	
299-W19-31	
299-W19-32	
299-W19-34A	
299-W19-34B	
299-W19-35	
299-W19-36	
299-W19-37	
299-W19-38	
299-W19-39	
299-W19-4	
299-W19-40	
299-W19-41	
299-W19-42	
299-W19-43	
299-W19-44	
299-W19-45	
299-W19-9	
299-W22-10	
299-W22-2	
299-W22-20	
299-W22-26	
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299-W22-40	
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299-W22-42	
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299-W22-80	
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299-W22-82	
299-W22-83	
299-W22-84	
299-W22-85	
299-W22-9	
299-W23-1	
299-W23-10	
299-W23-13	
299-W23-14	
299-W23-15	
299-W23-19	
299-W23-2	
299-W23-20	
299-W23-21	
299-W23-234	
299-W23-3	
299-W23-4	
299-W23-7	
299-W23-9	
299-W26-10	
299-W26-12	
299-W26-13	
299-W26-6	
299-W26-7	
299-W26-8	
299-W26-9	
299-W27-1	
299-W27-2	
699-19-58	
699-25-70	
699-32-62	
699-32-70B	
699-32-72A	
699-34-61	
699-35-66A	
699-35-70	
699-35-78A	
699-36-61A	
699-36-67	
699-36-70A	
699-37-68	
699-38-65	
699-38-68A	
699-38-70	
699-40-62	

Table C.1. (contd)

Well Name	Comment(b)
200-ZP-1	
299-W10-1	
299-W10-12	
299-W10-13	
299-W10-14	
299-W10-16	
299-W10-17	
299-W10-18	
299-W10-19	
299-W10-20	
299-W10-21	
299-W10-22	
299-W10-23	
299-W10-24	
299-W10-26	
299-W10-27	
299-W10-28	
299-W10-3	
299-W10-4	
299-W10-5	
299-W10-8	
299-W11-10	
299-W11-12	
299-W11-13	
299-W11-14	
299-W11-18	
299-W11-23	
299-W11-24	
299-W11-27	
299-W11-28	
299-W11-3	
299-W11-30	
299-W11-31	
299-W11-37	
299-W11-39	
299-W11-40	
299-W11-41	
299-W11-42	
299-W11-6	
299-W11-7	
299-W12-1	
299-W14-10	
299-W14-12	
299-W14-13	
299-W14-14	
299-W14-15	
299-W14-16	
299-W14-17	
299-W14-18	
299-W14-2	
299-W14-5	
299-W14-6	
299-W14-9	
299-W15-1	
299-W15-11	
299-W15-12	
299-W15-15	
299-W15-16	
299-W15-17	
299-W15-18	
299-W15-19	
299-W15-2	
299-W15-22	
299-W15-30	
299-W15-31A	
299-W15-32	
299-W15-33	
299-W15-34	
299-W15-35	
299-W15-36	
299-W15-38	
299-W15-39	
299-W15-4	
299-W15-40	
299-W15-41	
299-W15-42	
299-W15-44	
299-W15-7	
299-W15-763	
299-W15-765	
299-W18-1	
299-W18-23	
299-W18-24	
299-W18-26	
299-W18-27	
299-W18-28	
299-W18-4	
299-W6-10	
299-W6-11	
299-W6-12	
299-W6-2	
299-W6-3	
299-W6-4	
299-W6-6	
299-W6-7	
299-W6-8	
299-W6-9	
299-W7-1	
299-W7-10	
299-W7-11	
299-W7-12	
299-W7-2	
299-W7-3	
299-W7-4	
299-W7-5	
299-W7-6	
299-W7-7	
299-W7-8	
299-W7-9	
299-W8-1	
299-W9-1	
699-17-70	
699-19-88	
699-22-70	
699-26-89	
699-34-88	
699-36-93	
699-37-82A	
699-39-79	
699-43-89	
699-44-64	
699-45-69A	
699-47-60	
699-48-71	
699-48-77A	
699-48-77C	
699-48-77D	
699-48-96	
699-49-100C	
699-49-79	
699-50-85	
699-51-63	
699-51-75	
699-51-75P	Piezometer
699-55-76	
699-55-89	
300-FF-5	
399-1-1	
399-1-10A	
399-1-10B	
399-1-11	
399-1-12	
399-1-13A	
399-1-14A	

Table C.1. (contd)

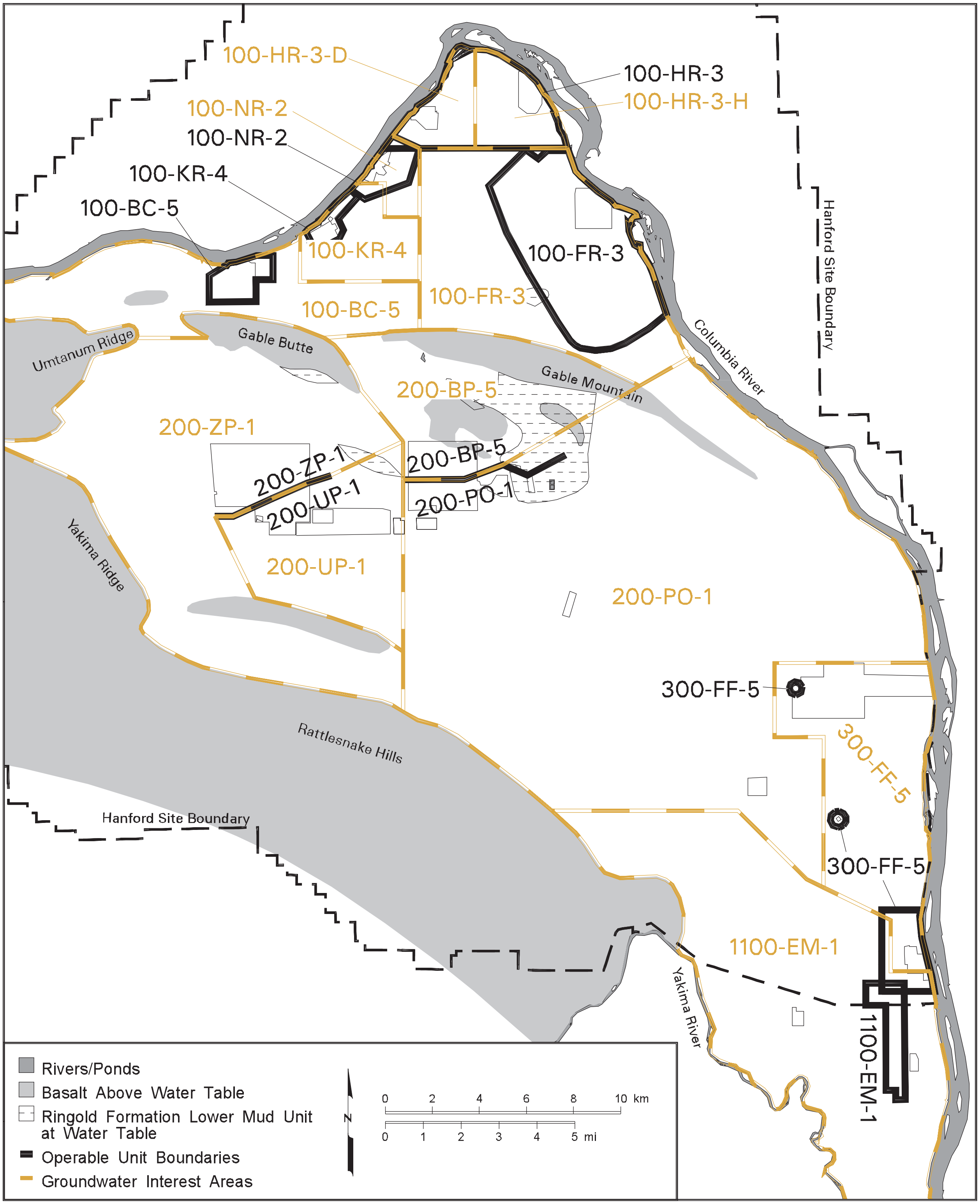
Well Name	Comment[(b)]
399-1-15	
399-1-16A	
399-1-16B	
399-1-16C	
399-1-17A	
399-1-17B	
399-1-18A	
399-1-18B	
399-1-18C	
399-1-2	
399-1-21A	
399-1-21B	
399-1-3	
399-1-5	
399-1-6	
399-1-7	
399-1-8	
399-2-1	
399-2-2	
399-3-1	
399-3-10	
399-3-11	
399-3-12	
399-3-2	
399-3-3	
399-3-6	
399-4-1	
399-4-10	
399-4-11	
399-4-12	
399-4-7	
399-4-9	
399-5-1	
399-5-4B	
399-6-1	
399-6-2	
399-8-1	
399-8-3	
399-8-5A	
399-8-5B	
399-8-5C	
699-10-E12	
699-12-2C	
699-12-4D	
699-13-0A	
699-13-1A	
699-13-1B	
699-13-1C	
699-13-1D	
699-13-1E	
699-13-2C	
699-13-2D	
699-13-3A	
699-9-E2	
699-S11-E12A	
699-S11-E12AP	Piezometer
699-S19-E13	
699-S19-E14	
699-S3-E12	
699-S6-E14A	
699-S6-E4A	
699-S6-E4B	
699-S6-E4CS	Piezometer
699-S6-E4CT	Piezometer
699-S6-E4D	
699-S6-E4E	
C3071	Well ID
C3072	Well ID
C3073	Well ID
C3074	Well ID
C3075	Well ID
C3076	Well ID
C3077	Well ID
C3078	Well ID
C3079	Well ID
C3080	Well ID
C3081	Well ID
C3252	Well ID
C3255	Well ID
C3264	Well ID
C3265	Well ID
Offsite	
09N28E06C02	
10N27E14F03	
10N28E24R03	
10N29E02Q01	
10N29E06H01	
10N29E19E01	
699-42-E9B	

(a) Wells sampled in last five years. Areas of interest are informally-defined regions named after the groundwater operable unit they encompass. See Figure C.1 for map of areas.

(b) Well ID numbers are listed for wells without a Hanford well number. Most indicate a characterization borehole or a new monitoring well.

Table C.2. Monitoring Wells That Have Gone Dry Since 1998

Well	FY Dry	Project(s) Using Well	Comments
199-F5-3	2000	100-FR-3, SURV	
199-N-59	2001	1324N/NA, SURV	Sampled when water table higher (successful in September 2002)
299-E17-9	2002	PUREX	Replaced with 299-E17-16
299-E26-9	2000	LERF, SURV	
299-E28-10	2000	200-BP-5	
299-E28-12	1998	SURV	
299-E34-11	2002	LLWMA 2	
299-W10-17	2002	WMA TX-TY	
299-W10-2	1999	WMA T	
299-W11-23	2001	WMA T	Replaced with 299-W11-39
299-W11-24	2002	WMA T	Replaced with 299-W11-42
299-W11-30	2002	WMA T	
299-W11-31	2000	WMA T	Far-field well; replacement not needed
299-W14-4	2000	WMA TX-TY	Old well at 216-T-28; not replaced
299-W15-18	2002	200-ZP-1	
299-W15-22	2000	SURV	
299-W15-24	1998	SURV	
299-W15-4	2000	200-ZP-1, WMA TX-TY, SURV	Replaced with 299-W15-763
299-W18-25	2001	WMA U, SURV	Replaced with 299-18-40
299-W18-26	1999	200-ZP-1, LLWMA 4	
299-W19-14	2002	SURV	
299-W19-21	2000	SURV	
299-W19-23	2000	200-UP-1	
299-W19-24	1999	200-UP-1	
299-W19-28	1999	200-UP-1	
299-W19-31	2000	SST U	Replaced with 299-W19-42
299-W19-32	2000	SST U	Replaced with 299-W19-41
299-W22-12	2000	SURV	
299-W22-39	2000	WMA S-SX	Replaced with 299-W22-49
299-W22-40	1999	U-12	
299-W22-41	1999	U-12	
299-W22-42	1999	U-12	
299-W22-43	2000	U-12	
299-W22-7	2002	SURV	May be sampleable in future; needs rehabilitation.
299-W23-1	2001	WMA S-SX	Inside S Farm; replaced with well 299-W22-48 outside the farm
299-W23-13	2002	WMA S-SX	Replaced with 299-W23-20
299-W23-14	2002	WMA S-SX	Replaced with 299-W23-21
299-W23-2	2001	WMA S-SX	Inside SX Farm; replaced with well 299-W22-85 outside the farm
299-W23-3	2000	WMA S-SX	Inside SX Farm, replaced with well 299-W22-80 outside the farm
299-W23-7	1999	WMA S-SX	Between S and SX Farms; replaced with well 299-W22-81 outside the farm
299-W26-10	1999	S-10	
299-W26-8	1998	S-10, SURV	
299-W26-9	2001	S-10	
299-W6-2	2002	SURV	
299-W7-10	2001	LLWMA 3	
299-W7-11	2002	LLWMA 3	
299-W7-6	2002	SURV	May be sampleable with special equipment.
299-W7-9	2002	LLWMA 3	
299-W9-1	2001	LLWMA 3, SURV	
699-25-34B	2002	NRDWL	May be sampleable after pump lowered.
699-29-78	1998	SURV	
699-42-41	2001	SURV	
699-43-43	2002	B-POND, A-29	B-Pond revised monitoring network; no longer needed
699-49-28	1998	SURV	Replaced with 699-50-28B
699-50-53A	2000	WMA B-BX-BY	
699-52-57	1999	200-BP-5, SURV	



can_gwf02030 February 10, 2003 1:48 PM

Figure C.1. Groundwater Operable Units and Groundwater Interest Areas

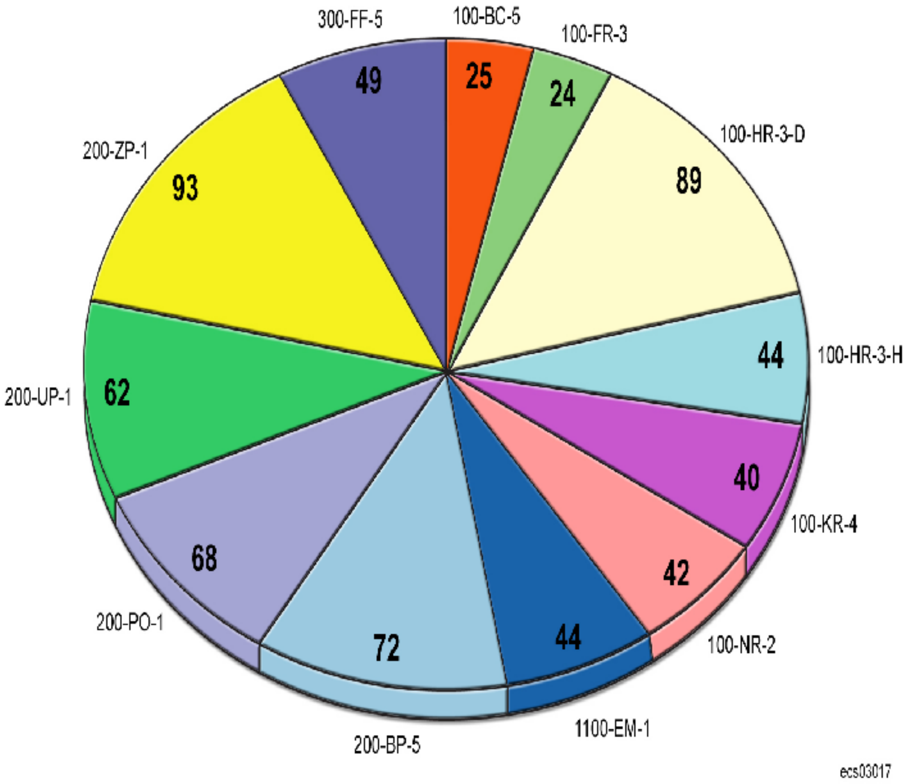


Figure C.2. Summary of Wells Sampled in Each Groundwater Interest Area

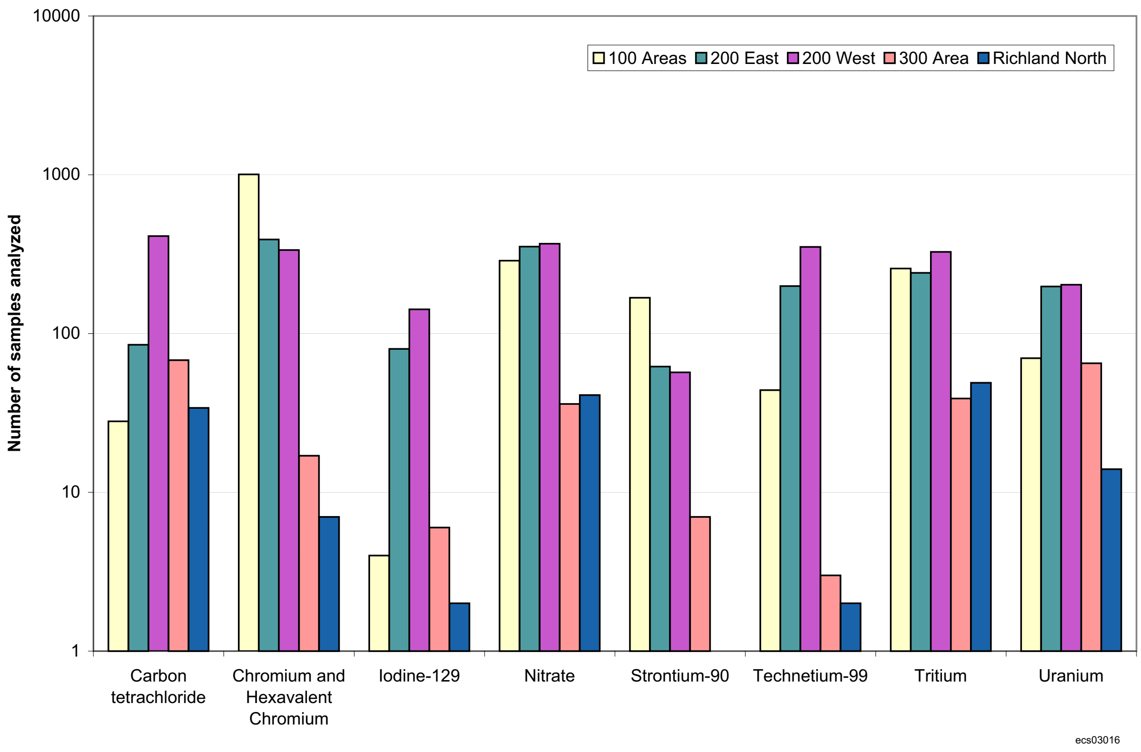


Figure C.3. Summary of Analyses by Groundwater Geographic Region

Historical Bibliography

Reports related to groundwater monitoring are listed in chronological order and by type. Miscellaneous groundwater reports are listed in alphabetical order.

Contents

Environmental Monitoring Monthly and Quarterly Reports (1946 through 1957)

Turner, L. D. 1947. *Trend of Contamination in the Air, Columbia River, Rain, Sanitary Water, Vegetation and Wastes at Hanford Works and Vicinity - Quarterly, 1946*. HW 3-5402, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Turner, L. D. 1947. *Trend of Contamination in the Air, Columbia River, Rain, Sanitary Water, Vegetation and Wastes at Hanford Works and Vicinity - Quarterly, 1/1/47 to 3/25/47*. HW 3-5511, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Healy, J. W. 1947. *Trend of Contamination in the Air, Columbia River, Rain, Sanitary Water, Vegetation and Wastes at Hanford Works and Vicinity - Quarterly, 3/25/47 to 6/30/47*. HW-7317, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Singlevich, W. 1947. *Trend of Contamination in the Air, Columbia River, Rain, Sanitary Water, Vegetation and Wastes at Hanford Works and Vicinity - Quarterly, 7/1/47 to 9/30/47*. HW-8549 DEL, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Singlevich, W. 1947. *Trend of Contamination in the Air, Columbia River, Rain, Sanitary Water, Vegetation and Wastes at Hanford Works and Vicinity - Quarterly, 10/1/47 to 12/31/47*. HW-9496 DEL, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Singlevich, W. 1948. *Radioactive Contamination in the Environs of the Hanford Works for the Period January-March 1948*. HW-10242, General Electric Company, Hanford Works, Richland, Washington.

Singlevich, W. 1948. *Radioactive Contamination in the Environs of the Hanford Works for the Period April-June 1948*. HW-11333 DEL, General Electric Company, Hanford Works, Richland, Washington.

Singlevich, W. 1949. *Radioactive Contamination in the Environs of the Hanford Works for the Period July-September 1948*. HW-12677 DEL, General Electric Company, Hanford Works, Richland, Washington.

Singlevich, W. 1949. *Radioactive Contamination in the Environs of the Hanford Works for the Period October-December 1948*. HW-13743 DEL, General Electric Company, Hanford Works, Richland, Washington.

Singlevich, W., and H. J. Paas. 1949. *Radioactive Contamination in the Environs of the Hanford Works for the Period January-March 1949*. HW-14243 DEL, General Electric Company, Hanford Works, Richland, Washington.

Singlevich, W., and H. J. Paas. 1949. *Radioactive Contamination in the Environs of the Hanford Works for the Period April-June 1949*. HW-17434 DEL, General Electric Company, Hanford Works, Richland, Washington.

Paas, H. J., and W. Singlevich. 1950. *Radioactive Contamination in the Environs of the Hanford Works for the Period July-September 1949*. HW-18615, General Electric Company, Hanford Works, Richland, Washington.

Paas, H. J., and W. Singlevich. 1950. *Radioactive Contamination in the Environs of the Hanford Works for the Period October-December 1949*. HW-17003 DEL, General Electric Company, Hanford Works, Richland, Washington.

Paas, H. J., and W. Singlevich. 1950. *Radioactive Contamination in the Environs of the Hanford Works for the Period January-March 1950*. HW-18446, General Electric Company, Hanford Works, Richland, Washington.

Paas, H. J., and W. Singlevich. 1950. *Radioactive Contamination in the Environs of the Hanford Works for the Period April-June 1950*. HW-19454, General Electric Company, Hanford Works, Richland, Washington.

Singlevich, W. 1950. *H.I. Environs Report of the Month of September 1950*. HW-19046, General Electric Company, Hanford Works, Richland, Washington.

Singlevich, W. 1950. *H.I. Environs Report of the Month of October 1950*. HW-19454, General Electric Company, Hanford Works, Richland, Washington.

Singlevich, W. 1950. *H.I. Environs Report of the Month of November 1950*. HW-19625, General Electric Company, Hanford Works, Richland, Washington.

Singlevich, W. 1950. *H.I. Environs Report of the Month of December 1950*. HW-19896, General Electric Company, Hanford Works, Richland, Washington.

Paas, H. J., and W. Singlevich. 1951. *Radioactive Contamination in the Environs of the Hanford Works for the Period July-September 1950*. HW-20700, General Electric Company, Hanford Works, Richland, Washington.

Paas, H. J. 1951. *Radioactive Contamination in the Environs of the Hanford Works for the Period October-December 1950*. HW-21566, General Electric Company, Hanford Works, Richland, Washington.

Paas, H. J., and W. Singlevich. 1951. *Radioactive Contamination in the Environs of the Hanford Works for the Period January-March 1951*. HW-21214, General Electric Company, Hanford Works, Richland, Washington.

Paas, H. J. 1951. *Radioactive Contamination in the Environs of the Hanford Works for the Period April-June 1951*. HW-22313, General Electric Company, Hanford Works, Richland, Washington.

Paas, H. J. 1951. *Radioactive Contamination in the Environs of the Hanford Works for the Period July-September 1951*. HW-23133, General Electric Company, Hanford Works, Richland, Washington.

Paas, H. J. 1952. *Radioactive Contamination in the Environs of the Hanford Works for the Period October-December 1951*. HW-24203, General Electric Company, Hanford Works, Richland, Washington.

Paas, H. J. 1952. *Radioactive Contamination in the Environs of the Hanford Works for the Period January-March 1952*. HW-25866, General Electric Company, Hanford Works, Richland, Washington.

Paas, H. J. 1952. *Radioactive Contamination in the Environs of the Hanford Works for the Period April-June 1952*. HW-26493, General Electric Company, Hanford Works, Richland, Washington.

Paas, H. J. 1952. *Radioactive Contamination in the Environs of the Hanford Works for the Period July-September 1952*. HW-27510, General Electric Company, Hanford Works, Richland, Washington.

Paas, H. J. 1953. *Radioactive Contamination in the Environs of the Hanford Works for the Period October-December 1952*. HW-27641, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Paas, H. J. 1953. *Radioactive Contamination in the Environs of the Hanford Works for the Period January-March 1953*. HW-28009, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Paas, H. J. 1953. *Radioactive Contamination in the Environs of the Hanford Works for the Period April-June 1953*. HW-29514, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Paas, H. J. 1953. *Radioactive Contamination in the Environs of the Hanford Works for the Period July-September 1953*. HW-30174, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Paas, H. J. 1954. *Radioactive Contamination in the Environs of the Hanford Works for the Period October-December 1953*. HW-30744, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Paas, H. J. 1954. *Radioactive Contamination in the Environs of the Hanford Works for the Period January-March 1954*. HW-31818, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Paas, H. J., and G. E. Pilcher. 1954. *Radioactive Contamination in the Environs of the Hanford Works for the Period April-June 1954*. HW-33896, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Pilcher, G. E., J. K. Soldat, and Z. E. Carey. 1955. *Radioactive Contamination in the Environs of the Hanford Works for the Period July-September 1954*. HW-36504, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Pilcher, G. E. 1955. *Radioactive Contamination in the Environs of the Hanford Works for the Period October-December 1954*. HW-36505, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Pilcher, G. E. 1955. *Radioactive Contamination in the Environs of the Hanford Works for the Period January-March 1955*. HW-36506, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Anderson, B. V. 1955. *Radioactive Contamination in the Environs of the Hanford Works for the Period April-June 1955*. HW-38566, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Anderson, B. V., and J. K. Soldat. 1955. *Radioactive Contamination in the Environs of the Hanford Works for the Period July-September 1955*. HW-39429, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Anderson, B. V., and J. K. Soldat. 1956. *Radioactive Contamination in the Environs of the Hanford Works for the Period October-December 1955*. HW-40871, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Anderson, B. V., and J. K. Soldat. 1956. *Radioactive Contamination in the Environs of the Hanford Works for the Period January-March 1956*. HW-43012, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Anderson, B. V., and J. K. Soldat. 1956. *Radioactive Contamination in the Environs of the Hanford Works for the Period April-June 1956*. HW-44215, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Anderson, B. V., J. K. Soldat, and M. W. McConiga. 1956. *Radioactive Contamination in the Environs of the Hanford Works for the Period July-September 1956*. HW-46726, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Anderson, B. V., J. K. Soldat, and M. W. McConiga. 1957. *Radioactive Contamination in the Environs of the Hanford Works for the Period October-December 1956*. HW-48374, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

McConiga, M. W., and J. K. Soldat. 1957. *Radioactive Contamination in the Environs of the Hanford Works for the Period January-March 1957*. HW-51009, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

McConiga, M. W., and J. K. Soldat. 1957. *Radioactive Contamination in the Environs of the Hanford Works for the Period April-June 1957*. HW-52803, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

McConiga, M. W., and J. K. Soldat. 1957. *Radioactive Contamination in the Environs of the Hanford Works for the Period July-September 1957*. HW-54841, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

McConiga, M. W., J. M. Selby, and J. K. Soldat. 1958. *Radioactive Contamination in the Environs of the Hanford Works for the Period October-December 1957*. HW-54842, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Effluent and Waste Technology Quarterly and Semiannual Reports (1956 through 1965)

Earth Sciences Personnel. 1956. *Earth Sciences' Waste Disposal Monitoring Activities Summary, January 1956*. HW-43149, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Earth Sciences Personnel. 1956. *Earth Sciences' Waste Disposal Monitoring Activities Summary, April 1956*. HW-44354, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Brown, D. J. (ed.). 1957. *Chemical Effluents Technology Waste Disposal Investigations - July-September 1956*. HW-49465, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Brown, D. J. (ed.). 1957. *Chemical Effluents Technology Waste Disposal Investigations - October-December 1956*. HW-50186, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Brown, D. J. (ed.). 1957. *Chemical Effluents Technology Waste Disposal Investigations - January-March 1957*. HW-51095, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Brown, D. J. (ed.). 1957. *Chemical Effluents Technology Waste Disposal Investigations - April-June 1957*. HW-53225, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Brown, D. J. (ed.). 1957. *Chemical Effluents Technology Waste Disposal Investigations - July-September 1957*. HW-54655, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Bierschenk, W. H. (ed.). 1958. *Chemical Effluents Technology Waste Disposal Investigations - October-December 1957*. HW-54848, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Bierschenk, W. H. (ed.). 1958. *Chemical Effluents Technology Waste Disposal Investigations - January-March 1958*. HW-55841-RD, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Bierschenk, W. H. (ed.). 1958. *Chemical Effluents Technology Waste Disposal Investigations - April-June 1958*. HW-57002-RD, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Bierschenk, W. H. (ed.). 1958. *Chemical Effluents Technology Waste Disposal Investigations - July-September 1958*. HW-58023-RD, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Bierschenk, W. H. (ed.). 1959. *Chemical Effluents Technology Waste Disposal Investigations - October-December 1958*. HW-58811-RD, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Bierschenk, W. H. (ed.). 1959. *Chemical Effluents Technology Waste Disposal Investigations - January-March 1959*. HW-60163-RD, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Bierschenk, W. H. (ed.). 1959. *Chemical Effluents Technology Waste Disposal Investigations - April-June 1959*. HW-61197-RD, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Bierschenk, W. H. (ed.). 1959. *Chemical Effluents Technology Waste Disposal Investigations - July-September 1959*. HW-62692-RD, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Haney, W. A. (ed.). 1960. *Chemical Effluents Technology Waste Disposal Investigations - October-December 1959*. HW-64094-RD, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Haney, W. A. (ed.). 1960. *Chemical Effluents Technology Waste Disposal Investigations - January-March 1960*. HW-65464-RD, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Haney, W. A. (ed.) 1960. *Chemical Effluents Technology Waste Disposal Investigations - April-June 1960*. HW-66859-RD, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Haney, W. A. (ed.). 1960. *Chemical Effluents Technology Waste Disposal Investigations - July-September 1960*. HW-67753-RD, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Haney, W. A. (ed.). 1961. *Chemical Effluents Technology Waste Disposal Investigations - October-December 1960*. HW-68953-RD, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Haney, W. A. (ed.). 1961. *Chemical Effluents Technology Waste Disposal Investigations - January-June 1961*. HW-70806-RD, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Brown, D. J. (ed.). 1962. *Chemical Effluents Technology Waste Disposal Investigations - July-December 1961*. HW-72645-RD, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Brown, D. J. 1962. *Chemical Effluents Technology Waste Disposal Investigations - January-June 1962*. HW-74915-RD, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Brown, D. J. 1963. *Chemical Effluents Technology Waste Disposal Investigations - July-December 1962*. HW-76120-RD, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Haney, W. A. 1963. *Chemical Effluents Technology Waste Disposal Investigations - January-June 1963*. HW-78951-RD, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Brown, D. J., and W. A. Haney. 1964. *Chemical Effluents Technology Waste Disposal Investigations - July-December 1963*. HW-80909, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Brown, D. J. 1964. *Chemical Effluents Technology Waste Disposal Investigations - January-December 1964*. HW-84549, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Brown, D. J. 1965. *Chemical Effluents Technology Waste Disposal Investigations - January-June 1965*. BNWL-CC-285, Battelle Northwest Laboratory, Richland, Washington.

Eliason, J. R. 1966. *Earth Sciences Waste Disposal Investigations - July-December 1965.* BNWL-CC-574, Battelle Northwest Laboratory, Richland, Washington.

Eliason, J. R. 1966. *Earth Sciences Waste Disposal Investigations - January-June 1965.* BNWL-CC-887, Battelle Northwest Laboratory, Richland, Washington.

Environmental Monitoring Annual Reports (1958 through 2001)

Anderson, B. V. 1959. *Hanford Environmental Monitoring Annual Report 1958*. HW-61676, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Junkins, R. L., E. C. Watson, I. C. Nelson, and R. C. Henle. 1960. *Evaluation of Radiological Conditions in the Vicinity of Hanford for 1959*. HW-64371, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Foster, R. F., and I. C. Nelson. 1961. *Evaluation of Radiological Conditions in the Vicinity of Hanford for 1960*. HW-68435, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Foster, R. F., and I. C. Nelson. 1962. *Evaluation of Radiological Conditions in the Vicinity of Hanford for 1961*. HW-71999, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Foster, R. F., and R. H. Wilson. 1963. *Evaluation of Radiological Conditions in the Vicinity of Hanford for 1962*. HW-76526, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Foster, R. F., and R. H. Wilson. 1964. *Evaluation of Radiological Conditions in the Vicinity of Hanford for 1963*. HW-80991, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Foster, R. F., and R. H. Wilson. 1965. *Evaluation of Radiological Conditions in the Vicinity of Hanford for 1964*. BNWL-90, Battelle Northwest Laboratory, Richland, Washington.

Foster, R. F., J. K. Soldat, and T. H. Essig. 1966. *Evaluation of Radiological Conditions in the Vicinity of Hanford for 1965*. BNWL-316, Battelle Northwest Laboratory, Richland, Washington.

Foster, R. F., D. Moore, and T. H. Essig. 1966. *Evaluation of Radiological Conditions in the Vicinity of Hanford for 1965 Appendices*. BNWL-316 APP, Battelle Northwest Laboratory, Richland, Washington.

Honstead, J. F., T. H. Essig, and J. K. Soldat. 1967. *Evaluation of Radiological Conditions in the Vicinity of Hanford for 1966*. BNWL-439, Battelle Northwest Laboratory, Richland, Washington.

Honstead, J. F., and T. H. Essig. 1967. *Evaluation of Radiological Conditions in the Vicinity of Hanford for 1966 Appendices*. BNWL-439 APP, Battelle Northwest Laboratory, Richland, Washington.

Corley, J. P., and C. B. Wooldridge. 1969. *Evaluation of Radiological Conditions in the Vicinity of Hanford for 1967*. BNWL-983, Battelle Northwest Laboratory, Richland, Washington.

Corley, J. P., and C. B. Wooldridge. 1969. *Evaluation of Radiological Conditions in the Vicinity of Hanford for 1967 Appendices*. BNWL-983 APP, Battelle Northwest Laboratory, Richland, Washington.

Fisher, W. L., and C. B. Wilson. 1970. *Evaluation of Radiological Conditions in the Vicinity of Hanford for 1968*. BNWL-1341, Battelle Northwest Laboratory, Richland, Washington.

Fisher, W. L., and C. B. Wilson. 1970. *Evaluation of Radiological Conditions in the Vicinity of Hanford for 1968 Appendices*. BNWL-1341 APP, Battelle Northwest Laboratory, Richland, Washington.

Corley, J. P., C. B. Wilson, and T. H. Essig. 1970. *Evaluation of Radiological Conditions in the Vicinity of Hanford for 1969*. BNWL-1505, Battelle Northwest Laboratory, Richland, Washington.

Corley, J. P., and C. B. Wilson. 1970. *Evaluation of Radiological Conditions in the Vicinity of Hanford for 1969 Appendices*. BNWL-1505 APP, Battelle Northwest Laboratory, Richland, Washington.

Bramson, P. E., and J. P. Corley. 1972. *Environmental Surveillance at Hanford for CY 1971*. BNWL-1683, Battelle Northwest Laboratory, Richland, Washington.

Bramson, P. E., and J. P. Corley. 1972. *Environmental Surveillance at Hanford for CY 1971 (Addendum)*. BNWL-1683 ADD, Battelle Northwest Laboratory, Richland, Washington.

Corley, J. P. 1973. *Environmental Surveillance at Hanford for CY 1970*. BNWL-1669, Battelle Northwest Laboratory, Richland, Washington.

Corley, J. P. 1973. *Environmental Surveillance at Hanford for CY 1970 Data*. BNWL-1669 ADD, Battelle Northwest Laboratory, Richland, Washington.

Bramson, P. E., and J. P. Corley. 1973. *Environmental Surveillance at Hanford for CY 1972*. BNWL-1727, Battelle Northwest Laboratory, Richland, Washington.

Bramson, P. E., and J. P. Corley. 1973. *Environmental Surveillance at Hanford for CY 1972 Data*. BNWL-1727 ADD, Battelle Northwest Laboratory, Richland, Washington.

Nees, W. L., and J. P. Corley. 1974. *Environmental Surveillance at Hanford for CY 1973*. BNWL-1811, Battelle Northwest Laboratory, Richland, Washington.

Nees, W. L., and J. P. Corley. 1974. *Environmental Surveillance at Hanford for CY 1973 Data*. BNWL-1811 ADD, Battelle Northwest Laboratory, Richland, Washington.

Fix, J. J. 1975. *Environmental Surveillance at Hanford for CY 1974*. BNWL-1910, Battelle Northwest Laboratory, Richland, Washington.

Fix, J. J., and P. J. Blumer. 1975. *Environmental Surveillance at Hanford for CY 1974 Data*. BNWL-1910 ADD, Battelle Northwest Laboratory, Richland, Washington.

Speer, D. R., J. J. Fix, and P. J. Blumer. 1976. *Environmental Surveillance at Hanford for CY 1975*. BNWL-1979 Rev., Battelle Northwest Laboratory, Richland, Washington.

Fix, J. J., P. J. Blumer, and D. R. Speer. 1976. *Environmental Surveillance at Hanford for CY 1975 Data*. BNWL-1980, Battelle Northwest Laboratory, Richland, Washington.

Fix, J. J., P. J. Blumer, G. R. Hoenes, and P. E. Bramson. 1977. *Environmental Surveillance at Hanford for CY 1976*. BNWL-2142, Battelle Northwest Laboratory, Richland, Washington.

Blumer, P. J., and J. J. Fix. 1977. *Environmental Surveillance at Hanford for CY 1976 Data*. BNWL-2142 ADD, Battelle Northwest Laboratory, Richland, Washington.

Houston, J. R., and P. J. Blumer. 1978. *Environmental Surveillance at Hanford for CY 1977*. PNL-2614, Pacific Northwest Laboratory, Richland, Washington.

Houston, J. R., and P. J. Blumer. 1979. *Environmental Surveillance at Hanford for CY 1978*. PNL-2932, Pacific Northwest Laboratory, Richland, Washington.

Houston, J. R., and P. J. Blumer. 1980. *Environmental Surveillance at Hanford for CY 1979*. PNL-3283, Pacific Northwest Laboratory, Richland, Washington.

Sula, M. J., and P. J. Blumer. 1981. *Environmental Surveillance at Hanford for CY 1980*. PNL-3728, Pacific Northwest Laboratory, Richland, Washington.

Sula, M. J., W. D. McCormack, R. L. Dirkes, K. R. Price, and P. A. Eddy. 1982. *Environmental Surveillance at Hanford for CY 1981*. PNL-4211, Pacific Northwest Laboratory, Richland, Washington.

Sula, M. J., J. M. V. Carlile, K. R. Price, and W. D. McCormack. 1983. *Environmental Surveillance at Hanford for CY 1982*. PNL-4657, Pacific Northwest Laboratory, Richland, Washington.

Price, K. R., J. M. V. Carlile, R. L. Dirkes, and M. S. Trevathan. 1984. *Environmental Surveillance at Hanford for CY 1983*. PNL-5038, Pacific Northwest Laboratory, Richland, Washington.

Price, K. R., J. M. V. Carlile, R. L. Dirkes, R. E. Jaquish, M. S. Trevathan, and R. K. Woodruff. 1985. *Environmental Surveillance at Hanford for CY 1984*. PNL-5407, Pacific Northwest Laboratory, Richland, Washington.

Price, K. R. 1986. *Environmental Monitoring at Hanford for 1985*. PNL-5817, Pacific Northwest Laboratory, Richland, Washington.

Pacific Northwest Laboratory. 1987. *Environmental Monitoring at Hanford for 1986*. PNL-6120, Richland, Washington.

Jaquish, R. E., and P. J. Mitchell (eds.). 1988. *Environmental Monitoring at Hanford for 1987*. PNL-6464, Pacific Northwest Laboratory, Richland, Washington.

Jaquish, R. E., and R. W. Bryce (eds.). 1989. *Hanford Site Environmental Report for Calendar Year 1988*. PNL-6825, Pacific Northwest Laboratory, Richland, Washington.

Jaquish, R. E., and R. W. Bryce (eds.). 1990. *Hanford Site Environmental Report for Calendar Year 1989*. PNL-7346, Pacific Northwest Laboratory, Richland, Washington.

Woodruff, R. K., R. W. Hanf, M. G. Hefty, and R. E. Lundgren (eds.). 1991. *Hanford Site Environmental Report for Calendar Year 1990*. PNL-7930, Pacific Northwest Laboratory, Richland, Washington.

Woodruff, R. K., R. W. Hanf, and R. E. Lundgren (eds.). 1992. *Hanford Site Environmental Report for Calendar Year 1991*. PNL-8148, Pacific Northwest Laboratory, Richland, Washington.

Woodruff, R. K., R. W. Hanf, and R. E. Lundgren (eds.). 1993. *Hanford Site Environmental Report for Calendar Year 1992*. PNL-8682, Pacific Northwest Laboratory, Richland, Washington.

Dirkes, R. L., R. W. Hanf, R. K. Woodruff, and R. E. Lundgren (eds.). 1994. *Hanford Site Environmental Report for Calendar Year 1993*. PNL-9823, Pacific Northwest Laboratory, Richland, Washington.

Dirkes, R. L., and R. W. Hanf. 1995. *Hanford Site Environmental Report for Calendar Year 1994*. PNL-10574, Pacific Northwest Laboratory, Richland, Washington.

Schmidt, J. W., J. W. Fassett, A. R. Johnson, V. G. Johnson, B. M. Markes, S. M. McKinney, K. J. Moss, C. J. Perkins, and L. R. Richterich. 1995. *Westinghouse Hanford Company Operational Environmental Monitoring Annual Report, Calendar Year 1994*. WHC-EP-0573-3, Westinghouse Hanford Company, Richland, Washington.

Palmer, A. J., and S. M. Beeler. 1996. *Annual Environmental Monitoring Report for Calendar Year 1995, US Ecology Richland, Washington Low-Level Radioactive Waste Disposal Facility*. US Ecology, Inc., Richland, Washington.

Dirkes, R. L., and R. W. Hanf (eds.). 1996. *Hanford Site Environmental Report for Calendar Year 1995*. PNNL-11139, Pacific Northwest National Laboratory, Richland, Washington.

Schmidt, J. W., J. W. Fasset, V. G. Johnson, R. M. Mitchell, B. M. Markes, S. M. McKinney, K. J. Moss, and C. J. Perkins. 1996. *Westinghouse Hanford Company Operational Environmental Monitoring Annual Report, Calendar Year 1995*. WHC-EP-0573-4, Westinghouse Hanford Company, Richland, Washington.

Dirkes, R. L., and R. W. Hanf (eds.). 1997. *Hanford Site Environmental Report for Calendar Year 1996*. PNNL-11472, Pacific Northwest National Laboratory, Richland, Washington.

Gleckler, B. P. 1997. *Environmental Releases for Calendar Year 1996*. HNF-EP-0527-6, Waste Management Federal Services of Hanford Inc. for Fluor Daniel Hanford, Inc., Richland, Washington.

Perkins, C. J., A. R. Johnson, B. M. Markes, S. M. McKinney, and R. M. Mitchell. 1997. *Hanford Site Near-Facility Environmental Monitoring Annual Report, Calendar Year 1996*. HNF-EP-0573-5, Waste Management Federal Services of Hanford, Inc. for Fluor Daniel Hanford, Inc., Richland, Washington.

Tanaka, K. 1997. *Siemens Power Corporation - Nuclear Division, 1996 Annual RCRA Report, Groundwater Quality Assessment Program*. EMF-1933, Siemens Power Corporation, Richland, Washington.

Dirkes, R. L., and R. W. Hanf (eds.). 1998. *Hanford Site Environmental Report for Calendar Year 1997*. PNNL-11795, Pacific Northwest National Laboratory, Richland, Washington.

Perkins, C. J., A. R. Johnson, B. M. Markes, S. M. McKinney, and R. M. Mitchell. 1998. *Hanford Site Near-Facility Environmental Monitoring Annual Report, Calendar Year 1997*. HNF-EP-0573-6, Waste Management Federal Services, Inc. for Fluor Daniel Hanford, Inc., Richland, Washington.

Dirkes, R. L., R. W. Hanf, and T.M. Poston (eds.). 1999. *Hanford Site Environmental Report for Calendar Year 1998*. PNNL-12088, Pacific Northwest National Laboratory, Richland, Washington.

Poston, T. M., R. W. Hanf, and R.L. Dirkes (eds.). 2000. *Hanford Site Environmental Report for Calendar Year 1999*. PNNL-13230, Pacific Northwest National Laboratory, Richland, Washington.

Poston, T. M., R. W. Hanf, R.L. Dirkes, and L.F. Morasch (eds.). 2001. *Hanford Site Environmental Report for Calendar Year 2000*. PNNL-13487, Pacific Northwest National Laboratory, Richland, Washington.

Poston, T. M., R. W. Hanf, R.L. Dirkes, and L.F. Morasch (eds.). 2002. *Hanford Site Environmental Report for Calendar Year 2001*. PNNL-13910, Pacific Northwest National Laboratory, Richland, Washington.

Rockwell Hanford Operations/Westinghouse Hanford Company Environmental Surveillance Reports

Wheeler, R. E., and A. G. Law. 1980. *Rockwell Hanford Operations Environmental Surveillance Report for Calendar Year 1979*. RHO-LD-132, Rockwell Hanford Operations, Richland, Washington.

Conklin, A. W., R. E. Elder, W. L. Osborne, and J. M. Pisarcik. 1982. *Rockwell Hanford Operations Environmental Surveillance Annual Report - Calendar Year 1981*. RHO-HS-SR-82-4P, Rockwell Hanford Operations, Richland, Washington.

Conklin, A. W., R. E. Elder, and W. L. Osborne. 1982. *Rockwell Hanford Operations Environmental Surveillance Annual Report - Calendar Year 1982*. RHO-HS-SR-82-13 P, Rockwell Hanford Operations, Richland, Washington.

Conklin, A. W., R. E. Elder, V. G. Johnson, W. L. Osborne, and A. G. Law. 1984. *Rockwell Hanford Operations Environmental Surveillance Annual Report - Calendar Year 1983*. RHO-HS-SR-83-13 Rev 1P, Rockwell Hanford Operations, Richland, Washington.

Elder, R. E., A. W. Conklin, G. W. Egert, D. D. Brekke, and W. L. Osborne. 1986. *Rockwell Hanford Operations Environmental Surveillance Annual Report - Calendar Year 1985*. RHO-HS-SR-85-13 P, Rockwell Hanford Operations, Richland, Washington.

Elder, R. E., G. W. Egert, A. R. Johnson, and W. L. Osborne. 1986. *Rockwell Hanford Operations Environmental Surveillance Annual Report - Calendar Year 1986*. RHO-HS-SR-86-13 P, Rockwell Hanford Operations, Richland, Washington.

Perkins, C. J. 1988. *Westinghouse Hanford Company Environmental Surveillance Annual Report - 100 Areas, Calendar Year 1987*. WHC-EP-0161, Westinghouse Hanford Company, Richland, Washington.

UNC Nuclear Industries' Environmental Surveillance Reports

Greager, E. M. 1980. *Radiological Surveillance Report for the 100-N Area Environment - 1980*. UNI-1581, UNC Nuclear Industries, Richland, Washington.

Greager, E. M. 1981. *UNC Environmental Surveillance Report for the 100 Areas - FY 1981*. UNI-1849, UNC Nuclear Industries, Richland, Washington.

Greager, E. M. 1982. *UNC Environmental Surveillance Report for the 100 Areas - FY 1982*. UNI-2226, UNC Nuclear Industries, Richland, Washington.

Greager, E. M. 1983. *UNC Environmental Surveillance Report for the 100 Areas - FY 1983*. UNI-2640, UNC Nuclear Industries, Richland, Washington.

Greager, E. M. 1984. *UNC Environmental Surveillance Report for the 100 Areas - FY 1984*. UNI-3069, UNC Nuclear Industries, Richland, Washington.

Jacques, I. D. 1986. *UNC Environmental Surveillance Report for the 100 Areas - FY 1985*. UNI-3760, UNC Nuclear Industries, Richland, Washington.

Jacques, I. D. 1987. *UNC Environmental Surveillance Report for the 100 Areas - FY 1986*. UNI-4065, UNC Nuclear Industries, Richland, Washington.

Environmental Status Annual Reports (1965 through 1983)

Essig, T. H., and R. B. Ball. 1966. *Environmental Status of the Hanford Project - 1965 Annual Summary*. BNWL-CC-913, Battelle Northwest Laboratory, Richland, Washington.

Essig, T. H., and R. B. Ball. 1967. *Environmental Status of the Hanford Reservation from December 1966*. BNWL-CC-637-12, Battelle Northwest Laboratory, Richland, Washington.

Wooldridge, C. B. (ed.). 1968. *Environmental Status of the Hanford Reservation for November-December 1967*. BNWL-CC-1197-6, Battelle Northwest Laboratory, Richland, Washington.

Wooldridge, C. B. (ed.). 1968. *Environmental Status of the Hanford Reservation for January-June 1968*. BNWL-CC-1850, Battelle Northwest Laboratory, Richland, Washington.

Wooldridge, C. B. (ed.). 1969. *Environmental Status of the Hanford Reservation for July-December 1968*. BNWL-CC-2026, Battelle Northwest Laboratory, Richland, Washington.

Wilson, C. B., and T. H. Essig (eds.). 1970. *Environmental Status of the Hanford Reservation for January-June 1969*. BNWL-CC-2478, Battelle Northwest Laboratory, Richland, Washington.

Wilson, C. B., and T. H. Essig (eds.). 1971. *Environmental Status of the Hanford Reservation for July-December 1969*. BNWL-CC-2583, Battelle Northwest Laboratory, Richland, Washington.

Bramson, P. E. (ed.) 1972. *Environmental Status of the Hanford Reservation for 1970*. BNWL-C-96, Battelle Northwest Laboratory, Richland, Washington.

Bramson, P. E., and J. P. Corley. 1972. *Environmental Status of the Hanford Reservation for 1971*. BNWL-B-228, Battelle Northwest Laboratory, Richland, Washington.

Bramson, P. E., J. P. Corley, and W. L. Nees. 1973. *Environmental Status of the Hanford Reservation for CY 1972*. BNWL-B-278, Battelle Northwest Laboratory, Richland, Washington.

Nees, W. L., and J. P. Corley. 1975. *Environmental Status of the Hanford Reservation for CY 1973*. BNWL-B-336, Battelle Northwest Laboratory, Richland, Washington.

Fix, J. J. 1975. *Environmental Status of the Hanford Reservation for CY 1974*. BNWL-B-429, Battelle Northwest Laboratory, Richland, Washington.

Fix, J. J., D. R. Speer, and P. J. Blumer. 1976. *Environmental Status of the Hanford Site for CY 1975*. BNWL-B-477, Battelle Northwest Laboratory, Richland, Washington.

Fix, J. J., P. J. Blumer, and P. E. Bramson. 1977. *Environmental Status of the Hanford Site for CY 1976*. BNWL-2246, Battelle Northwest Laboratory, Richland, Washington.

Houston, J. R., and P. J. Blumer. 1978. *Environmental Status of the Hanford Site for CY 1977*. PNL-2677, Pacific Northwest Laboratory, Richland, Washington.

Houston, J. R., and P. J. Blumer. 1979. *Environmental Status of the Hanford Site for CY 1978*. PNL-2933, Pacific Northwest Laboratory, Richland, Washington.

Houston, J. R., and P. J. Blumer. 1980. *Environmental Status of the Hanford Site for CY 1979*. PNL-3284, Pacific Northwest Laboratory, Richland, Washington.

Sula, M. J., P. J. Blumer, and R. L. Dirkes. 1981. *Environmental Status of the Hanford Site for CY 1980*. PNL-3729, Pacific Northwest Laboratory, Richland, Washington.

Sula, M. J., P. J. Blumer, and R. L. Dirkes. 1982. *Environmental Status of the Hanford Site for CY 1981*. PNL-4212, Pacific Northwest Laboratory, Richland, Washington.

Sula, M. J., P. J. Blumer, R. L. Dirkes, and J.M.V. Carlile. 1983. *Environmental Status of the Hanford Site for CY 1982*. PNL-4658, Pacific Northwest Laboratory, Richland, Washington.

Price, K. R., P. J. Blumer, J.M.V. Carlile, R. L. Dirkes, and M. S. Trevathan. 1984. *Environmental Status of the Hanford Site for CY 1983*. PNL-5039, Pacific Northwest Laboratory, Richland, Washington.

Groundwater Monitoring Quarterly and Annual Reports

Essig, T. H. 1968. *Radiological Status of the Groundwater Beneath the Hanford Project, July-December 1967*. BNWL-835, Battelle Northwest Laboratory, Richland, Washington.

Essig, T. H. 1969. *Radiological Status of the Groundwater Beneath the Hanford Project, January-June 1968*. BNWL-984, Battelle Northwest Laboratory, Richland, Washington.

Denham, D. H. 1969. *Radiological Status of the Groundwater Beneath the Hanford Project, July-December 1968*. BNWL-1047, Battelle Northwest Laboratory, Richland, Washington.

Denham, D. H. 1969. *Radiological Status of the Groundwater Beneath the Hanford Project, January-June 1969*. BNWL-1233, Battelle Northwest Laboratory, Richland, Washington.

Denham, D. H. 1970. *Radiological Status of the Groundwater Beneath the Hanford Project, July-December 1969*. BNWL-1392, Battelle Northwest Laboratory, Richland, Washington.

Essig, T. H. 1970. *Radiological Status of the Groundwater Beneath the Hanford Project, January-June 1970*. BNWL-1539, Battelle Northwest Laboratory, Richland, Washington.

Essig, T. H. 1971. *Radiological Status of the Groundwater Beneath the Hanford Project, July-December 1970*. BNWL-1613, Battelle Northwest Laboratory, Richland, Washington.

Kipp, K. L., Jr. 1972. *Radiological Status of the Groundwater Beneath the Hanford Project, January-June 1971*. BNWL-1649, Battelle Northwest Laboratory, Richland, Washington.

Kipp, K. L., Jr. 1973. *Radiological Status of the Groundwater Beneath the Hanford Project, July-December 1971*. BNWL-1680, Battelle Northwest Laboratory, Richland, Washington.

Kipp, K. L., Jr. 1973. *Radiological Status of the Groundwater Beneath the Hanford Project, January-June 1972*. BNWL-1737, Battelle Northwest Laboratory, Richland, Washington.

Kipp, K. L., Jr. 1973. *Radiological Status of the Groundwater Beneath the Hanford Project, July-December 1972*. BNWL-1752, Battelle Northwest Laboratory, Richland, Washington.

Kipp, K. L., Jr. 1975. *Radiological Status of the Groundwater Beneath the Hanford Project, January-December 1973*. BNWL-1860, Battelle Northwest Laboratory, Richland, Washington.

Raymond, J. R., D. A. Myers, J. J. Fix, V. L. McGhan, and P. M. Schrotke. 1976. *Environmental Monitoring Report on Radiological Status of the Groundwater Beneath the Hanford Site, January-December 1974*. BNWL-1970, Battelle Northwest Laboratory, Richland, Washington.

Myers, D. A., J. J. Fix, P. J. Blumer, J. R. Raymond, V. L. McGhan, and E. L. Hilty. 1976. *Environmental Monitoring Report on Radiological Status of the Groundwater Beneath the Hanford Site, January-December 1975*. BNWL-2034, Battelle Northwest Laboratory, Richland, Washington.

Myers, D. A., J. J. Fix, and J. R. Raymond. 1977. *Environmental Monitoring Report on Radiological Status of the Groundwater Beneath the Hanford Site, January-December 1976*. BNWL-2199, Battelle Northwest Laboratory, Richland, Washington.

Myers, D. A. 1978. *Environmental Monitoring Report on Radiological Status of the Groundwater Beneath the Hanford Site, January-December 1977*. PNL-2624, Pacific Northwest Laboratory, Richland, Washington.

Eddy, P. A. 1979. *Environmental Monitoring Report on Radiological Status of the Groundwater Beneath the Hanford Site, January-December 1978*. PNL-2899, Pacific Northwest Laboratory, Richland, Washington.

Eddy, P. A., and J. S. Wilbur. 1980. *Environmental Monitoring Report on Radiological Status of the Groundwater Beneath the Hanford Site, January-December 1979*. PNL-3346, Pacific Northwest Laboratory, Richland, Washington.

Eddy, P. A., and J. S. Wilbur. 1981. *Environmental Monitoring Report on Radiological Status of the Groundwater Beneath the Hanford Site, January-December 1980*. PNL-3768, Pacific Northwest Laboratory, Richland, Washington.

Eddy, P. A., C. S. Cline, and L. S. Prater. 1982. *Environmental Monitoring Report on Radiological Status of the Groundwater Beneath the Hanford Site, January-December 1981*. PNL-4237, Pacific Northwest Laboratory, Richland, Washington.

Eddy, P. A., L. S. Prater, and J. T. Rieger. 1983. *Ground-Water Surveillance at the Hanford Site for CY 1982*. PNL-4659, Pacific Northwest Laboratory, Richland, Washington.

Prater, L. S., J. T. Rieger, C. S. Cline, E. J. Jensen, T. L. Liikala, K. R. Oster, and P. A. Eddy. 1984. *Ground-Water Surveillance at the Hanford Site for CY 1983*. PNL-5041, Pacific Northwest Laboratory, Richland, Washington.

Cline, C. S., J. T. Rieger, J. R. Raymond, and P. A. Eddy. 1985. *Ground-Water Monitoring at the Hanford Site, January-December 1984*. PNL-5408, Pacific Northwest Laboratory, Richland, Washington.

Evans, J. C., P. J. Mitchell, and D. I. Dennison. 1988. *Hanford Site Ground-Water Monitoring for April through June 1987*. PNL-6315-1, Pacific Northwest Laboratory, Richland, Washington.

Evans, J. C., D. I. Dennison, R. W. Bryce, P. J. Mitchell, D. R. Sherwood, K. M. Krupka, N. W. Hinman, E. A. Jacobson, and M. D. Freshley. 1988. *Hanford Site Ground-Water Monitoring for July Through December 1987*. PNL-6315-2, Pacific Northwest Laboratory, Richland, Washington.

Evans, J. C., R. W. Bryce, and D. R. Sherwood. 1989. *Hanford Site Ground-Water Monitoring for January through June 1988*. PNL-6886, Pacific Northwest Laboratory, Richland, Washington.

Evans, J. C., R. W. Bryce, D. R. Sherwood, M. L. Kemner, and D. R. Newcomer. 1989. *Hanford Site Ground-Water Monitoring for July through December 1988*. PNL-7120, Pacific Northwest Laboratory, Richland, Washington.

Evans, J. C., R. W. Bryce, and M. L. Kemner. 1990. *Hanford Site Ground-Water Surveillance for 1989*. PNL-7396, Pacific Northwest Laboratory, Richland, Washington.

Evans, J. C., R. W. Bryce, and D. J. Bates. 1992. *Hanford Site Ground-Water Monitoring for 1990*. PNL-8073, Pacific Northwest Laboratory, Richland, Washington.

Evans, J. C., R. W. Bryce, and D. J. Bates. 1992. *Hanford Site Ground-Water Monitoring for 1991*. PNL-8284, Pacific Northwest Laboratory, Richland, Washington.

Dresel, P. E., D. J. Bates, and J. K. Merz. 1993. *Hanford Site Environmental Data for Calendar Year 1990 - Ground Water*. PNL-8582, Pacific Northwest Laboratory, Richland, Washington.

Dresel, P. E., D. J. Bates, and J. K. Merz. 1993. *Hanford Site Environmental Data for Calendar Year 1991 - Ground Water*. PNL-8581, Pacific Northwest Laboratory, Richland, Washington.

Dresel, P. E., D. R. Newcomer, J. C. Evans, W. D. Webber, F. A. Spane, Jr., R. G. Raymond, and B. E. Opitz. 1993. *Hanford Site Ground-Water Monitoring for 1992*. PNL-8716, Pacific Northwest Laboratory, Richland, Washington.

Merz, J. K., and P. E. Dresel. 1993. *Hanford Site Environmental Data for Calendar Year 1992 - Ground Water*. PNL-8884, Pacific Northwest Laboratory, Richland, Washington.

Dresel, P. E., S. P. Luttrell, J. C. Evans, W. D. Webber, P. D. Thorne, M. A. Chamness, B. M. Gillespie, B. E. Opitz, J. T. Rieger, and J. K. Merz. 1994. *Hanford Site Ground-Water Monitoring for 1993*. PNL-10082, Pacific Northwest Laboratory, Richland, Washington.

Dresel, P. E., P. D. Thorne, S. P. Luttrell, B. M. Gillespie, W. D. Webber, J. K. Merz, J. T. Rieger, M. A. Chamness, S. K. Wurstner, and B. E. Opitz. 1995. *Hanford Site Ground-Water Monitoring for 1994*. PNL-10698, Pacific Northwest Laboratory, Richland, Washington.

Kemp, C. J., and B. H. Ford. 1996. *Fiscal Year 1996 Groundwater Sampling for the Horn Rapids Landfill*. BHI-00949, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Geraghty & Miller, Inc. 1996. *Siemens Power Corporation Quarterly Groundwater Monitoring Summary Fourth Quarter 1995*. EMF-1865, Addendum 3, Issue Date: 3/7/96, for Siemens Power Corporation, Richland, Washington.

Siemens Power Corporation. 1996. *Quarterly Groundwater Monitoring Summary, Second Quarter 1996.* EMF-1865, Addendum 5, Richland, Washington.

Dresel, P. E., J. T. Rieger, W. D. Webber, P. D. Thorne, B. M. Gillespie, S. P. Luttrell, S. K. Wurstner, and T. L. Liikala. 1996. *Hanford Site Ground-Water Monitoring for 1995*. PNNL-11141, Pacific Northwest National Laboratory, Richland, Washington.

Hartman, M. J., and P. E. Dresel (eds.). 1997. *Hanford Site Groundwater Monitoring for Fiscal Year 1996*. PNNL-11470, Pacific Northwest National Laboratory, Richland, Washington.

Siemens Power Corporation. 1997. *1996 Annual RCRA Report, Groundwater Quality Assessment Program*. EMF-1933, Richland, Washington.

Hartman, M. J., and P. E. Dresel (eds.). 1998. *Hanford Site Groundwater Monitoring for Fiscal Year 1997*. PNNL-11793, Pacific Northwest National Laboratory, Richland, Washington.

Siemens Power Corporation. 1998. *Quarterly Groundwater Monitoring Summary - Fourth Quarter 1997*. EMF-1865, Addendum 11, Richland, Washington.

Siemens Power Corporation. 1998. *Quarterly Groundwater Monitoring Summary - Third Quarter 1998*. EMF-1865, Addendum 14, Richland, Washington.

Hartman, M. J. (ed.). 1999. *Hanford Site Groundwater Monitoring for Fiscal Year 1998*. PNNL-12086, Pacific Northwest National Laboratory, Richland, Washington.

Siemens Power Corporation. 1999. *Quarterly Groundwater Monitoring Summary - Fourth Quarter 1998*. EMF-1865, Addendum 15, Richland, Washington.

Siemens Power Corporation. 1999. *Quarterly Groundwater Monitoring Summary - Third Quarter 1999*. EMF-1865, Addendum 18, Richland, Washington.

Siemens Power Corporation. 2000. *Quarterly Groundwater Monitoring Summary - Fourth Quarter 1999*. EMF-1865, Addendum 19. Siemens Power Corporation, Richland, Washington.

Siemens Power Corporation. 2000. *Quarterly Groundwater Monitoring Summary - Third Quarter 2000*.

EMF-1865, Addendum 22, Siemens Power Corporation, Richland, Washington.

Faurote, J. M., T. M. Johnson, and C. W. Miller. 2000. *Groundwater Monitoring and Sampling at the Environmental Restoration Disposal Facility, Calendar Year 2000.* BHI-01489, Bechtel Hanford, Inc., Richland, Washington.

City of Richland. 2001. *Horn Rapids Landfill Environmental Monitoring Report – First Quarter 2001.* City of Richland, Public Works Department, Richland, Washington.

City of Richland. 2001. *Horn Rapids Landfill Environmental Monitoring Report – Second Quarter 2001.* City of Richland, Public Works Department, Richland, Washington.

City of Richland. 2001. *Horn Rapids Landfill Environmental Monitoring Report – Calendar Year 2000.* City of Richland, Public Works Department, Richland, Washington.

City of Richland. 2001. *Horn Rapids Landfill Environmental Monitoring Report – Third Quarter 2001.* City of Richland, Public Works Department, Richland, Washington.

Framatome ANP Richland, Inc. 2001. *Quarterly Groundwater Monitoring Summary – Second Quarter 2001.* EMF-1865, Addenda 25. Framatome ANP Richland, Inc., Richland, Washington.

Framatome ANP Richland, Inc. 2001. *Quarterly Groundwater Monitoring Summary – Third Quarter 2001.* EMF-1865, Addenda 26, Framatome ANP Richland, Inc., Richland, Washington.

Hartman, M. J., L. F. Morasch, and W. D. Webber (eds.). 2001. *Hanford Site Groundwater Monitoring for Fiscal Year 2000.* PNNL-13404, Pacific Northwest National Laboratory, Richland, Washington.

City of Richland. 2002a. *Horn Rapids Landfill Environmental Monitoring Report – Calendar Year 2001.* City of Richland, Public Works Department, Richland, Washington.

City of Richland. 2002b. *Horn Rapids Landfill Environmental Monitoring Report – First Quarter 2002.* City of Richland, Public Works Department, Richland, Washington.

City of Richland. 2002c. *Horn Rapids Landfill Environmental Monitoring Report – Second Quarter 2002.* City of Richland, Public Works Department, Richland, Washington.

City of Richland. 2002d. *Horn Rapids Landfill Environmental Monitoring Report – Third Quarter 2002.* City of Richland, Public Works Department, Richland, Washington.

Framatome ANP Richland, Inc. 2002. *Quarterly Groundwater Monitoring Summary – Fourth Quarter 2001.* EMF-1865, Addenda 27, Richland, Washington.

Framatome ANP Richland, Inc. 2002. *Quarterly Groundwater Monitoring Summary – Third Quarter 2002.* EMF-1865, Addenda 30, Richland, Washington.

Hartman, M. J., L. F. Morasch, and W. D. Webber (eds.). 2002. *Hanford Site Groundwater Monitoring for Fiscal Year 2001.* PNNL-13788, Pacific Northwest National Laboratory, Richland, Washington.

Miller, C. W., C. S. Wright, and R. S. Edrington. 2002. *Groundwater Monitoring and Sampling at the Environmental Restoration Disposal Facility, Calendar Year 2001*. BHI-01641, Rev. 0, Bechtel Hanford Inc., Richland, Washington.

Separations Areas Annual Reports

Graham, M. J., and W. R. Brown. 1981. *Results of the Separations Area Ground-Water Monitoring Network for 1980*. RHO-LD-165, Informal Report, Rockwell Hanford Operations, Richland, Washington.

Wilbur, J. S., M. J. Graham, and A. H. Lu. 1983. *Results of the Separations Area Ground-Water Monitoring Network for 1982*. RHO-RE-SR-83-24P, Rockwell Hanford Operations, Richland, Washington.

Law, A. G., and R. M. Allen. 1984. *Results of the Separations Area Ground-Water Monitoring Network for 1983*. RHO-RE-SR-84-24P, Rockwell Hanford Operations, Richland, Washington.

Law, A. G., and A. L. Schatz. 1986. *Results of the Separations Area Ground-Water Monitoring Network for 1985*. RHO-RE-SR-86-24P, Rockwell Hanford Operations, Richland, Washington.

Law, A. G., A. L. Schatz, M. R. Fuchs, and K. L. Dillon. 1986. *Results of the Separations Area Ground-Water Monitoring Network for 1984*. RHO-RE-SR-85-24P, Rockwell Hanford Operations, Richland, Washington.

Law, A. G., J. A. Serkowski, and A. L. Schatz. 1987. *Results of the Separations Area Ground-Water Monitoring Network for 1986*. RHO-RE-SR-87-24P, Rockwell Hanford Operations, Richland, Washington.

Serkowski, J. A., A. G. Law, J. J. Ammerman, and A. L. Schatz. 1988. *Results of Ground-Water Monitoring for Radionuclides in the Separations Area - 1987*. WHC-EP-0152, Westinghouse Hanford Company, Richland, Washington.

Serkowski, J. A., and W. A. Jordan. 1989. *Operational Groundwater Monitoring at the Hanford Site-1988*. WHC-EP-0260, Westinghouse Hanford Company, Richland, Washington.

Groundwater Compliance (RCRA) Monitoring Reports

U.S. Department of Energy. 1985. *Closure/Post-Closure Plan for the 300 Areas Process Trenches*. TRAC-0098, Richland Operations Office, Richland, Washington.

Pacific Northwest Laboratory. 1986. *Ground-Water Monitoring Compliance Projects for Hanford Site Facilities: Progress Report for the Period May 1 to September 30, 1986*. PNL-6466, Richland, Washington.

Pacific Northwest Laboratory. 1986. *Revised Ground-Water Monitoring Compliance Plan for the 183-H Solar Evaporation Basins*. PNL-6470, prepared for the U.S. Department of Energy, Richland, Washington.

Pacific Northwest Laboratory. 1987. *Ground-Water Monitoring Compliance Projects for Hanford Site Facilities: Progress Report for the Period October 1 to December 31, 1986*, 3 vols. PNL-6465, Richland, Washington.

Pacific Northwest Laboratory. 1987. *Ground-Water Monitoring Compliance Projects for Hanford Site Facilities: Progress Report for the Period January 1 to March 31, 1987*, 3 vols. PNL-6467, Richland, Washington.

Pacific Northwest Laboratory. 1987. *Ground-Water Monitoring Compliance Projects for Hanford Site Facilities: Progress Report for the Period April 1 to June 30, 1987*. PNL-6468, Richland, Washington.

Pacific Northwest Laboratory. 1987. *Ground-Water Monitoring Compliance Projects for Hanford Site Facilities: Progress Report for the Period July 1 to September 30, 1987*. PNL-6469, Richland, Washington.

Pacific Northwest Laboratory. 1987. *Interim Characterization Report for the Area Surrounding the 183-H Solar Evaporation Basins*. PNL-6471, Richland, Washington.

Pacific Northwest Laboratory. 1988. *Ground-Water Monitoring Compliance Projects for Hanford Site Facilities: Progress Report for the Period October 1 to December 31, 1987*. PNL-6536, Richland, Washington.

Pacific Northwest Laboratory. 1988. *Ground-Water Monitoring Compliance Projects for Hanford Site Facilities: Progress Report for the Period January 1 to March 31, 1988*. PNL-6581, Richland, Washington.

Pacific Northwest Laboratory. 1988. *Ground-Water Monitoring Compliance Projects for Hanford Site Facilities: Progress Report for the Period April 1 to June 30, 1988*. PNL-6675, Richland, Washington.

Schalla, R., R. L. Aaberg, D. J. Bates, J.V.M. Carlile, M. D. Freshley, T. L. Liikala, P. J. Mitchell, K. B. Olsen, and J. T. Rieger. 1988. *Revised Ground-Water Monitoring Compliance Plan for the 300 Area Process Trenches*. PNL-6671, Pacific Northwest Laboratory, Richland, Washington.

U.S. Department of Energy. 1988. *Final Status, Post-Closure Permit Application for 183-H Solar Evaporation Basins*. DOE/RL 88-09, Richland Operations Office, Richland, Washington.

Chamness, M. A., S. P. Luttrell, and S. Dudziak. 1989. *40 CFR 265 Interim-Status Ground-Water Monitoring Plans for the 2101-M Pond*. PNL-6851, Pacific Northwest Laboratory, Richland, Washington.

Fruland, R. M., D. J. Bates, and R. E. Lundgren. 1989. *Resource Conservation and Recovery Act Ground-Water Monitoring Projects for Hanford Facilities: Progress Report for the Period July 1 to September 30, 1988*. PNL-6789, Pacific Northwest Laboratory, Richland, Washington.

Fruland, R. M., D. J. Bates, and R. E. Lundgren. 1989. *Resource Conservation and Recovery Act Ground-Water Monitoring Projects for Hanford Facilities: Progress Report for the Period October 1 to December 31, 1988*. PNL-6844, Pacific Northwest Laboratory, Richland, Washington.

Fruland, R. M., and R. E. Lundgren (eds.). 1989. *RCRA Ground-Water Monitoring Projects for Hanford Facilities: Annual Progress Report for 1988*. PNL-6852, Pacific Northwest Laboratory, Richland, Washington.

Gilmore, T. J, and E. J. Jensen. 1989. *Ground-Water Quality Assessment Program for the 1301-N Liquid Waste Disposal Facility*. WHC-SD-EN-AP-004, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Gilmore, T. J. 1989. *Ground-Water Quality Assessment for the 1324-N/NA Facilities*. WHC-SD-EN-AP-005, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Jensen, E. J., S. P. Airhart, M. A. Chamness, T. J Gilmore, D. R. Newcomer, and K. R. Oster. 1989. *40 CFR 265 Interim-Status Groundwater Monitoring Plan for the Single Shell Tanks*. WHC-SD-EN-AP-012, Westinghouse Hanford Company, Richland, Washington.

Last, G. V., and B. N. Bjornstad. 1989. *Revised Ground-Water Monitoring Plan for the 200 Areas Low-Level Burial Grounds*. WHC-SD-EN-AP-015, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Luttrell, S. P., M. A. Chamness, and S. Dudziak. 1989. *Interim-Status Ground-Water Monitoring Plan for the 216-B-3 Pond*. WHC-SD-EN-AP-013, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Luttrell, S. P., and S. Dudziak. 1989. *40 CFR 265 Interim-Status Ground-Water Monitoring Plan for the 216-A-29 Ditch*. PNL-7556, Pacific Northwest Laboratory, Richland, Washington.

Bjornstad, B. N., and S. Dudziak. 1989. *40 CFR 265 Interim-Status Groundwater Monitoring Plan for the 216-B-63 Trench*. PNL-6862, Pacific Northwest Laboratory, Richland, Washington.

Smith, R. M., D. J. Bates, and R. E. Lundgren. 1989. *Resource Conservation and Recovery Act Ground-Water Monitoring Projects for Hanford Facilities: Progress Report for the Period January 1 to March 31, 1989*. PNL-6957, Pacific Northwest Laboratory, Richland, Washington.

Smith, R. M., D. J. Bates, and R. E. Lundgren. 1989. *Resource Conservation and Recovery Act Ground-Water Monitoring Projects for Hanford Facilities: Progress Report for the Period April 1 to June 30, 1989*. PNL-7134, Pacific Northwest Laboratory, Richland, Washington.

Smith, R. M., D. J. Bates, and R. E. Lundgren. 1989. *Resource Conservation and Recovery Act Ground-Water Monitoring Projects for Hanford Facilities: Progress Report for the Period July 1 to September 30, 1989*. PNL-7222, Pacific Northwest Laboratory, Richland, Washington.

Teel, S. S., B. N. Bjornstad, and D. R. Newcomer. 1989. *Interim-Status Ground-Water Monitoring Plan for the Grout Treatment Facility*. WHC-SD-EN-AP-006, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

U.S. Department of Energy. 1989. *Single-Shell Tank Closure/Corrective Action Work Plan*. DOE/RL-89-16, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1989. *216-B-3 Pond System Closure/Postclosure Plan*. DOE/RL 89-28, Richland Operations Office, Richland, Washington.

Airhart, S. P., J. V. Borghese, and S. Dudziak. 1990. *Interim Status Ground-Water Monitoring Plan for the 216-S-10 Pond and Ditch*. WHC-EN-AP-018, Rev. 0., Westinghouse Hanford Company, Richland, Washington.

Chamness, M. A., E. J. Jensen, and G. V. Last. 1990. *Interim-Status Ground-Water Quality Assessment Plan for Waste Management Area 1 of the 200 Areas Low-Level Burial Grounds*. WHC-SD-EN-AP-021, prepared by Pacific Northwest Laboratory for Westinghouse Hanford Company, Richland, Washington.

Chamness, M. A., E. J. Jensen, and G. V. Last. 1990. *Interim-Status Ground-Water Quality Assessment Plan for Waste Management Area 3 of the 200 Areas Low-Level Burial Grounds*. WHC-SD-EN-AP-022, prepared by Pacific Northwest Laboratory for Westinghouse Hanford Company, Richland, Washington.

Chou, C. J., G. L. Kasza, and R. B. Mercer. 1990. *Interim-Status Groundwater Quality Assessment Plan for the 216-A-29 Ditch*. WHC-SD-EN-AP-031, Westinghouse Hanford Company, Richland, Washington.

Harris, S. F. 1990. *Ground Water Quality Assessment Plan for the 216-B-3 Pond System*. WHC-SD-EN-AP-030, Westinghouse Hanford Company, Richland, Washington.

Jensen, E. J., S. P. Airhart, S. M. Goodwin, S. H. Hall, and D. R. Newcomer. 1990. *Interim-Status Groundwater Monitoring Plan for the 216-U-12 Crib*. WHC-SD-EN-AP-019, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Lerch, R. E. 1990. *Quarterly Report of Resource Conservation and Recovery Act Ground-Water Monitoring Data for Period January 1, 1990 Through March 31, 1990*. Internal letter #9053781 to R. D. Izatt, May 25, 1990. Westinghouse Hanford Company, Richland, Washington.

Schmid, J. S. 1990. *Interim Status Groundwater Monitoring Plan for the 200 East Area Liquid Effluent Retention Facility*. WHC-SD-EN-AP-024, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Smith, R. M., D. J. Bates, and R. E. Lundgren. 1990. *Resource Conservation and Recovery Act Ground-Water Monitoring Projects for Hanford Facilities: Progress Report for the Period October 1 to December 31, 1989*. PNL-7306, Pacific Northwest Laboratory, Richland, Washington.

Smith, R. M., and W. R. Gorst (eds.). 1990. *RCRA Ground-Water Monitoring Projects for Hanford Facilities: Annual Progress Report for 1989*. PNL-7305, Pacific Northwest Laboratory, Richland, Washington.

U.S. Department of Energy. 1990. *183-H Solar Evaporation Basins Closure/Postclosure Plan*. DOE/RL 88-04, Rev. 2, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1990. *Nonradioactive Dangerous Waste Landfill Closure/Postclosure Plan*. DOE/RL-90-17, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1990. *Quarterly Report of RCRA Groundwater Monitoring Data for Period April 1, 1990 through June 30, 1990*. DOE/RL-90-36, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1990. *Quarterly Report of RCRA Groundwater Monitoring Data for Period July 1, 1990 through September 30, 1990*. DOE/RL-90-46, Richland Operations Office, Richland, Washington.

Caggiano, J. A., and S. M. Goodwin. 1991. *Interim-Status Groundwater Monitoring Plan for the Single Shell Tanks*. WHC-SD-EN-AP-012, Rev. 1, Westinghouse Hanford Company, Richland, Washington.

Hartman, M. J. 1991. *Groundwater Monitoring Plan for the 1301-N, 1324-N/NA, and 1325-N Facilities*. WHC-SD-EN-AP-038, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Hartman, M. J. 1991. *Groundwater Monitoring Plan for the 100-D Ponds*. WHC-SD-EN-AP-048, Westinghouse Hanford Company, Richland, Washington.

Kasza, G. L., and S. M. Goodwin. 1991. *Groundwater Monitoring Plan for the 216-A-29 Ditch*. WHC-SD-EN-AP-045, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Schmid, J. S. 1991. *Interim Status Groundwater Monitoring Plan for the 200 East Area Liquid Effluent Retention Facility*. WHC-SD-EN-AP-024, Rev. 1, Westinghouse Hanford Company, Richland, Washington.

U.S. Department of Energy. 1991. *183-H Solar Evaporation Basins Closure/Postclosure Plan*. DOE/RL 88-04, Rev. 3, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1991. *2101-M Pond Closure Plan*. DOE/RL-88-41, Rev. 1, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1991. *Quarterly Report of RCRA Groundwater Monitoring Data for Period October 1, 1990 through December 31, 1990*. DOE/RL-91-04, Richland Field Office, Richland, Washington.

U.S. Department of Energy. 1991. *Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities for 1990*. DOE/RL-91-03, Richland Field Office, Richland, Washington.

U.S. Department of Energy. 1991. *Quarterly Report of RCRA Groundwater Monitoring Data for Period January 1, 1991 through March 31, 1991*. DOE/RL-91-26, Richland Field Office, Richland, Washington.

U.S. Department of Energy. 1991. *Quarterly Report of RCRA Groundwater Monitoring Data for Period April 1, 1991 through June 30, 1991*. DOE/RL-91-47, Richland Field Office, Richland, Washington.

U.S. Department of Energy. 1991. *Quarterly Report of RCRA Groundwater Monitoring Data for Period July 1, 1991 through September 30, 1991*. DOE/RL-91-57, Richland Field Office, Richland, Washington.

Hartman, M. J. 1992. *Results of Groundwater Quality Assessment Monitoring at the 1301-N and 1324-N/NA Facilities*. WHC-SD-EN-EV-003, Rev. 1, Westinghouse Hanford Company, Richland, Washington.

Tyler, D. K. 1992. *Groundwater Impact Assessment Report for the 400 Area Ponds*. WHC-EP-0587, Westinghouse Hanford Company, Richland, Washington.

U.S. Department of Energy. 1992. *Quarterly Report of RCRA Groundwater Monitoring Data for Period October 1, 1991 through December 31, 1991*. DOE/RL-92-26, Richland Field Office, Richland, Washington.

U.S. Department of Energy. 1992. *Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities for 1991*. DOE/RL-92-03, Richland Field Office, Richland, Washington.

U.S. Department of Energy. 1992. *Quarterly Report of RCRA Groundwater Monitoring Data for Period January 1, 1992 through March 31, 1992*. DOE/RL-92-26-1, Richland Field Office, Richland, Washington.

U.S. Department of Energy. 1992. *Quarterly Report of RCRA Groundwater Monitoring Data for Period April 1, 1992 through June 30, 1992*. DOE/RL-92-26-2, Richland Field Office, Richland, Washington.

U.S. Department of Energy. 1992. *Quarterly Report of RCRA Groundwater Monitoring Data for Period July 1, 1992 through September 30, 1992*. DOE/RL-92-26-3, Richland Field Office, Richland, Washington.

Alexander, D. J. 1993. *Groundwater Impact Assessment Report for the 100-D Ponds*. WHC-EP-0666, Westinghouse Hanford Company, Richland, Washington.

Alexander, D. J., and V. G. Johnson. 1993. *Groundwater Impact Assessment Report for the 1325-N Liquid Waste Disposal Facility*. WHC-EP-0675, Westinghouse Hanford Company, Richland, Washington.

Alexander, D. J., V. G. Johnson, and K. A. Lindsey. 1993. *Groundwater Impact Assessment Report for the 284-WB Powerplant Ponds*. WHC-EP-0679, Westinghouse Hanford Company, Richland, Washington.

Caggiano, J. A., and C. J. Chou. 1993. *Interim-Status Groundwater Quality Assessment Plan for the Single Shell Tank Waste Management Areas T and TX-TY*. WHC-SD-EN-AP-132, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Hartman, M. J. 1993. *Revised Groundwater Quality Assessment Plan for the 1324-N/NA Facilities*. WHC-SD-EN-AP-005, Rev. 1, Westinghouse Hanford Company, Richland, Washington.

Hartman, M. J. 1993. *Groundwater Monitoring Plan for the 1301-N and 1325-N Facilities*. WHC-SD-EN-AP-038, Rev. 1, Westinghouse Hanford Company, Richland, Washington.

Hodges, F. N. 1993. *Interim Status Groundwater Monitoring Plan for the Nonradioactive Dangerous Waste Landfill, Hanford Washington*. WHC-SD-EN-AP-026, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Hodges, F. N. 1993. *Groundwater Monitoring Plan for the Hanford Solid Waste Landfill*. WHC-SD-EN-AP-043, Rev. 0, Westinghouse Hanford Company, Richland Washington.

Lindberg, J. W., S. D. Evelo, and D. J. Alexander. 1993. *Groundwater Impact Assessment Report for the 216-S-26 Crib, 200 West Area*. WHC-EP-0690, Westinghouse Hanford Company, Richland, Washington.

Reidel, S. P., V. G. Johnson, and N. W. Kline. 1993. *Groundwater Impact Assessment for the 216-U-17 Crib, 200 West Area*. WHC-EP-0664, Westinghouse Hanford Company, Richland, Washington.

U.S. Department of Energy. 1993. *100-D Ponds Closure Plan*. DOE/RL-92-71, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1993. *216-B-3 Pond System Closure/Post-Closure Plan*. DOE/RL-89-28, Rev. 1, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1993. *2101-M Pond Closure Plan*. DOE/RL-88-41, Rev. 2, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1993. *Quarterly Report of RCRA Groundwater Monitoring Data for Period October 1, 1992 through December 31, 1992*. DOE/RL-92-26-4, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1993. *Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities for 1992*. DOE/RL-93-09, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1993. *Quarterly Report of RCRA Groundwater Monitoring Data for Period January 1, 1993 through March 31, 1993*. DOE/RL-93-56-1, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1993. *Quarterly Report of RCRA Groundwater Monitoring Data for Period April 1, 1993 through June 30, 1993*. DOE/RL-93-56-2, Richland Operations Office, Richland, Washington.

Williams, B. A., and C. J. Chou. 1993. *Interim-Status Groundwater Quality Assessment Plan for the 216-U-12 Crib*. WHC-SD-EN-AP-108, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Hodges, F. N. 1994. *Corrective Action Plan for the Hanford Site Solid Waste Landfill*. DOE/RL-94-143, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Mercer, R. B. 1994. *Results of Groundwater Quality Assessment Program at Low-Level Waste Management Area 1 of the Low-Level Burial Grounds*. WHC-SD-EN-EV-025, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Mercer, R. B. 1994. *Results of Groundwater Quality Assessment Program at Low-Level Waste Management Area 3 of the Low-Level Burial Grounds*. WHC-SD-EN-EV-026, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Peterson, R. E. 1994. *Groundwater Monitoring Results for the 100-K Area Fuel Storage Basins: January 1 to March 31, 1994*. WHC-SD-EN-TI-280, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Singleton, K. M., and K. A. Lindsey. 1994. *Groundwater Impact Assessment Report for the 216-U-14 Ditch*. WHC-EP-0698, Westinghouse Hanford Company, Richland, Washington.

U.S. Department of Energy. 1994. *216-B-3 Expansion Ponds Closure Plan*. DOE/RL-89-28, Rev. 2, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1994. *Quarterly Report of RCRA Groundwater Monitoring Data for Period July 1, 1993 through September 30, 1993*. DOE/RL-93-56-3, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1994. *Quarterly Report of RCRA Groundwater Monitoring Data for Period October 1, 1993 through December 31, 1993*. DOE/RL-93-56-4, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1997. *300 Area Process Trenches Modified Closure/Postclosure Plan*. DOE/RL-93-73, Rev. 2, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1994. *Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities for 1993*. DOE/RL-93-88, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1994. *Quarterly Report of RCRA Groundwater Monitoring Data for Period January 1, 1994 through March 31, 1994*. DOE/RL-94-36-1, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1994. *Quarterly Report of RCRA Groundwater Monitoring Data for Period April 1, 1994 through June 30, 1994*. DOE/RL-94-36-2, Richland Operations Office, Richland, Washington.

Westinghouse Hanford Company. 1994. *Interim-Status Groundwater Monitoring Plan for the 216-A-10 and 216-A-36B Cribs*. WHC-SD-EN-AP-170, Rev. 0-A, Richland, Washington.

Alexander, D. J., S. D. Evelo, V. G. Johnson, and M. D. Sweeney. 1995. *Groundwater Impact Assessment Report for the 216-T-4-2 Ditch*. WHC-EP-0815, Westinghouse Hanford Company, Richland, Washington.

Hartman, M. J., and C. J. Chou. 1995. *Groundwater Monitoring Plan for the 183-H Solar Evaporation Basins*. WHC-SD-EN-AP-180, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Johnson, V. G., and C. J. Chou. 1995. *Groundwater Monitoring Results for the 100 K Area Fuel Storage Basins: March to December 1994*. WHC-SD-EN-TI-280, Rev. 1, Westinghouse Hanford Company, Richland, Washington.

Johnson, V. G., and S. D. Evelo. 1995. *Groundwater Monitoring Results for the 100-K Area Fuel Storage Basins: January to June 1995*. WHC-SD-EN-TI-280, Rev. 2, Westinghouse Hanford Company, Richland, Washington.

Johnson, V. G., C. J. Chou, and J. W. Lindberg. 1995. *Groundwater Monitoring and Assessment Plan for the 100-K Area Fuel Storage Basins*. WHC-SD-EN-AP-174, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Johnson, V. G., A. G. Law, S. P. Reidel, S. D. Evelo, D. B. Barnett, and M. D. Sweeney. 1995. *Groundwater Impact Assessment Report for the 216-B-3 Pond System*. WHC-EP-0813, Westinghouse Hanford Company, Richland, Washington.

Kaplan, D. I., and R. J. Serne. 1995. *Distribution Coefficient Values Describing Iodine, Neptunium, Selenium, Technetium, and Uranium Sorption to Hanford Sediments*. PNL-10379, SUP. 1, Pacific Northwest Laboratory, Richland, Washington.

Lindberg, J. W., C. J. Chou, and V. G. Johnson. 1995. *Groundwater Monitoring Plan for the 300 Area Process Trenches*. WHC-SD-EN-AP-185, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Sweeney, M. D. 1995. *Interim-Status Groundwater Monitoring Plan for the 216-B-3 Pond System*. WHC-SD-EN-AP-013, Rev. 1, Westinghouse Hanford Company, Richland, Washington.

Sweeney, M. D. 1995. *Interim Status Groundwater Monitoring Plan for the 216-B-63 Trench*. WHC-SD-EN-AP-165, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Sweeney, M. D. 1995. *Interim Status Groundwater Monitoring Plan for the 216-B-63 Trench*. WHC-SD-EN-AP-165, Rev. 1, Westinghouse Hanford Company, Richland, Washington.

Sweeney, M. D, D. J. Alexander, S. D. Evelo, K. A. Lindsay, V. M. Johnson, and K. M. Singleton. 1995. *Groundwater Impact Assessment Report for the 216-T-1 Ditch*. WHC-EP-0814, Westinghouse Hanford Company, Richland, Washington.

U.S. Department of Energy. 1995. *Quarterly Report of RCRA Groundwater Monitoring Data for Period July 1, 1994 through September 30, 1994*. DOE/RL-94-36-3, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1995. *Quarterly Report of RCRA Groundwater Monitoring Data for Period October 1, 1994 through December 31, 1994*. DOE/RL-94-36-4, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1995. *Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities for 1994*. DOE/RL-94-136, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1995. *Quarterly Report of RCRA Groundwater Monitoring Data for Period January 1, 1995 through March 31, 1995*. DOE/RL-94-69-1, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1995. *Quarterly Report of RCRA Groundwater Monitoring Data for Period April 1, 1995 through June 30, 1995*. DOE/RL-94-69-2, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1995. *Quarterly Report of RCRA Groundwater Monitoring Data for Period July 1, 1995 through September 30, 1995*. DOE/RL-94-69-3, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1995. *Single-Shell Tank Closure Work Plan*. DOE-RL-89-16, Rev. A, Richland Operations Office, Richland, Washington.

Votava, J. M. 1995. *Results of the Groundwater Quality Assessment Program at the 216-A-29 Ditch RCRA Facility*. WHC-SD-EN-EV-032, Westinghouse Hanford Company, Richland, Washington.

Caggiano, J. A. 1996. *Assessment Groundwater Monitoring Plan for Single Shell Tank Waste Management Area S-SX*. WHC-SD-EN-AP-191, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Caggiano, J. A. 1996. *Assessment Groundwater Monitoring Plan for SST Waste Management Area B-BX-BY*. WHC-SD-ENV-AP-002, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Hartman, M. J. 1996. *Groundwater Monitoring Plan for the 1301-N, 1325-N, and 1324-N/NA Sites*. WHC-SD-EN-AP-038, Rev. 2, Westinghouse Hanford Company, Richland, Washington.

Hartman, M. J. 1996. *RCRA Assessment Report: Total Organic Halogen at the 1324-N/NA Site*. WHC-SD-EN-EV-031, Rev. 1, Westinghouse Hanford Company, Richland, Washington.

Hartman, M. J. 1996. *100-D Ponds Groundwater Quality Assessment*. WHC-SD-EN-EV-033, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Lindberg, J. W., C. J. Chou, and V. G. Johnson. 1996. *Groundwater Monitoring Plan for the 300 Area Process Trenches*. WHC-SD-EN-AP-185, Rev. 0-A, Westinghouse Hanford Company, Richland, Washington.

Siemens Power Corporation. 1996. *Groundwater Quality Assessment Plan, Surface Impoundment System*. EMF-96-194, Richland, Washington.

U.S. Department of Energy. 1996. *Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities for 1995*. DOE/RL-96-01, Rev. 0, Prepared by Earth and Environmental Technical Services, Westinghouse Hanford Company, Richland, Washington.

Barnett, D. B., and S. S. Teel. 1997. *Results of RCRA Groundwater Quality Assessment at the 216-B-3 Pond Facility*. PNNL-11604, Pacific Northwest National Laboratory, Richland, Washington.

Hartman, M. J. 1997. *Groundwater Monitoring Plan for the 183-H Solar Evaporation Basins*. PNNL-11573, Pacific Northwest National Laboratory, Richland, Washington.

Lindberg, J. W. 1997. *Combination RCRA Groundwater Monitoring Plan for the 216-A-10, 216-A-36B, and 216-A-37-1 PUREX Cribs*. PNNL-11523, Pacific Northwest National Laboratory, Richland, Washington

Lindberg, J. W., B. A. Williams, and F. A. Spane. 1997. *Borehole Data Package for Well 699-37-47A, PUREX Plant Cribs, CY 1996*. PNNL-11515, Pacific Northwest National Laboratory, Richland, Washington.

Smith, R. C. 1997. *Nonradioactive Dangerous Waste Landfill Sampling and Analysis Plan and Data Quality Objectives Process Summary Report*. BHI-01073, Bechtel Hanford, Inc., Richland, Washington.

Sweeney, M. D., C. J. Chou, and B. N. Bjornstad. 1997. *Liquid Effluent Retention Facility Final-Status Groundwater Monitoring Plan*. PNNL-11620, Pacific Northwest National Laboratory, Richland, Washington.

U.S. Department of Energy. 1997. *300 Area Process Trenches Modified Closure/Postclosure Plan*. DOE/RL-93-73, Rev. 2, Richland Operations Office, Richland, Washington.

Williams, B. A., and C. J. Chou. 1997. *Results of RCRA Groundwater Quality Assessment Program at the 216-U-12 Crib*. PNNL-11574, Pacific Northwest National Laboratory, Richland, Washington.

Hartman, M. J. 1998. *Groundwater Quality Assessment Plan for the 1324-N/NA Site – Phase 1 (First Determination)*. PNNL-11885, Pacific Northwest National Laboratory, Richland, Washington.

Hodges, F. N. 1998. *Results of Phase I Groundwater Quality Assessment for Single-Shell Tank Waste Management Areas T and TX-TY at the Hanford Site*. PNNL-11809, Pacific Northwest National Laboratory, Richland, Washington.

Johnson, V. G., and C. J. Chou. 1998. "Implications of RCRA Groundwater Quality Assessment Results for Hanford's Single Shell Tank Waste Management Areas." In *Proceedings of the 39th Annual Meeting of the Institute of Nuclear Materials Management, Florida, July 1998*. Institute of Nuclear Materials Management, Northbrook, Illinois.

Johnson, V. G., and C. J. Chou. 1998. *Results of Phase I Groundwater Quality Assessment for Single-Shell Tank Waste Management Areas S-SX at the Hanford Site*. PNNL-11810, Pacific Northwest National Laboratory, Richland, Washington.

Johnson, V. G., C. J. Chou, M. J. Hartman, and W. D. Webber. 1998. *Groundwater Monitoring for the 100-K Area Fuel-Storage Basins: July 1996 through April 1998*. PNNL-12023, Pacific Northwest National Laboratory, Richland, Washington.

Last, G. V., and B. N. Bjornstad. 1998. *Revised Ground-Water Monitoring Plan for the 200 Areas Low-Level Burial Grounds*. WHC-SD-EN-AP-015, Pacific Northwest National Laboratory, Richland, Washington.

Narbutovskih, S. M. 1998. *Results of Phase I Groundwater Quality Assessment for Single-Shell Tank Waste Management Areas B-BX-BY at the Hanford Site*. PNNL-11826, Pacific Northwest National Laboratory, Richland, Washington.

U.S. Department of Energy. 1998. *100-D Ponds Closure Plan*. DOE/RL-92-71, Rev. 2, Richland Operations Office, Richland, Washington.

Johnson, V. G., and C. J. Chou. 1999. *RCRA Assessment Plan for Single-Shell Tank Waste Management Area S-SX at the Hanford Site*. PNNL-12114, Pacific Northwest National Laboratory, Richland, Washington.

Lindberg, J. W. and M. J. Hartman. 1999. *Groundwater Monitoring Plan for the Nonradioactive Dangerous Waste Landfill*. PNNL-12227, Pacific Northwest National Laboratory, Richland, Washington.

Newcomer, D. R. 1999. *Sampling and Analysis Plan Update for Groundwater Monitoring – 1100-EM-1 Operable Unit*. PNNL-12220, Pacific Northwest National Laboratory, Richland, Washington.

Sweeney, M. D. 1999. *Groundwater Monitoring Plan for the 216-A-29 Ditch*. PNNL-13047, Pacific Northwest National Laboratory, Richland, Washington.

Barnett, D. B. 2000. *Groundwater Monitoring Plan for the Hanford Site 200 Area Treated Effluent Disposal Facility*. PNNL-13032, Pacific Northwest National Laboratory, Richland, Washington.

Barnett, D., R. M. Smith, and C. J. Chou. 2000. *Groundwater Monitoring Plan for the Hanford Site 216-B-3 Pond RCRA Facility*. PNNL-13367, Pacific Northwest National Laboratory, Richland, Washington.

Johnson, V. G. and C. J. Chou. 2000. *RCRA Groundwater Quality Assessment Report for Waste Management Area S-SX (November 1997 through April 2000)*. PNNL-13441, Pacific Northwest National Laboratory, Richland, Washington.

Lindberg, J. W. and C. J. Chou. 2000. *Groundwater Monitoring Plan for the Solid Waste Landfill*. PNNL-13014, Pacific Northwest National Laboratory, Richland, Washington.

Narbutovskih, S. M. 2000. *Groundwater Quality Assessment Plan for Single-Shell Waste Management Area B-BX-BY at the Hanford Site*. PNNL-13022, Pacific Northwest National Laboratory, Richland, Washington.

U.S. Department of Energy. 2000. *Performance Assessment Monitoring Plan for the Hanford Site Low-Level Burial Grounds*. DOE/RL-2000-72, Rev. 0, Richland Operations Office, Richland, Washington.

Hodges, F. N. and C. J. Chou. 2001. *RCRA Assessment Plan for Single-Shell Tank Waste Management Area T at the Hanford Site*. PNNL-12057, Pacific Northwest National Laboratory, Richland, Washington.

Hodges, F. N. and C. J. Chou. 2001. *RCRA Assessment Plan for Single-Shell Tank Waste Management Area TX-TY at the Hanford Site*. PNNL-12072, Pacific Northwest National Laboratory, Richland, Washington.

Horton, D. G. and S. M. Narbutovskih. 2001. *RCRA Groundwater Monitoring Plan for Single-Shell Tank Waste Management Area C at the Hanford Site*. PNNL-13024, Pacific Northwest National Laboratory, Richland, Washington.

Lindberg, J. W. and C. J. Chou. 2001. *300 Area Process Trenches Groundwater Monitoring Plan*. PNNL-13645, Pacific Northwest National Laboratory, Richland, Washington.

Narbutovskih, S. M. 2001. *RCRA Groundwater Monitoring Plan for Single-Shell Tank Waste Management Area A-AX at the Hanford Site*. PNNL-13023, Pacific Northwest National Laboratory, Richland, Washington.

Smith, R. M., F. N. Hodges, and B. A Williams. 2001. *Groundwater Quality Assessment Plan for Single-Shell Tank Waste Management Area U*. PNNL-13612, Pacific Northwest National Laboratory, Richland, Washington.

Barnett, D. B. 2002. *Interim Change Notice for Groundwater Monitoring Plan for the Hanford Site 216-B-3 Pond RCRA Facility*. PNNL-13367-ICN-1, Pacific Northwest National Laboratory, Richland, Washington.

Barnett, D. B. and J. T. Rieger. 2002. *Results of Tritium Tracking and Groundwater Monitoring at the Hanford Site 200 Area State-Approved Land Disposal Site – Fiscal Year 2002*. PNNL-14038, Pacific Northwest National Laboratory, Richland, Washington.

Hartman, M. J. 2002. *Groundwater Monitoring Plan for the 1301-N, 1324-N/NA, and 1325-N RCRA Facilities*. PNNL-13914, Pacific Northwest National Laboratory, Richland, Washington.

Horton, D. G. 2002. *Interim Change Notice for RCRA Assessment Plan for Single-Shell Tank Waste Management Area T at the Hanford Site*. PNNL-12057-ICN-1, Pacific Northwest National Laboratory, Richland, Washington.

Horton, D. G. 2002. *Interim Change Notice for RCRA Assessment Plan for Single-Shell Tank Waste Management Area T at the Hanford Site*. PNNL-12072-ICN-1, Pacific Northwest National Laboratory, Richland, Washington.

Horton, D. G., F. N. Hodges, V. G. Johnson, and C. J. Chou. 2002. *RCRA Groundwater Quality Assessment Report for Single-Shell Tank Waste Management Area T (January 1998 through December 2001)*. PNNL-13929, Pacific Northwest National Laboratory, Richland, Washington.

Johnson, V. G. and C. J. Chou. 2002. *Groundwater Quality Assessment Report for Waste Management Area S-SX: (April 2000 through December 2001)*. PNNL-13801, Pacific Northwest National Laboratory, Richland, Washington.

Narbutovskih, S. M. 2002. *Interim Change Notice for RCRA Groundwater Monitoring Plan for Single-Shell Tank Waste Management Area A-AX at the Hanford Site*. PNNL-13023-ICN-1, Pacific Northwest National Laboratory, Richland, Washington.

Narbutovskih, S. M. and D. G. Horton. 2002. *Interim Change Notice for RCRA Groundwater Monitoring Plan for Single-Shell Tank Waste Management Area C*. PNNL-13024-ICN-1, Pacific Northwest National Laboratory, Richland, Washington.

Peterson, R. E. 2002. *Groundwater Monitoring and Assessment Plan for the 100-K Area Fuel Storage Basins*. PNNL-14033, Pacific Northwest National Laboratory, Richland, Washington.

Smith, R. M. 2002. *Interim Change Notice RCRA Assessment Plan for Single-Shell Tank Waste Management Area S-SX at the Hanford Site*. ICN-PNNL-12114-September 1999.2, Pacific Northwest National Laboratory, Richland, Washington.

Sweeney, M. D. 2002. *Groundwater Monitoring Plan for the 216-B-63 Trench on the Hanford Site*. PNNL-14112, Pacific Northwest National Laboratory, Richland, Washington.

Williams, B. A. and C. J. Chou. 2002. *Groundwater Monitoring Plan for the 216-S-10 Pond and Ditch*. PNNL-14070, Pacific Northwest National Laboratory, Richland, Washington.

Operable Unit Reports

U.S. Department of Energy. 1989. *RCRA Facility Investigation/Corrective Measures Study Work Plan for the 100-HR-3 Operable Unit, Hanford Site, Richland, Washington*. DOE/RL-88-36 DRAFT, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1990. *Remedial Investigation/Feasibility Study Work Plan for the 300-FF-1 Operable Unit, Hanford Site, Richland, Washington*. DOE/RL-88-31, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1990. *Remedial Investigation/Feasibility Study Work Plan for the 300-FF-5 Operable Unit, Hanford Site, Richland, Washington*. DOE/RL-89-14, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1990. *Phase 1 Remedial Investigation Report for the Hanford Site 1100-EM-1 Operable Unit*. DOE/RL-90-18, Richland Operations Office, Richland, Washington.

Young, J. S. and J. S. Fruchter. 1991. *Addendum to Data Compilation Task Report for the Source Investigation of the 300-FF-1 Operable Unit Phase 1 Remedial Investigations*. EMO-1026, Pacific Northwest National Laboratory, Richland, Washington.

U.S. Department of Energy. 1991. *Expedited Response Action Proposal (EE/CA & EA) for 200 West Area Carbon Tetrachloride Plume*. DOE/RL-91-32, Draft B, Richland Field Office, Richland, Washington.

U.S. Department of Energy. 1991. *RCRA Facility Investigation/Corrective Measures Study Work Plan for the 100-NR-2 Operable Unit, Hanford Site, Richland, Washington*. DOE/RL-91-46, Draft A, Richland Field Office, Richland, Washington.

U.S. Department of Energy. 1991. *Remedial Investigation/Feasibility Study Work Plan for the 100-FR-3 Operable Unit, Hanford Site, Richland, Washington*. DOE/RL-91-53 DRAFT A, Richland Field Office, Richland, Washington.

U.S. Department of Energy. 1991. *Remedial Investigation/Feasibility Study Work Plan for the 100-KR-4 Operable Unit, Hanford Site, Richland, Washington*. DOE/RL-90-21, Richland Field Office, Richland, Washington.

Swanson, L. C. 1992. *Phase I Hydrogeologic Summary of the 300-FF-5 Operable Unit, 300 Area*. WHC-SD-EN-TI-052, Westinghouse Hanford Company, Richland, Washington.

U.S. Department of Energy. 1992. *RCRA Facility Investigation/Corrective Measures Study Work Plan for the 100-HR-3 Operable Unit, Hanford Site, Richland, Washington*. DOE/RL-88-36 DRAFT D, Richland Field Office, Richland, Washington.

U.S. Department of Energy. 1992. *RCRA Facility Investigation/Corrective Measures Study Work Plan for the 100-HR-3 Operable Unit, Hanford Site, Richland, Washington*. DOE/RL-88-36, Rev. 0, Richland Field Office, Richland, Washington.

U.S. Department of Energy. 1992. *Remedial Investigation/Feasibility Study Work Plan for the 100-BC-5 Operable Unit, Hanford Site, Richland, Washington*. DOE/RL-90-08, Rev. 0, Richland Field Office, Richland, Washington.

U.S. Department of Energy. 1992. *Remedial Investigation/Feasibility Study Work Plan for the 100-KR-4 Operable Unit, Hanford Site, Richland, Washington*. DOE/RL-90-21, Rev. 0, Richland Field Office, Richland, Washington.

U.S. Department of Energy. 1992. *Remedial Investigation/Feasibility Study Work Plan for the 100-FR-3 Operable Unit, Hanford Site, Richland, Washington*. DOE/RL-91-53 DRAFT B, Richland Field Office, Richland, Washington.

U.S. Department of Energy. 1992. *Remedial Investigation/Feasibility Study Work Plan for the 100-FR-3 Operable Unit, Hanford Site, Richland, Washington*. DOE/RL-91-53, Rev. 0, Richland Field Office, Richland, Washington.

U.S. Department of Energy. 1992. *Sampling and Analysis of 100 Area Springs*. DOE/RL-92-12, Rev. 1, prepared by IT Corporation for Westinghouse Hanford Company and Richland Operations Office, Richland, Washington.

Deford, D. H. 1993. *100-F Reactor Site Technical Baseline Report, Including Operable Units 100-FR-1 and 100-FR-2*. WHC-SD-EN-TI-169, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Kasza, G. L. 1993. *Potential for Groundwater Contamination from High Density Wastes Disposed at the BY Cribs, 200-BP-1 CERCLA Operable Unit*. WHC-SD-EN-TA-003, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Record of Decision. 1993. *Declaration of the Record of Decision, USDOE Hanford 1100 Area, Hanford Site, Benton County, Washington (1100-EM-1, 1100-EM-2, 1100-EM-3, and 1100-IU-1 Operable Units)*. State of Washington Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1993. *Draft Remedial Investigation/Feasibility Study for the 100-EM-1 Operable Unit, Hanford*. DOE/RL-92-67 DRAFT C, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1993. *RCRA Facility Investigation/Corrective Measures Study Work Plan for the 100-HR-2 Operable Unit, Hanford Site, Richland, Washington*. DOE/RL-93-20 DRAFT A, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1993. *Sodium Dichromate Barrel Landfill Expedited Response Action Assessment*. DOE/RL-93-64, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1993. *Interim Remedial Measures Proposed Plan for the 200-ZP-1 Operable Unit, Hanford Site, Washington*. DOE/RL-93-68, Richland Operations Office, Richland, Washington.

Westinghouse Hanford Company. 1993. *Carbon Tetrachloride Evaporative Losses and Residual Inventory Beneath 200 West Area at the Hanford Site*. WHC-SD-EN-TI-101, Rev. 0, prepared by Ebasco Services, Inc., for Westinghouse Hanford Company, Richland, Washington.

Bechtel Hanford, Inc. 1994. *Qualitative Risk Assessment for the 100-FR-3 Groundwater Operable Unit*. Richland, Washington.

Bechtel Hanford, Inc. 1994. *Pilot Scale Treatability Test for the 200-BP-5 Groundwater Operable Unit (Agreement)*. BHI-00013, Richland, Washington.

Bechtel Hanford, Inc. 1994. *Qualitative Risk Assessment for the 100-NR-2 Groundwater Operable Unit*. BHI-00055, Richland, Washington.

Bechtel Hanford, Inc. 1994. *200-UP-1 Groundwater Operable Unit Interim Remedial Measure Proposed Plan Schedule*. BHI-00206, Richland, Washington.

Deford D. H., R. W. Carpenter, and M. W. Einan. 1994. *300-FF-2 Operable Unit Technical Baseline Report*. BHI-00012, Rev. 00. Bechtel Hanford, Inc., Richland, Washington.

Fancher, J. D. 1994. *Carbon Tetrachloride ERA Soil-Gas Baseline Monitoring*. WHC-SD-EN-TI-265, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Raidl, R. F. 1994. *Geology of the 100-FR-3 Operable Unit, Hanford Site, South-Central Washington*. WHC-SD-EN-TI-221, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Rohay, V. J., K. J. Swett, and G. V. Last. 1994. *1994 Conceptual Model of Carbon Tetrachloride Contamination in the 200 West Area at the Hanford Site*. WHC-SD-EN-TI-248, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

State of Washington Department of Ecology and U.S. Environmental Protection Agency. 1994. *Action Memorandum: N-Springs Expedited Response Action Cleanup Plan, U.S. Department of Energy, Hanford Site, Washington*. Olympia, Washington.

U.S. Department of Energy. 1994. *Limited Field Investigation Report for the 100-BC-5 Operable Unit*. DOE/RL-93-37, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1994. *Remedial Investigation/Feasibility Study Work Plan for the 200-UP-1 Groundwater Operable Unit, Hanford Site, Richland, Washington*. DOE/RL-92-76, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1994. *Phase I Remedial Investigation Report for the 300-FF-5 Operable Unit*. DOE/RL-93-21, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1994. *Phase I and II Feasibility Study Report for the 300-FF-5 Operable Unit*. DOE/RL-93-22, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1994. *Limited Field Investigation Report for the 100-HR-3 Operable Unit*. DOE/RL-93-43, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1994. *Limited Field Investigation for the 100-KR-4 Operable Unit*. DOE/RL-93-79, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1994. *Limited Field Investigation Report for the 100-FR-3 Operable Unit*. DOE/RL-93-83, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1994. *Remedial Investigation and Feasibility Study Report for the Environmental Restoration Disposal Facility*. DOE/RL-93-99, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1994. *Remedial Investigation and Feasibility Study Report for the Environmental Restoration Disposal Facility*. DOE/RL-93-99, Rev. 1, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1994. *Phase III Feasibility Study Report for the 300-FF-1 Operable Unit*. DOE/RL-94-49, Draft A, Richland, Washington.

Bechtel Hanford, Inc. 1995. *Data Validation Final Summary Report for the 200-UP-1 Round 2 Interim Remedial Measure Groundwater Sampling Task*. BHI-00113, Bechtel Hanford, Inc., Richland, Washington.

Bechtel Hanford, Inc. 1995. *100-NR-2 Streamlined Groundwater Sampling and Analysis Plan*. BHI-00165, Richland, Washington.

Bechtel Hanford, Inc. 1995. *100-NR-2 Groundwater Summary Report*. BHI-00168, Richland, Washington.

Bechtel Hanford, Inc. 1995. *200-ZP-1 Groundwater Sampling and Analysis Plan, Revision 0*. BHI-00190, Richland, Washington.

Bechtel Hanford, Inc. 1995. *100-FR-3 Soil Gas/Groundwater Survey Description of Work*. BHI-00322, Richland, Washington.

Bechtel Hanford, Inc. 1995. *Data Validation Summary Report for the 200-UP-1 Round 3 Interim Remedial Measure Groundwater Sampling Task*. BHI-00401, Bechtel Hanford, Inc., Richland, Washington.

Bechtel Hanford, Inc. 1995. *Data Validation Summary Report for the 200-UP-1 Round 1 Limited Field Investigation and Vertical Profile Groundwater Sampling Task*. BHI-00406, Bechtel Hanford, Inc., Richland, Washington.

Bechtel Hanford, Inc. 1995. *Validation Summary Report for the 100-NR-2 Round 7 Groundwater*. BHI-00407, Bechtel Hanford, Inc., Richland, Washington.

Bechtel Hanford, Inc. 1995. *200-BP-5 Validation Summary Report Groundwater Round 3*. BHI-00408, Bechtel Hanford, Inc., Richland, Washington.

Bechtel Hanford, Inc. 1995. *200-UP-1 Groundwater Operable Unit Interim Remedial Measure*. BHI-00419, Richland, Washington.

Bechtel Hanford, Inc. 1995. *200-NPL 200-ZP-1 Groundwater*. BHI-00447, Richland, Washington.

Bechtel Hanford, Inc. 1995. *N Springs Expedited Response Action Performance Monitoring Plan*. BHI-00164, Rev. 1A, Richland, Washington.

Ford, B. H. 1995. *200-UP-1 Vertical Profiling Activity Summary Report*. BHI-00149, Rev. 00, Bechtel Hanford, Inc., Richland, Washington.

Frain, J. M., and G. J. Jackson. 1995. *N Springs Groundwater Pump-and-Treat System Functional and Operational Requirements*. BHI-00030, Rev. 1, Bechtel Hanford, Inc., Richland, Washington.

Gustafson, F. W., J. W. Green, and C. D. Wittreich. 1995. *Treatability Test Report for the 200-UP-1 Operable Unit, Hanford Site*. DOE/RL-95-02, Rev. 0, International Technology Hanford Corporation for the U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Mukherjee, B. 1995. *N Springs Expedited Response Action Performance Monitoring Plan*. BHI-00164, Rev. 1, Bechtel Hanford, Inc., Richland, Washington.

Record of Decision. 1995. *Declaration of the Record of Decision, USDOE Hanford Environmental Restoration Disposal Facility, Hanford Site, Benton County, Washington*. State of Washington Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Record of Decision. 1995. *Declaration of the Record of Decision, USDOE Hanford 200 Area, Hanford Site, Benton County, Washington (200-ZP-1 Operable Unit)*. State of Washington Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Singleton, K. M. 1995. *200-ZP-1 Groundwater Sampling and Analysis Plan/Quality Assurance Plan*. BHI-00038, Rev. 01, Bechtel Hanford, Inc., Richland, Washington.

Singleton, K. M. 1995. *Description of Work for the 300-FF-2 Operable Unit Groundwater Limited Field Investigation at the 618-10 and 618-11 Burial Grounds*. BHI-00424, Rev. 0A, Bechtel Hanford, Inc., Richland, Washington.

U.S. Department of Energy. 1995. *100-HR-3 Operable Unit Focused Feasibility Study*. DOE/RL-94-67, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1995. *Remedial Investigation/Feasibility Study Report for the 300-FF-5 Operable Unit*. DOE/RL-94-85, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1995. *Proposed Plan for Interim Remedial Measures at the 100-BC-1 Operable Unit*. DOE/RL-94-99, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1995. *Proposed Plan for Interim Remedial Measures at the 100-DR-1 Operable Unit*. DOE/RL-94-100, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1995. *Proposed Plan for Interim Remedial Measures at the 100-HR-1 Operable Unit*. DOE/RL-94-101, Rev. 1, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1995. *Proposed Plan for Interim Remedial Measures at the 100-HR-3 Operable Unit*. DOE/RL-94-102, Rev. 1, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1995. *Proposed Plan for Interim Remedial Measures at the 100-KR-4 Operable Unit*. DOE/RL-94-113, Rev. 1, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1995. *Proposed Plan for Interim Remedial Measures at the 100-KR-1 Operable Unit*. DOE/RL-94-119, Rev. 1, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1995. *Proposed Plan for Interim Remedial Measures at the 100-HR-2 Operable Unit*. DOE/RL-94-135, Draft A, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1995. *200-ZP-1 Operable Unit Treatability Test Report*. DOE/RL-95-30, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1995. *Proposed Plan for Interim Remedial Measures at the 100-FR-1 Operable Unit*. DOE/RL-95-54, Draft B, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1995. *Proposed Plan for Interim Remedial Measures at the 100-BC-2 Operable Unit*. DOE/RL-95-66, Draft A, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1995. *Proposed Plan for Interim Remedial Measures at the 100-DR-2 Operable Unit*. DOE/RL-95-67, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1995. *The Pilot-Scale Treatability Test Summary for the 100-HR-3 Operable Unit*. DOE/RL-95-83, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1995. *Proposed Plan for Interim Remedial Measures at the 100-FR-2 Operable Unit*. DOE/RL-95-92, Decisional Draft, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1995. *Proposed Plan for Interim Remedial Measures at the 100-KR-2 Operable Unit*. DOE/RL-95-96, Decisional Draft, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1995. *RCRA Facility Investigation Report for the 200-PO-1 Operable Unit*. DOE/RL-95-100, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1995. *RCRA Facility Investigation Report for the 200-PO-1 Operable Unit*. DOE/RL-95-100, Rev. 1, Richland Operations Office, Richland, Washington.

Bechtel Hanford, Inc. 1996. *BHI Engineering Evaluation/Conceptual Plan for the 200-UP-1 Groundwater Operable Unit Interim Remedial Measure*. BHI-00187, Rev. 2, Richland, Washington.

Bechtel Hanford, Inc. 1996. *Data Validation Summary Report for the 100-HR-3 Round 8, Phases I and II Groundwater Sampling Task*. BHI-00402, Bechtel Hanford, Inc., Richland, Washington.

Bechtel Hanford, Inc. 1996. *200-ZP-1 Semi-Annual Groundwater Sampling Validation Summary March 1995*. BHI-00410, Bechtel Hanford, Inc., Richland, Washington.

Bechtel Hanford, Inc. 1996. *Preliminary Engineering Assessment of Treatment Alternatives for Groundwater from the Hanford 200 Area 200-BP-5 Plumes*. BHI-00456, Bechtel Hanford, Inc., Richland, Washington.

Bechtel Hanford, Inc. 1996. *Data Validation Summary Report for the 100-Fr-3 Operable Unit, Round 7 Groundwater Samples*. BHI-00551, Bechtel Hanford, Inc., Richland, Washington.

Bechtel Hanford, Inc. 1996. *Validation Summary Report for the 200-UP-1 Groundwater Round 2*. BHI-00552, Bechtel Hanford, Inc., Richland, Washington.

Bechtel Hanford, Inc. 1996. *Validation Summary Report for the 100-KR-4 Groundwater Round 8*. BHI-00553, Bechtel Hanford, Inc., Richland, Washington.

Bechtel Hanford, Inc. 1996. *Validation Summary Report for the 100-HR-3 Groundwater Round 9 Phase I And II*. BHI-00554, Bechtel Hanford, Inc., Richland, Washington.

Bechtel Hanford, Inc. 1996. *Data Validation Summary Report for the 100-NR-2 Operable Unit Groundwater Sampling Round 8*. BHI-00555, Bechtel Hanford, Inc., Richland, Washington.

Bechtel Hanford, Inc. 1996. *Description of Work and Sampling and Analysis Plan for Pore Water Sampling at Groundwater-River Interface Adjacent to 100-D/DR, -K, and -H*. BHI-00620, Richland, Washington.

Borghese, J. V., M. J. Hartman, S. P. Luttrell, C. J. Perkins, J. P. Zoric, and S. C. Tindall. 1996. *100-N Pilot Project: Proposed Consolidated Groundwater Monitoring Program*. BHI-00725, Bechtel Hanford, Inc., Richland, Washington.

Chiaramonte, G. R. 1996. *Risk-Based Decision Analysis for the 200-BP-5 Groundwater Operable Unit*. BHI-00416, Rev. 2, Bechtel Hanford, Inc., Richland, Washington.

Borghese, J. V., J. N. Winters, S. W. Petersen, J. T. Hadley, J. M. Shorey, and R. W. Ovink. 1996. *Interim Action Monitoring Plan for the 100-HR-3 and 100-KR-4 Operable Units*. DOE/RL-96-090, prepared by Bechtel Hanford, Inc. for U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Freeman-Pollard, J. R., I. D. Jacques, W. J. McMahon, K. M. Singleton, S. A. Strope, L. C. Swanson, and C. R. Windmueller. 1996. *200-ZP-1 Phase II Interim Remedial Measure Quarterly Report, August - October 1996*. BHI-00952-01, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Freeman-Pollard, J. R. 1996. *200-ZP-1 IRM Phase II and III Remedial Design Report*. DOE/RL-96-07, Rev. 1, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Hadley, J. T. 1996. *CERCLA Substantive Requirement Document, 200-ZP-1, Phases II and III Interim Remedial Measure Groundwater Treatment Project*. BHI-00453, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Kearney, A. T. 1996. *Data Validation Summary Report for the 100-BC-5 Operable Unit Round 8 Groundwater Sampling*. BHI-00409, Bechtel Hanford, Inc., Richland, Washington.

Kearney, A. T. 1996. *Data Validation Summary Report for the 100-BC-5 Operable Unit Round 9 Groundwater Sampling Plan*. BHI-00556, , Bechtel Hanford, Inc., Richland, Washington.

Kearney, A. T. 1996. *Data Validation Summary Report for the 100-FR-3 Operable Unit Round 8 Groundwater*. BHI-00557, Bechtel Hanford, Inc., Richland, Washington.

McKinley, W. S., D. K. Tyler, R. E. Peterson, D. L. Parker, J. T. Hadley, and W. J. McMahon. 1996. *Remedial Design Report and Remedial Action Work Plan for the 100-HR-3 and 100-KR-4 Groundwater Operable Units' Interim Action*. BHI-00765, Draft A, Bechtel Hanford, Inc., Richland, Washington.

Myers, D. A., C. W. Denslow, D. B. Erb, F. W. Gustafson, J. W. Green, Jr., and W. J. McMahon. 1996. *200-UP-1 Groundwater Pump-and-Treat Phase I Annual Report, FY 1996*. BHI-00951, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Piepho, M. G. 1996. *Numerical Analysis of Carbon Tetrachloride Movement in the Saturated and Unsaturated Zones in the 200 West Area, Hanford Site*. BHI-00459, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Peterson, R. E., and R. F. Raidl. 1996. *Groundwater Monitoring Implementation Plan for the 100-BC-5, 100-KR-4, 100-HR-3, and 100-FR-3 Operable Units.* BHI-00916, Rev. 0, prepared by CH2M Hill Hanford, Inc. for Bechtel Hanford, Inc., Richland, Washington.

Peterson, R. E., R. F. Raidl, and C. W. Denslow. 1996. *Conceptual Site Models for Groundwater Contamination at 100-BC-5, 100-KR-4, 100-HR-3, and 100-FR-3 Operable Units*. BHI-00917, Rev. 0, prepared by CH2M Hill Hanford, Inc. for Bechtel Hanford, Inc., Richland, Washington.

Record of Decision. 1996. *Declaration of the Record of Decision, USDOE Hanford Area 300-FF-1 and 300-FF-5 Operable Units, Hanford Site, Benton County, Washington*. State of Washington Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Record of Decision. 1996. *Record of Decision, USDOE Hanford 100 Area, 100-IU-1, 100-IU-3, 100-IU-4, and 100-IU-5 Operable Units, Hanford Site, Benton County, Washington*. State of Washington Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Record of Decision. 1996. *Declaration of the Record of Decision, USDOE Hanford 100 Area, 100-HR-3 and 100-KR-4 Operable Units, Hanford Site, Benton County, Washington*. State of Washington Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Rohay, V. J. 1996. *Performance Evaluation Report for Soil Vapor Extraction System Operations at the Carbon Tetrachloride Site, February 1992 - June 1995*. BHI-00720, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Rohay, V. J. 1996. *Performance Evaluation Report for Soil Vapor Extraction System Operations at the Carbon Tetrachloride Site, February 1992 - June 1996*. BHI-00720, Rev. 1, Bechtel Hanford, Inc., Richland, Washington.

Rohay, V. J., and W. J. McMahon. 1996. *Airflow Modeling Report for Vapor Extraction Operations at the 200-ZP-2 Operable Unit (Carbon Tetrachloride Expedited Response Action)*. BHI-00882, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Rohay, V. J., and R. K. Tranbarger. 1996. *Test Plan for the FY 1997 Rebound Study at the Carbon Tetrachloride Soil Vapor Extraction Site*. BHI-00947, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Singleton, K. M. 1996. *Limited Field Investigation for the 200-UP-1 Operable Unit*. DOE/RL-96-33, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Swanson, L. C., M. A. Buckmaster, B. H. Ford, and W. J. McMahon. 1996. *200-ZP-1 Interim Remedial Measure Quarterly Report, October-December 1996*. BHI-00952-02, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

U.S. Department of Energy. 1996. *RCRA Facility Investigation/Corrective Measures Study Work Plan for the 100-NR-2 Operable Unit Hanford Site, Richland, Washington*. DOE/RL-91-46, Rev. 0, Richland Field Office, Richland, Washington.

U.S. Department of Energy. 1996. *200-BP-5 Operable Unit Treatability Test Report*. DOE/RL-95-59, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1996. *Operation and Maintenance Plan for the 300-FF-5 Operable Unit*. DOE/RL-95-73, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1996. *100-FR-3 Groundwater/Soil Gas Supplemental Limited Field Investigation Report*. DOE/RL-95-99, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1996. *Limited Field Investigation Report for the 300-FF-2 Operable Unit*. DOE/RL-96-42, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1996. *RCRA Corrective Measure Study for the 200-PO-1 Operable Unit*. DOE/RL-96-66, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1996. *N-Springs Expedited Response Action Performance Evaluation Report*. DOE/RL-95-110, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1996. *1301-N and 1325-N Liquid Waste Disposal Facilities, Limited Field Investigation Report*. DOE/RL-96-11, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1996. *Remedial Design Report and Remedial Action Work Plan for the 100-HR-3 and 100-KR-4 Groundwater Operable Units' Interim Action*. DOE/RL-96-84, Richland Operations Office, Richland, Washington.

Borghese, J. V., R. E. Peterson, L. C. Swanson, and P. B. Tolley. 1997. *Fiscal Year 1997 Annual Report for the 100-NR-2, 200-UP-1, and 200-ZP-1 Pump and Treat Operations and Operable Units*. BHI-01126, CH2M Hill Hanford, Inc. for Bechtel Hanford, Inc., Richland, Washington.

Record of Decision. 1997. *Declaration of the Record of Decision, USDOE Hanford 100 Area, Hanford Site, Benton County, Washington (100-BC-1, 100-DR-1 and 100-HR-1 Operable Units)*. State of Washington Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Record of Decision. 1997. *Declaration of the Record of Decision, U.S. DOE Hanford 200 Area, Hanford Site, Benton County, Washington (200-UP-1 Operable Unit)*. State of Washington Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1997. *Corrective Measures Study for the 100-NR-1 and 100-NR-2 Operable Units*. DOE/RL-95-111, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1997. *Interim Action Monitoring Plan for the 100-HR-3 and 100-KR-4 Operable Units*. DOE/RL-96-90, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1997. *Proposed Plan for Final Remedial Actions at the 100-NR-1 Source Sites Operable Unit and Interim Remedial Action at the 100-NR-2 Groundwater Operable Unit.* DOE/RL-96-102, Draft B, Richland Operations Office, Richland, Washington.

Bechtel Hanford, Inc. 1998. *N-Springs Expedited Response Action Performance Monitoring Plan: Update*. BHI-01165, Rev. 0, Richland, Washington.

Rohay, V. J. 1998. *Performance Evaluation Report for Soil Vapor Extraction Operations at the Carbon Tetrachloride Site, February 1992 - September 1997*. BHI-00720, Rev. 2, Bechtel Hanford, Inc., Richland, Washington.

U.S. Department of Energy. 1998. *100-NR-1 Treatment, Storage, and Disposal Units Corrective Measures Study/Closure Plan*. DOE/RL-96-39, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1998. *Corrective Measures Study for the 100-NR-1 and 100-NR-2 Operable Units*. DOE/RL-95-111, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1998. *100-NR-1 Treatment, Storage, and Disposal Units Corrective Measure Study/Closure Plan*. DOE/RL-96-39, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1998. *Proposed Plan for Interim Action at the 100-NR-1 Source Sites Operable Unit and the 100-NR-2 Groundwater Operable Unit*. DOE/RL-96-102, prepared by Bechtel Hanford, Inc., Richland, Washington.

U.S. Department of Energy. 1998. *100-KR-4 and 100-HR-3 Operable Units Interim Action Performance Evaluation Report*. DOE/RL-97-96, prepared by CH2M Hill Hanford, Inc. for Bechtel Hanford, Inc., Richland, Washington.

U.S. Department of Energy. 1998. *Fiscal Year 1997 Annual Report for the 100-NR-2, 200-UP-1, and 200-ZP-1 Pump and Treat Operations and Operable Units*. DOE/RL-98-38, Rev. 0, Richland Operations, Office, Richland, Washington.

Record of Decision. 1999. *Amended Record of Decision, Decision Summary and Responsiveness Summary for the 100-HR-3 Operable Unit*. U.S. Environmental Protection Agency, Region X, Seattle, Washington.

Record of Decision. 1999. *Record of Decision for the USDOE Hanford 100-KR-2 Operable Unit K Basins Interim Remedial Action*. (EPA 541-R99-059). Agreement between the U.S. Department of Energy and the U.S. Environmental Protection Agency, with concurrence by the Washington State Department of Ecology, Olympia, Washington.

Record of Decision (ROD). 1999. *DOE Environmental Restoration Disposal Facility, Hanford Site, 200 Area – Amended Record of Decision, Decision Summary and Responsiveness Summary.* U.S. Environmental Protection Agency, Region 10; Washington State Department of Ecology, and U.S. Department of Energy, Olympia, Washington.

Rohay, V. J., D. C. Weekes, W. J. McMahon, and J. V. Borghese. 1999. *The Chromium Groundwater Plume West of the 100-D/DR Reactors: Summary and Fiscal Year 1999 Update.* BHI-01309, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

U.S. Department of Energy. 1999. *Fiscal Year 1998 Annual Summary Report for the 200-UP-1, 200-ZP-1, and 100-NR-2 Pump-and-Treat Operations and Operable Units*. DOE/RL-99-02, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1999. *Annual Summary Report, February to December 1998, for the 100-HR-3 and 100-KR-4 Pump-and-Treat Operations and Operable Units*. DOE/RL-99-13, Richland Operations Office, Richland, Washington.

Record of Decision (ROD). 1999. *Interim Remedial Action Record of Decision for the 100-NR-1 and -NR-2 Operable Units of the Hanford 100-N Area*. Washington State Department of Ecology, Olympia, Washington.

Bechtel Hanford, Inc. 2000. *System Assessment Capability (Revision 0)*. BHI-01365, Draft A., Prepared by Bechtel Hanford, Inc. for the U.S. Department of Energy, Richland, Washington.

Bergstrom, K. A., T. H. Mitchell, and B. J. Bolin. 1995. *Geophysical Investigations of the 316-4 (300 North Crib), the 618-8 Burial Ground, the 618-13 (Mound), the Undocumented Solid Waste Burial Ground, the Solid Waste Burial Ground (Early Burial Ground), and the Burial Trench West of the Process Trenches, 300-FF-2 Operable Unit*. BHI-00212, Rev. 00, prepared by CH2M HILL Hanford, Inc. for Bechtel Hanford, Inc., Richland, Washington.

Bergstrom, K. A., D. J. Brolin, and T. H. Mitchell. 1997. *Geophysical Investigation of the 618-10 and 618-11 Burial Grounds, 300-FF-2 Operable Unit.* BHI-00291, Rev. 1, Bechtel Hanford, Inc., Richland, Washington.

Cearlock, C. S., K. M. Singleton, M. E. Todd, and D. B. Barnett. 2000. *200-CW-1 Operable Unit Borehole/Test Pit Summary Report.* BHI-01367, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Laurenz, J. E. and L .D. Walker. 2000. *In Situ Redox Manipulation Barrier Well Completion Report for the 100-HR-3 Groundwater Operable Unit, FY 2000.* BHI-01381, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Sweeney, M. D. 2000. *Groundwater Sampling and Analysis Plan for the 100-BC-5 Operable Unit*. PNNL-13326, Pacific Northwest National Laboratory, Richland, Washington.

Sweeney, M. D. 2000. *Groundwater Sampling and Analysis Plan for the 100-FR-3 Operable Unit*. PNNL-13327, Pacific Northwest National Laboratory, Richland, Washington.

U.S. Department of Energy. 2000. *200-CW-1 Operable Unit RI/FS Work Plan and 216-B-3 RCRA TSD Unit Sampling Plan*. DOE/RL-99-07, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 2000. *Remedial Design Report and Remedial Action Work Plan for the 100-HR-3 Groundwater Operable Unit In Situ Redox Manipulation*. DOE/RL-99-51, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 2000. *Fiscal Year 1999 Annual Summary Report for the 200-UP-1, 200-ZP-1, and 100-NR-2 Pump-and-Treat Operations and Operable Units*. DOE/RL-99-79, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 2000. *Annual Summary Report Calendar Year 1999 for the 100-HR-3 and 100-KR-4 Pump-and-Treat Operations and Operable Units*. DOE/RL-2000-01, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Environmental Protection Agency. 2000. "Explanation of Significant Difference for the 300-FF-5 Record of Decision" (see ROD 1996). Issued by U.S. Environmental Protection Agency, Region 10, and U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Swanson, L. C. 2001. *Fiscal Year 2000 Annual Summary Report for Three 200-UP-1 and 200-ZP-1 Pump-and-Treat Operations*. DOE/RL-2000-71, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 2001. *200-TW-1 Scavenged Waste Group Operable Unit and 200-TW-2 Tank Waste Group Operable Unit RI/FS Work Plan*. DOE/RL-2000-38, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 2001. *Calendar Year 2000 Annual Summary Report for the 100-HR-3, 100-KR-4, and 100-NR-2 Pump-and-Treat Operations*. DOE/RL-2001-04, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 2001. *Calendar Year 2001 Annual Summary Report for the 100-HR-3, 100-KR-4, and 100-NR-2 Operable Units and Pump-and-Treat Operations*. DOE/RL-2002-05, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 2001. *Fiscal Year 2001 Annual Summary Report for the In-Situ REDOX Manipulation Operations*. DOE/RL-2002-01, Richland Operations Office, Richland, Washington.

Byrnes, M. E., and B. A. Williams. 2002. *Data Quality Objective Summary Report for Establishing a RCRA/CERCLA/AEA Integrated 200-UP-1 and 200-ZP-1 Groundwater Monitoring Network.* HNF-12236, Rev. 0, Draft, Fluor Hanford, Inc., Richland, Washington.

Cearlock, C. S. and D. L. Bowers. 2002. *200-CS-1 Operable Unit Test Pit Summary Report for Fiscal Year 2002*. BHI-01651, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Thornton, E. C. and J. W. Lindberg. 2002. *Data Quality Objectives Summary Report – Designing a Groundwater Monitoring Network for the 200-BP-5 and 200-PO-1 Operable Units*. PNNL-14049, Pacific Northwest National Laboratory, Richland, Washington.

U.S. Department of Energy. 2002. *Fiscal Year 2001 Annual Summary Report for the 200-UP-1 and 200-ZP-1 Pump-and-Treat Operations*. DOE/RL-2001-53, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 2002. *200-PW-1 Operable Unit Dispersed Carbon Tetrachloride Vadose Zone Plume Sampling and Analysis Plan – Step I.* DOE/RL-2001-67, Rev. 1, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 2002. *Sampling and Analysis Plan for the 200-UP-1 Groundwater Monitoring Well Network*. DOE/RL-2002-10, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 2002. *300-FF-5 Operable Unit Sampling and Analysis Plan*. DOE/RL-2002-11, Richland Operations Office, Richland, Washington.

Hartman, M. J. and J. W. Lindberg. 2003. *Sampling and Analysis Plan for the 200-PO-1 Groundwater Operable Unit*. DOE/RL-2003-04, Decisional Draft, Pacific Northwest National Laboratory, Richland, Washington.

Rohay, V. J. and D. C. Weekes. 2003. *200-PW-1 Operable Unit Report on Step I Sampling and Analysis of the Dispersed Carbon Tetrachloride Vadose Zone Plume*. CP-13514, Rev. 0, Fluor Hanford, Inc., Richland, Washington.

Aggregate Area Reports

Connelly, M. P., B. H. Ford, and J. V. Borghese. 1992. *Hydrogeologic Model for the 200 West Groundwater Aggregate Area*. WHC-SD-EN-TI-014, Westinghouse Hanford Company, Richland, Washington.

Connelly, M. P., J. V. Borghese, B. H. Ford, J. W. Lindberg, C. D. Delaney, and S. J. Trent. 1992. *Hydrogeologic Model for the 200 East Groundwater Aggregate Area*. WHC-SD-EN-TI-019, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Newcomer, D. R., S. S. Teel, A. W. Pearson, K. R. O. Barton, B. N. Bjornstad, and T. J Gilmore. 1992. *Unconfined Aquifer Hydrologic Test Data Package for the 200 West Groundwater Aggregate Area Management Study*. WHC-SD-EN-DP-029, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Newcomer, D. R., R. J. Brockman, M. A. Chamness, S. M. Goodwin, D. L. McAlister, A. W. Pearson, and S. S. Teel. 1992. *Confined Aquifer Hydrologic Test Data Package for the 200 West Groundwater Aggregate Area Management Study*. WHC-SD-EN-DP-031, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Ford, B. H. 1993. *Groundwater Field Characterization Report for the 200 Aggregate Area Management Study*. WHC-SD-EN-TI-020, Westinghouse Hanford Company, Richland, Washington.

U.S. Department of Energy. 1993. *200 West Groundwater Aggregate Area Management Study Report.* DOE/RL-92-16, Richland Operations Office, Richland, Washington.

Water-Table Reports and Maps

Bierschenk, W. H. 1957. *Fluctuations of Hanford Water Levels*. HW-53599, General Electric Company, Richland, Washington.

Kipp, K. L., and R. D. Mudd. 1974. *Selected Water Table Contour Maps and Well Hydrographs for the Hanford Reservation, 1944-1973*. BNWL-B-360, Pacific Northwest Laboratory, Richland, Washington.

Atlantic Richfield Hanford Company. 1976. *Water Table Measurement Data Maps - December 1975*. H-2-38396 Rev. 1, H-2-38397 Rev. 1, H-2-38877 Rev. 1, H-2-38398 Rev. 1, H-2-38399 Rev. 1, Richland, Washington.

Atlantic Richfield Hanford Company. 1977. *Water Table Measurement Data Maps - December 1976*. H-2-38396 Rev. 2, H-2-38397 Rev. 2, H-2-38877 Rev. 2, H-2-38398 Rev. 2, H-2-38399 Rev. 2, Richland, Washington.

Rockwell Hanford Operations. 1977. *Hanford Reservation Water Table Map July 1977*. H-2-38396 Rev. 3, Richland, Washington.

Rockwell Hanford Operations. 1978. *Water Table Measurement Data Maps - December 1977*. H-2-38396 Rev. 4, H-2-38397 Rev. 3, H-2-38877 Rev. 3, H-2-38398 Rev. 3, H-2-38399 Rev. 3, Richland, Washington.

Rockwell Hanford Operations. 1978. *Hanford Reservation Water Table Map June 1978*. H-2-38396 Rev. 5, Richland, Washington.

Brown, R. E. 1979. *A Review of Water-Well Data from the Unconfined Aquifer in the Eastern and Southern Parts of the Pasco Basin*. RHO-BWI-C-56, Rockwell Hanford Operations, Richland, Washington.

Rockwell Hanford Operations. 1979. *Water Table Measurement Data Maps - December 1978*. H-2-38396 Rev. 6, H-2-38397 Rev. 4, H-2-38877 Rev. 4, H-2-38398 Rev. 4, H-2-38399 Rev. 4, Richland, Washington.

Rockwell Hanford Operations. 1979. *Hanford Reservation Water Table Map June 1979*. H-2-38396 Rev. 7, Richland, Washington.

Rockwell Hanford Operations. 1980. *Water Table Measurement Data Maps - December 1979*. H-2-38396 Rev. 8, H-2-38397 Rev. 5, H-2-38877 Rev. 5, H-2-38398 Rev. 5, H-2-38399 Rev. 5, Richland, Washington.

Rockwell Hanford Operations. 1980. *Hanford Site Water Table Map July 1980*. H-2-38396 Rev. 9, Richland, Washington.

Rockwell Hanford Operations. 1981. *Water Table Measurement Data Maps - December 1980*. H-2-38396 Rev. 10, H-2-38397 Rev. 6, H-2-38877 Rev. 6, H-2-38398 Rev. 6, H-2-38399 Rev. 6, Richland, Washington.

Rockwell Hanford Operations. 1981. *Water Table Measurement Data Maps - June 1981*. H-2-38396, Rev. 11, Richland, Washington.

Wilbur, J. S. 1982. *Water Table Measurement Data Maps - December 1981*. H-2-38396 Rev. 12, H-2-38397 Rev. 7, H-2-38877 Rev. 7, H-2-38398 Rev. 7, H-2-38399 Rev. 7, Rockwell Hanford Operations, Richland, Washington.

Wilbur, J. S. 1982. *Water Table Measurement Data Maps - June 1982*. H-2-38396 Rev. 13, Rockwell Hanford Operations, Richland, Washington.

Wilbur, J. S. 1983. *Water Table Measurement Data Maps - December 1982*. H-2-38396 Rev. 14, Rockwell Hanford Operations, Richland, Washington.

Fuchs, M. R. 1983. *Water-Table Measurements Data Maps - June 1983*. H-2-38396 Rev. 15, Rockwell Hanford Operations, Richland, Washington.

Allen, R. M. 1984. *Water-Level Measurements Data Maps December 1983*. H-2-38396 Rev. 16, Rockwell Hanford Operations, Richland, Washington.

Binkhorst, G. K. 1984. *Unconfined Aquifer Water-Table Map June 1984*. H-2-38396 Rev. 17, Rockwell Hanford Operations, Richland, Washington.

Schatz, A. L. 1985. *Unconfined Aquifer & Rattlesnake Ridge Aquifer Water-Level Measurements Data Maps, December 1984*. H-2-38396 Rev. 18, Rockwell Hanford Operations, Richland, Washington.

Bauer, H. H., J. J. Vaccaro, and R. C. Lane. 1985. *Maps Showing Ground-Water Levels in the Columbia River Basalt and Overlying Materials, Spring 1983, Southeastern Washington*. Water Resources Investigation Report 84-4360, U.S. Geological Survey, Tacoma, Washington.

Schatz, A. L. 1985. *Unconfined Aquifer Water-Table Map, June 1985*. H-2-38396, Rev. 19, Rockwell Hanford Operations, Richland, Washington.

Rockwell Hanford Operations. 1986. *Unconfined Aquifer & Rattlesnake Ridge Aquifer Water-Level Measurements Data Maps - December 1986*. SD-WM-TI-273, Rev. 1, Richland, Washington.

Schatz, A. L., and E. J. Jensen. 1986. *Unconfined Aquifer Water-Table Map, June 1986*. H-2-38396 Rev. 21, Rockwell Hanford Operations, Richland, Washington.

Zimmerman, D. A., A. E. Reisenauer, G. D. Black, and M. A. Young. 1986. *Hanford Site Water Table Changes 1950 Through 1980 - Data Observations and Evaluation*. PNL-5506, Pacific Northwest Laboratory, Richland, Washington.

Jensen, E. J. 1987. *Summary of Water-Level Measurements Around the 1325-N Crib During the Fall of 1985 and the Winter of 1986-1987*. PNL-6374, Pacific Northwest Laboratory, Richland, Washington.

Schatz, A. L., J. J. Ammerman, and J. A. Serkowski. 1987. *Hanford Site Water Table Map June 1987*. WHC-EP-0054, Westinghouse Hanford Company, Richland, Washington.

Schatz, A. L., and M. D. McElroy. 1988. *Ground-Water Maps of the Hanford Site Separations Area June 1988*. WHC-EP-0142-1, Westinghouse Hanford Company, Richland, Washington.

Kasza, G. L., and A. L. Schatz. 1989. *Groundwater Maps of the Hanford Site Separations Area, January 1989*. WHC-EP-0142-2, Westinghouse Hanford Company, Richland, Washington.

Kasza, G. L., S. P. Reidel, and A. L. Schatz. 1989. *Groundwater Maps of the Hanford Site Separations Area, June 1989*. WHC-EP-0142-3, Westinghouse Hanford Company, Richland, Washington.

Kasza, G. L. 1990. *Ground-Water Maps of Hanford Site Separations Areas, December 1989*. WHC-EP-0142-4, Westinghouse Hanford Company, Richland, Washington.

Kasza, G. L., S. F. Harris, and M. J. Hartman. 1990. *Ground-Water Maps of the Hanford Site*. WHC-EP-0394-1, Westinghouse Hanford Company, Richland, Washington.

Newcomer, D. R. 1990. *Evaluation of Hanford Site Water-Table Changes - 1980 to 1990*. PNL-7498, Pacific Northwest Laboratory, Richland, Washington.

Newcomer, D. R., and J. P. McDonald. 1990. *Water-Table Elevations on the Hanford Site, December 1989*. PNL-7374, Pacific Northwest Laboratory, Richland, Washington.

Newcomer, D. R., J. P. McDonald, and S. M. Goodwin. 1990. *Water-Table Elevations on the Hanford Site, June 1989*. PNL-7282, Pacific Northwest Laboratory, Richland, Washington.

Kasza, G. L., M. J. Hartman, and F. N. Hodges. 1991. *Ground Water Maps of the Hanford Site, December 1990*. WHC-EP-0394-2, Westinghouse Hanford Company, Richland, Washington.

Kasza, G. L., M. J. Hartman, F. N. Hodges, and D. C. Weekes. 1991. *Ground Water Maps of the Hanford Site, June 1991*. WHC-EP-0394-3, Westinghouse Hanford Company, Richland, Washington.

Newcomer, D. R., K. D. Pohlod, and J. P. McDonald. 1991. *Water-Table Elevations on the Hanford Site, 1990*. PNL-7693, Pacific Northwest Laboratory, Richland, Washington.

Campbell, M. D., and D. R. Newcomer. 1992. *Automatic Measurement of Water Levels Within the 300-FF-5 Boundary*. PNL-7874, Pacific Northwest Laboratory, Richland, Washington.

Kasza, G. L., M. J. Hartman, F. N. Hodges, and D. C. Weekes. 1992. *Groundwater Maps of the Hanford Site, June 1992*. WHC-EP-0394-5, Westinghouse Hanford Company, Richland, Washington.

Kasza, G. L., M. J. Hartman, F. N. Hodges, and D. C. Weekes. 1992. *Ground Water Maps of the Hanford Site, December 1991*. WHC-EP-0394-4, Westinghouse Hanford Company, Richland, Washington.

Newcomer, D. R., K. D. Pohlod, and J. P. McDonald. 1992. *Water-Table Elevations on the Hanford Site and Outlying Areas, 1991*. PNL-8122, Pacific Northwest Laboratory, Richland, Washington

U.S. Department of Energy. 1992. *U Plant Source Aggregate Area Management Study Report*. DOE/RL-91-52, Richland Operations Office, Richland, Washington.

Campbell, M. D., W. J. McMahon, and K. R. Simpson. 1993. *Water Level Measurements for Modeling Hydraulic Properties in the 300-FF-5 and 100 Aggregate Area Operable Units*. PNL-8580, Pacific Northwest Laboratory, Richland, Washington.

Drost, B. W., J. C. Eddert, and S. E. Cox. 1993. *Long-Term Effects of Irrigation with Imported Water on Water Levels and Water Quality*. Water-Resources Investigations Report 93-4060, U.S. Geological Survey, Tacoma, Washington.

Kasza, G. L., M. J. Hartman, F. N. Hodges, K. R. Simpson, and D. C. Weekes. 1993. *Groundwater Maps of the Hanford Site, December 1992*. WHC-EP-0394-6, Westinghouse Hanford Company, Richland, Washington.

Kasza, G. L., M. J. Hartman, W. A. Jordan, and D. C. Weekes. 1994. *Groundwater Maps of the Hanford Site, June 1993*. WHC-EP-0394-7, Westinghouse Hanford Company, Richland, Washington.

Kasza, G. L., M. J. Hartman, W. A. Jordan, and J. V. Borghese. 1994. *Groundwater Maps of the Hanford Site, December 1993*. WHC-EP-0394-8, Westinghouse Hanford Company, Richland, Washington.

Serkowski, J. A., W. A. Jordan, and M. J. Hartman. 1994. *Groundwater Maps of the Hanford Site, June 1994*. WHC-EP-0394-9, Westinghouse Hanford Company, Richland, Washington.

Serkowski, J. A., M. J. Hartman, and M. D. Sweeney. 1995. *Groundwater Maps of the Hanford Site, December 1994*. WHC-EP-0394-10, Westinghouse Hanford Company, Richland, Washington.

Connelly, M. P., W. J. McMahon, and K. R. Simpson. 1996. *100-N Area Automated Groundwater-Level Monitoring Network*. BHI-00625, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Serkowski, J. A., M. J. Hartman, and M. D. Sweeney. 1996. *Groundwater Maps of the Hanford Site, June 1995*. WHC-EP-0394-11, Westinghouse Hanford Company, Richland, Washington.

Serkowski, J. A., M. J. Hartman, and M. D. Sweeney. 1996. *Groundwater Maps of the Hanford Site, December 1995*. WHC-EP-0394-12, Westinghouse Hanford Company, Richland, Washington.

Drinking Water Reports

Maas, L. J. 1977. *Hanford Sanitary Water Quality Surveillance CY 1976*. Hanford Environmental Health Foundation, Richland, Washington.

Maas, L. J. 1978. *Hanford Sanitary Water Quality Surveillance CY 1977*. Hanford Environmental Health Foundation, Richland, Washington.

Maas, L. J. 1979. *Hanford Sanitary Water Quality Surveillance CY 1978*. HEHF-29, Hanford Environmental Health Foundation, Richland, Washington.

Maas, L. J. 1980. *Hanford Sanitary Water Quality Surveillance CY 1979*. HEHF-31, Hanford Environmental Health Foundation, Richland, Washington.

Maas, L. J. 1981. *Hanford Sanitary Water Quality Surveillance CY 1980*. HEHF-33, Hanford Environmental Health Foundation, Richland, Washington.

Maas, L. J. 1982. *Hanford Sanitary Water Quality Surveillance CY 1981*. HEHF-36, Hanford Environmental Health Foundation, Richland, Washington.

Maas, L. J. 1983. *Hanford Sanitary Water Quality Surveillance CY 1982*. HEHF-39, Hanford Environmental Health Foundation, Richland, Washington.

Maas, L. J. 1984. *Hanford Sanitary Water Quality Surveillance CY 1983*. HEHF-42, Hanford Environmental Health Foundation, Hanford, Washington.

Maas, L. J. 1985. *Hanford Sanitary Water Quality Surveillance CY 1984*. HEHF-45, Hanford Environmental Health Foundation, Richland, Washington.

Somers, S. R. 1986. *Hanford Sanitary Water Quality Surveillance CY 1985*. HEHF-55, Hanford Environmental Health Foundation, Richland, Washington.

Somers, S. R. 1987. *Hanford Sanitary Water Quality Surveillance CY 1986*. HEHF-59, Hanford Environmental Health Foundation, Richland, Washington.

Somers, S. R. 1988. *Hanford Sanitary Water Quality Surveillance CY 1987*. HEHF-71, Hanford Environmental Health Foundation, Richland, Washington.

Somers, S. R. 1989. *Hanford Sanitary Water Quality Surveillance CY 1988*. HEHF-74, Hanford Environmental Health Foundation, Richland, Washington.

Thurman, P. A. 1990. *Hanford Sanitary Water Quality Surveillance CY 1989*. HEHF-76, Hanford Environmental Health Foundation, Richland, Washington.

Thurman, P. A. 1991. *Hanford Sanitary Water Quality Surveillance CY 1990*. HEHF-82, Hanford Environmental Health Foundation, Richland, Washington.

Clark, M. L., and P. A. Thurman. 1992. *Hanford Sanitary Water Quality Surveillance for Calendar Year 1991*. HEHF-88, Hanford Environmental Health Foundation, Richland, Washington.

Thurman, P. A. 1993. *Hanford Sanitary Water Quality Surveillance for Calendar Year 1992*. HEHF-90, Hanford Environmental Health Foundation, Richland, Washington.

Computer Models/Codes

Cearlock, D. B., and R. D. Mudd. 1970. *Analysis of Hydrological Factors Influencing the Operation of the 100-N Emergency Waste Disposal Crib*. BNWL-1503, Pacific Northwest Laboratory, Richland, Washington.

Cearlock, D. B., K. L. Kipp, and D. R. Friederichs. 1972. *The Transmissivity Iterative Calculation Routine - Theory and Numerical Implementation*. BNWL-1706, Pacific Northwest Laboratory, Richland, Washington.

Kipp, K. L., A. E. Reisenauer, C. R. Cole, and L. A. Bryan. 1972. *Variable Thickness Transient Groundwater Flow Model: Theory and Numerical Implementation*. BNWL-1703, Pacific Northwest Laboratory, Richland, Washington.

Arnett, R. C., R. A. Deju, R. W. Nelson, C. R. Cole, and R. E. Gephart. 1976. *Conceptual and Mathematical Modeling of the Hanford Groundwater Flow Regime*. ARH-ST-140, Atlantic Richfield Hanford Company, Richland, Washington.

Ahlstrom, S. W., H. P. Foote, R. C. Arnett, C. R. Cole, and R. J. Serne. 1977. *Multicomponent Mass Transport Model: Theory and Numerical Implementation (Discrete-Parcel-Random-Walk Version)*. BNWL-2127, Prepared for Atlantic Richfield Hanford Company by Pacific Northwest Laboratory, Richland, Washington.

Arnett, R. C., D. J. Brown, and R. G. Baca. 1977. *Hanford Groundwater Estimates for Hypothetical Radioactive Waste Incidents*. ARH-LD-162, Atlantic Richfield Hanford Company, Richland, Washington.

Friedrichs, D. R., C. R. Cole, and R. C. Arnett. 1977. *Hanford Pathline Calculational Program - Theory, Error Analysis and Applications*. ARH-ST-149, Atlantic Richfield Hanford Company, Richland, Washington.

INTERA Environmental Consultants, Inc. 1977. *Hydrology Model Evaluation at the Hanford Nuclear Waste Facility*. ARH-C-00017, Prepared for Atlantic Richfield Hanford Company by INTERA Environmental Consultants, Inc., Houston, Texas.

Gephart, R. E., R. C. Arnett, R. G. Baca, L. S. Leonhart, F. A. Spane, Jr., D. A. Palombo, and S. R. Strait. 1979. *Hydrologic Studies Within the Columbia Plateau, Washington: An Integration of Current Knowledge*. RHO-BWI-ST-5, Rockwell Hanford Operations, Richland, Washington.

McLaughlin, D. B. 1979. *Hanford Groundwater Modeling - Review of Parameter Estimation Techniques*. RHO-C-19, Prepared for Rockwell Hanford Operations, Richland, Washington, by Resource Management Associates.

McLaughlin, D. B. 1979. *Hanford Groundwater Modeling - A Numerical Comparison of Bayesian and Fisher Parameter Estimation Techniques*. RHO-C-24, Prepared for Rockwell Hanford Operations, Richland, Washington, by Resource Management Associates.

Moore, S. F., and D. B. McLaughlin. 1979. *Hanford Groundwater Modeling - Review of Sampling Design Methods*. RHO-C-20, Prepared for Rockwell Hanford Operations, Richland, Washington, by Resource Management Associates.

Arnett, R. C., R. D. Mudd, R. G. Baca, M. D. Martin, W. R. Norton, and D. B. McLaughlin. 1981. *Pasco Basin Hydrologic Modeling and Far-Field Radionuclide Migration Potential*. RHO-BWI-LD-44, Rockwell Hanford Operations, Richland, Washington.

Hall, M. D. 1981. *Near-Field Impact, 216-U-10 (U-Pond) Decommissioning on the Unconfined Aquifer*. RHO-LD-157, Rockwell Hanford Operations, Richland, Washington.

Dove, F. H., C. R. Cole, M. G. Foley, F. W. Bond, R. E. Brown, W. J. Deutsch, M. D. Freshley, S. K. Gupta, P. J. Gutknecht, W. L. Kuhn, J. W. Lindberg, W. A. Rice, R. Schalla, J. F. Washburn, and J. T. Zellmer. 1982. *AEGIS Technology Demonstration for a Nuclear Waste Repository in Basalt*. PNL-3632, Pacific Northwest Laboratory, Richland, Washington.

Schalla, R., and L. A. Leonhart. 1982. "Dealing with Regional Hydrologic Data Base Limitations and Uncertainties, Case Example: the Columbia River Basalts." In: *Proceedings of the Symposium on the Effectiveness of Geologic Isolation of High Level Radioactive Waste*, D. C. Kocher (ed.).

Clifton, P. M., R. G. Baca, and R. C. Arnett. 1983. *Stochastic Analysis of Groundwater Traveltime for Long-Term Repository Performance Assessment*. RHO-BW-SA-323P, Rockwell Hanford Operations, Richland, Washington.

Eyler, L. L., and M. J. Budden. 1984. *Verification and Benchmarking of PORFLO: An Equivalent Porous Continuum Code for Repository Scale Analysis*. PNL-5044, Pacific Northwest Laboratory, Richland, Washington.

Jones, T. L., G. S. Campbell, and G. W. Gee. 1984. *Water Balance at an Arid Site: A Model Validation Study of Bare Soil Evaporation*. PNL-4896, Pacific Northwest Laboratory, Richland, Washington.

Sagar, B., and P. M. Clifton. 1984. *Stochastic Groundwater Flow Modeling Using the Second-Order Method*. RHO-SA-364P, Rockwell Hanford Operations, Richland, Washington.

Clifton, P. M. 1985. *Groundwater Travel Time Uncertainty Analysis-Sensitivity of Results to Model Geometry and Correlations and Cross-Correlations Among Input Parameters*. RHO-BW-ST-70P, Rockwell Hanford Operations, Richland, Washington.

England, R. L., N. W. Kline, K. J. Ekblad, and R. G. Baca. 1985. *MAGNUM-2D Computer Code: Users Guide*. RHO-BW-CR-143P, Rockwell Hanford Operations, Richland, Washington.

Estey, S. A., R. C. Arnett, and D. R. Aichele. 1985. *Users Guide for MAGNUM-3D: A Three-Dimensional Groundwater Flow Numerical Model*. RHO-BW-ST-67P, Rockwell Hanford Operations, Richland, Washington.

Kline, N. W., R. L. England, and R. G. Baca. 1985. *CHAINT Computer Code. Users Guide*. RHO-BW-CR-144P, Rockwell Hanford Operations, Richland, Washington.

Runchal, A. K., B. Sagar, R. G. Baca, and N. W. Kline. 1985. *PORFLO - A Continuum Model for Fluid Flow, Heat Transfer, and Mass Transport in Porous Media. Model Theory, Numerical Methods, and Computational Tests*. RHO-BW-CR-150P, Rockwell Hanford Operations, Richland, Washington.

Spane, F. A., Jr., and R. B. Mercer. 1985. *HEADCO: A Program for Converting Observed Water Levels and Pressure Measurements to Formation Pressure and Standard Hydraulic Head*. RHO-BW-ST-71 P, Rockwell Hanford Operations, Richland, Washington.

Fayer, M. J., G. W. Gee, and T. L. Jones. 1986. *UNSAT-H Version 1.0: Unsaturated Flow Code Documentation and Applications for the Hanford Site*. PNL-5899, Pacific Northwest Laboratory, Richland, Washington.

Kincaid, C. T., and P. J. Mitchell. 1986. *Review of Multiphase Flow and Pollutant Transport Models for the Hanford Site*. PNL-6048, Pacific Northwest Laboratory, Richland, Washington.

Simmons, C. S., C. T. Kincaid, and A. E. Reisenauer. 1986. *A Simplified Model for Radionuclide Contaminant Transport: The TRANSS Code*. PNL-6029, Pacific Northwest Laboratory, Richland, Washington.

Gee, G. W. 1987. *Recharge at the Hanford Site: Status Report*. PNL-6403, Pacific Northwest Laboratory, Richland, Washington.

Gupta, S. K., C. R. Cole, C. T. Kincaid, and A. M. Monti. 1987. *Coupled Fluid, Energy, and Solute Transport (CFEST) Model: Formulation and User's Manual*. BMI/ONWI-660, Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, Ohio.

Hall, S. H., and V. G. Johnson. 1987. *Effects of Varying Recharge on Radionuclide Flux Rates to the Water Table at a Low-Level Solid Waste Burial Site*. WHC-SA-0184, Westinghouse Hanford Company, Richland, Washington.

Mitchell, P. J., and M. D. Freshley. 1987. "Ground-Water Monitoring and Modeling at the Hanford Site." In: *Waste Management '87, Proceedings of the Symposium on Waste Management 1987*, Vol. 1 General Interest, R. G. Post (ed.). University of Arizona Press, Tucson, Arizona.

Bian, S. H., M. J. Budden, C. L. Bartley, and S. C. Yung. 1988. *GEOTHER/VT4: A Two-Phase Groundwater Fluid Flow and Heat Transport Code for High-Level Radioactive Waste Applications*. PNL-6517, Pacific Northwest Laboratory, Richland, Washington.

Buelt, J. L., W. Conbere, M. D. Freshley, R. J. Hicks, W. L. Kuhn, D. A. Lamar, R. J. Serne, and J. L. Smoot. 1988. *The Predicted Impacts to the Groundwater and the Columbia River from Ammoniated Water Discharges to the 216-A-36B Crib*. PNL-6463, Pacific Northwest Laboratory, Richland, Washington.

Freshley, M. D., and M. J. Graham. 1988. *Estimation of Ground-Water Travel Time at the Hanford Site: Description, Past Work and Future Needs*. PNL-6328, Pacific Northwest Laboratory, Richland, Washington.

Jones, T. L. 1989. *Simulating the Water Balance of an Arid Site*. PNL-SA-17633, Dissertation, Washington State University, Pullman, Washington, published by Pacific Northwest Laboratory, Richland, Washington.

Smoot, J. L., J. E. Szecsody, B. Sagar, G. W. Gee, and C. T. Kincaid. 1989. *Simulation of Infiltration of Meteoric Water and Contaminant Plume Movement in the Vadose Zone at Single-Shell Tank 241-T-106 at the Hanford Site*. WHC-EP-0332, Westinghouse Hanford Company, Richland, Washington.

Freshley, M. D., M. P. Bergeron, N. J. Aimo, and A. G. Law. 1989. *Ground-Water Modeling Investigation of North Richland Well Field and the 1100 Area*. WHC-MR-0033, Pacific Northwest Laboratory and Westinghouse Hanford Company, Richland, Washington.

Connelly, M. P., J. D. Davis, and P. D. Rittmann. 1990. *Numerical Simulation of Sr-90 Transport from the 100-N Area Liquid Waste Disposal Facilities*. WHC-EP-0364, Westinghouse Hanford Company, Richland, Washington.

Jacobson, E. A., and M. D. Freshley. 1990. *An Initial Inverse Calibration of the Ground-Water Flow Model for the Hanford Unconfined Aquifer*. PNL-7144, Pacific Northwest Laboratory, Richland, Washington.

Khaleel, R., and T. Legore. 1990. *Effects of Varying Recharge on Radionuclide Flux Rates to the Water Table at a Low-Level Solid Waste Burial Site*. WHC-SA-0699, Westinghouse Hanford Company, Richland, Washington.

Sagar, B., and A. K. Runchal. 1990. *PORFLO-3 A Mathematical Model for Fluid Flow, Heat and Mass Transport in Variably Saturated Geologic Media*. WHC-EP-0042, Westinghouse Hanford Company, Richland, Washington.

Smoot, J. L., and B. Sagar. 1990. *Three-Dimensional Contaminant Plume Dynamics in the Vadose Zone: Simulation of the 241-T-106 Single-Shell Tank Leak at Hanford*. PNL-7221, Pacific Northwest Laboratory, Richland, Washington.

Connelly, M. P., J. D. Davis, and P. D. Rittmann. 1991. *Numerical Simulation of Strontium-90 Transport from the 100-N Area Liquid Waste Disposal Facilities*. WHC-SD-ER-TA-001, Westinghouse Hanford Company, Richland, Washington.

Gilmore, T. J, J. V. Borghese, and D. R. Newcomer. 1991. *Evaluations of the Effects of the Columbia River on the Unconfined Aquifer Beneath the 100-N Area*. PNL-7646, Pacific Northwest Laboratory, Richland, Washington.

Golder Associates, Inc. 1991. *Travel Time and Groundwater Mounding Estimates for Alternative Soil Column Disposal Sites, Hanford Site, Washington*. Prepared for Westinghouse Hanford Company, Richland, Washington.

Golder Associates, Inc. 1991. *Groundwater Mounding and Plume Migration Analyses for Candidate Soil Column Disposal Sites, Hanford Site, Washington*. Prepared for Westinghouse Hanford Company, Richland, Washington.

Lu, A. H. 1991. *Simulations of Strontium-90 Transport from the 100-N Area to the Columbia River Using VAM2DH*. WHC-EP-0369, Westinghouse Hanford Company, Richland, Washington.

McMahon, W. J. 1991. *Computer Simulation of the Projected Hydrologic Effects of the 200 Areas Treated Effluent Disposal Basin at Each Candidate Site*. WHC-SD-W049H-SE-004, Westinghouse Hanford Company, Richland, Washington.

Nichols, W. E. 1991. *Comparative Simulations of a Two-Layer Landfill Barrier Using the HELP Version 2.0 and UNSAT-H Version 2.0 Computer Codes*. PNL-7583, Pacific Northwest Laboratory, Richland, Washington.

Thomas, T. R. 1991. *Solute Transport Benchmark Studies for TRACR3D Code Verification*. WINCO-1083, Westinghouse Idaho Nuclear Company, Idaho Falls, Idaho.

U.S. Department of Energy. 1991. *Description of Codes and Models to be Used in Risk Assessment*. DOE/RL-91-44, Richland Operations Office, Richland, Washington.

Westinghouse Hanford Company. 1991. *PORMC: A Model for Monte Carlo Simulation of Fluid Flow, Heat and Mass Transport in Variably Saturated Geologic Media*. WHC-EP-0445, Richland, Washington.

Fayer, M. J., M. L. Rockhold, and D. J. Holford. 1992. *Model Assessments of Protective Barriers: Part III, Status of FY 1990 Work*. PNL-7975, Pacific Northwest Laboratory, Richland, Washington.

Gilmore, T. J, D. R. Newcomer, S. K. Wurstner, and F. A. Spane. 1992. *Calculation of Groundwater Discharge to the Columbia River in the 100-N Area*. PNL-8057, Pacific Northwest Laboratory, Richland, Washington.

Rhoads, K., B. N. Bjornstad, R. E. Lewis, S. S. Teel, K. J. Cantrell, R. J. Serne, J. L. Smoot, C. T. Kincaid, and S. K. Wurstner. 1992. *Estimation of the Release and Migration of Lead Through Soils and Groundwater at the Hanford Site 218-E-12B Burial Ground*. PNL-8356, 2 vols., Pacific Northwest Laboratory, Richland, Washington.

Wood, M. I. 1992. *Status of Performance Assessment Studies for the Disposal of Low-Level Radioactive Waste in the 218-W-5 Burial Ground, 200 West Area, Hanford Site*. WHC-SA-1365, Westinghouse Hanford Company, Richland, Washington.

Johnson, P. C. 1993. *HyperVentilate Users Manual (v1.01 and v2.0), A Software Guidance System Created for Vapor Extraction Applications*. EPA 510-R-93-001, Shell Development Westhollow Research Center for Solid Waste and Emergency Response, U.S. Environmental Protection Agency, Washington, D.C.

Meyer, P. D. 1993. *A Quantitative Method for Groundwater Surveillance Monitoring Network Design at the Hanford Site*. PNL-8868, Pacific Northwest Laboratory, Richland, Washington.

Nichols, W. E., and M. D. White. 1993. *MSTS-Multiphase Subsurface Transport Simulator User's Guide and Reference*. PNL-8637, Pacific Northwest Laboratory, Richland, Washington.

Wurstner, S. K., and J. L. Devary. 1993. *Hanford Site Ground-Water Model: Geographic Information System Linkages and Model Enhancements, FY 1993*. PNL-8991, Pacific Northwest Laboratory, Richland, Washington.

Connelly, M. P. 1994. *Capture Zone Analyses for the 200-ZP-1 and 200-UP-1 Pilot-Scale Pump-and-Treat Tests*. WHC-SD-EN-TI-252, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Whelan, G., J. W. Buck, K. J. Castleton, J. P. McDonald, C. Sato, G. M. Gelston, A. deHamer, R. J. Serne, S. K. Wurstner, and R. N. Kickert. 1994. *Unit Environmental Transport Assessment of Contaminants from Hanford's Past-Practice Waste Sites*. PNL-10233, Pacific Northwest Laboratory, Richland, Washington.

Wurstner, S. K., and M. D. Freshley. 1994. *Predicted Impacts of Future Water Level Decline on Monitoring Wells Using a Ground-Water Model of the Hanford Site*. PNL-10196, Pacific Northwest Laboratory, Richland, Washington.

Chilakapati, A. 1995. *DRAFT: A Simulator for Reactive Flow and Transport of Groundwater Contaminants*. PNL-10636, Pacific Northwest Laboratory, Richland, Washington.

Engelman, R. E., R. E. Lewis, and D. C. Stromswold. 1995. *Calibration Models for Measuring Moisture in Unsaturated Formations by Neutron Logging*. PNL-10801, Pacific Northwest Laboratory, Richland, Washington.

Kincaid, C. T., J. W. Shade, G. A. Whyatt, M. G. Piepho, K. Rhoads, J. A. Voogd, J. H. Westsik, Jr., M. D. Freshley, K. A. Blanchard, and B. G. Lauzon. 1995. *Performance Assessment of Grouted Double-Shell Tank Waste Disposal at Hanford*. WHC-SD-WM-EE-004, Rev. 1, 2 vols., Westinghouse Hanford Company, Richland, Washington.

U.S. Department of Energy. 1995. *Modeling Evaluation of N-Springs Barrier and Pump-and-Treat Systems*. DOE/RL-94-132, Rev. 0, Richland, Washington.

Wurstner, S. K., P. D. Thorne, M. A. Chamness, M. D. Freshley, and M. D. Williams. 1995. *Development of a Three-Dimensional Ground-Water Model of the Hanford Site Unconfined Aquifer System: FY 1995 Status Report*. PNL-10886, Pacific Northwest Laboratory, Richland, Washington.

Chiaramonte, G. R., C. W. Denslow, A. J. Knepp, R. D. Landon, and S. Panday. 1996. *Hanford Sitewide Groundwater Remediation Strategy - Groundwater Contaminant Predictions*. BHI-00469, Bechtel Hanford, Inc., Richland, Washington.

Law, A. G., S. Panday, C. W. Denslow, K. R. Fecht, and A. J. Knepp. 1996. *Hanford Sitewide Groundwater Flow and Transport Model Calibration Report.* BHI-00608, Bechtel Hanford, Inc., Richland, Washington.

White, M. D., and M. Oostrom. 1997. *STOMP: Subsurface Transport Over Multiple Phase-Users Guide*. PNNL-11218. Pacific Northwest National Laboratory, Richland, Washington.

Wood, M. I., R. Khaleel, A. H. Lu, P. D. Rittmann, S. H. Finfrock, T. H. DeLorenzo, and D. Y. Garbrick. 1996. *Performance Assessment for the Disposal of Low-level Waste in the 200 East Area Burial Grounds*. WHC-SD-WM-TI-730, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Cole, C. R., S. K. Wurstner, M. P. Bergeron, M. D. Williams, and P. D. Thorne. 1998. *Three-Dimensional Analysis of Future Groundwater Flow Conditions and Contaminant Plume Transport in the Hanford Site Unconfined Aquifer System: FY 1996 and 1997 Status Report*. PNNL-11801, Pacific Northwest National Laboratory, Richland, Washington.

Kincaid, C. T., M. P. Bergeron, C. R. Cole, M. D. Freshley, N. L. Hassig, V. G. Johnson, D. I. Kaplan, R. J. Serne, G. P. Streile, D. L. Strenge, P. D. Thorne, L. W. Vail, G. A. Whyatt, and S. K. Wurstner. 1998. *Composite Analysis for Low-Level Waste Disposal in the 200 Areas Plateau of the Hanford Site*. PNNL-11800, Pacific Northwest National Laboratory, Richland, Washington.

Ho, C. K., R. G. Baca, S. H. Conrad, G. A. Smith, L. Shyr, and T. A. Wheeler. 1999. *Stochastic Parameter Development for PORFLOW Simulations of the Hanford AX Tank Farm*. SAND98-2880, Sandia National Laboratories, Albuquerque, New Mexico.

Bergeron, M. P., E. J. Freeman, and S. K. Wurstner. 2001. *Addendum to Composite Analysis for Low-Level Waste Disposal in the 200 Area Plateau of the Hanford Site*. PNNL-11800 Addendum 1, Pacific Northwest National Laboratory, Richland, Washington.

Cole, C. R., M. P. Bergeron, S. K. Wurstner, P. D. Thorne, S. Orr, and M. I. McKinley. 2001. *Hanford Site-Wide Groundwater Model Calibration Using Inverse Methodology*. PNNL-13447, Pacific Northwest National Laboratory, Richland, Washington.

Cole, C. R., M. P. Bergeron, C. J. Murray, P. D. Thorne, S. K. Wurstner, and P. Rogers. 2001. *Uncertainty Analysis Framework – Hanford Site-Wide Groundwater Flow and Transport Model*. PNNL-13641, Pacific Northwest National Laboratory, Richland, Washington.

Riley, R. G. and C. A. Lo Presti. 2001. *Data Catalog for Models Simulating Release of Contaminants from Hanford Site Waste Sources*. PNNL-13666, Pacific Northwest National Laboratory, Richland, Washington.

Vermeul, V. R., C. R. Cole, M. P. Bergeron, P. D. Thorne, and S. K. Wurstner. 2001. *Transient Inverse Calibration of Site-Wide Groundwater Model to Hanford Operational Impacts from 1943 to 1996 – Alternative Conceptual Model Considering Interaction with Uppermost Basalt Confined Aquifer*. PNNL-13623, Pacific Northwest National Laboratory, Richland, Washington.

Miscellaneous Hanford-Related Reports (in alphabetical order)

Adams, M. R., R. A. Carlson, and P. K. Brockman. 1981. *Long-Term In Situ Disposal Engineering Study*. RHO-CD-1142, Rockwell Hanford Operations, Richland, Washington.

Agnew, S. F. 1995. *Hanford Defined Wastes: Chemical and Radionuclide Compositions*. LA-UR-94-2657, Rev. 2, Chemical Science and Technology Division, Los Alamos National Laboratory, Los Alamos, New Mexico.

Agnew, S. F. 1997. *Hanford Tank Chemical and Radionuclide Inventories: HDW Model, Rev. 4*. LA-UR-96-3860, Los Alamos National Laboratory, Los Alamos, New Mexico.

Agnew, S. F., J. Boyer, R. A. Corbin, T. B. Duran, J. R. FitzPatrick, K. A. Jurgensen, T. P. Ortiz, and B. L. Young. 1996. *Hanford Tank Chemical and Radionuclide Inventories: HDW Model Rev. 3.* LA-UR-96-858, Los Alamos National Laboratory, Los Alamos, New Mexico.

Airhart, S. P. 1990. *Borehole Completion Data Package for the 216-S-10 Ditch and Pond*. WHC-MR-0206, Westinghouse Hanford Company, Richland, Washington.

Airhart, S. P., J. V. Borghese, and S. Dudziak. 1990. *Interim-Status Ground Water Monitoring Plan for the 216-S-10 Pond and Ditch*. WHC-SD-EN-AP-018, prepared by Pacific Northwest Laboratory for Westinghouse Hanford Company, Richland, Washington.

Albenesius, E. L. 1959. "Tritium as a Product of Fission." *Physics Review. Letters* 3:274.

Albenesius, E. L., and R. S. Ondrejin. 1960. "Nuclear Fission Produces Tritium." *Nucleonics* 100.

Aldrich, R. C. 1985. *Radioactive Liquid Wastes Discharged to Ground in the 200 Areas During 1984*. RHO-HS-SR-84-3-4Q LIQ P, Rockwell Hanford Operations, Richland, Washington.

Aldrich, R. C. 1986. *Radioactive Liquid Wastes Discharged to Ground in the 200 Areas During 1985*. RHO-HS-SR-85-3-4Q LIQ P, Rockwell Hanford Operations, Richland, Washington.

Aldrich, R. C. 1987. *Radioactive Liquid Wastes Discharged to Ground in the 200 Areas During 1986*. RHO-HS-SR-86-3-4Q LIQ P, Rockwell Hanford Operations, Richland, Washington.

Ames, L. L., and D. Rai. 1978. *Radionuclide Interactions with Soil and Rock Media*. EPA 520/6-78-007a, U.S. Environmental Protection Agency, Washington, D.C.

Ames, L. L., P. F. Salter, J. E. McGarrah, and B. A. Walker. 1984. "Selenate-Selenium Sorption on a Columbia River Basalt (Umtanum Basalt, Washington, U.S.A.)." *Chem. Geol*. 43:287-302.

Anderson, J. D. 1990. *A History of the 200 Area Tank Farms*. WHC-MR-0132, Westinghouse Hanford Company, Richland, Washington.

Auten, J. E., and K. D. Reynolds. 1997. *Decommissioning Report for Well 299-W-15-5*. BHI-01121, CH2M Hill Hanford, Inc. and Waste Management Federal Services, Inc., Northwest Operations for Bechtel Hanford, Inc., Richland, Washington.

Baden, J. W., and R. E. Peterson. 1997. *183-H Postclosure Plan.* DOE/RL-97-48, Rev. 0, CH2M Hill Hanford, Inc. for Bechtel Hanford, Inc. for U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Baden, J. W., and R. E. Peterson. 1997. *183-H Postclosure Plan*. DOE/RL-97-48, Rev. 0, CH2M Hill Hanford, Inc. for Bechtel Hanford, Inc. for U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Baker, S. M., J. L. Devary, R. P. Elmore, R. F. Lorang, A. J. Rossi, and M. D. Freshley. 1988. *U1/U2 Uranium Plume Characterization, Remedial Action Review and Recommendation for Future Action*. WHC-EP-0133, Westinghouse Hanford Company, Richland, Washington.

Barnett, D. B. 1998. *Evaluation of Groundwater Monitoring Results at the Hanford Site 200 Area Treated Effluent Disposal Facility*. PNNL-11986, Pacific Northwest National Laboratory, Richland, Washington.

Barnett, D. B. 1999. *Results of Tritium Tracking and Groundwater Monitoring at the Hanford Site 200 Area State-Approved Land Disposal Site--FY 1999*. PNNL-13058, Pacific Northwest National Laboratory, Richland, Washington.

Barnett, D. B. 2000. *Groundwater Monitoring and Tritium-Tracking Plan for the 200 Area State-Approved Land Disposal Site*. PNNL-13121, Pacific Northwest National Laboratory, Richland, Washington.

Barnett, D. B. 2000. *Results of Tritium Tracking and Groundwater Monitoring at the Hanford Site 200 Area State-Approved Land Disposal Site--Fiscal Year 2000*. PNNL-13329, Pacific Northwest National Laboratory, Richland, Washington.

Barnett, D. B. and J. T. Rieger. 2001. *Results of Tritium Tracking and Groundwater Monitoring at the Hanford Site 200 Area State-Approved Land Disposal Site – Fiscal Year 2001*. PNNL-13689, Pacific Northwest National Laboratory, Richland, Washington.

Barnett, D. B., M. P. Bergeron, C. R. Cole, M. D. Freshley, and S. K. Wurstner. 1997. *Tritium Monitoring in Groundwater and Evaluation of Model Predictions for the Hanford Site 200 Area Effluent Treatment Facility*. PNNL-11665, Pacific Northwest National Laboratory, Richland, Washington.

Barnett, D. B., J. D. Davis, L. B. Collard, P. B. Freeman, and C. J. Chou. 1995. *Groundwater Screening Evaluation/Monitoring Plan -- 200 Area Treated Effluent Disposal Facility (Project W-049H)*. WHC-SD-EN-WP-012, Rev. 1, Westinghouse Hanford Company, Richland, Washington.

Barney, G. S. 1981. *Radionuclide Reactions with Groundwater and Basalts from Columbia River Basalts*. RHO-SA-217, Rockwell Hanford Operations, Richland, Washington.

Barney, G. S. 1984. "Radionuclide Sorption and Desorption Reactions with Interbed Materials from the Columbia River Basalt Formation." In: *Geochemical Behavior of Disposed Radioactive Waste*, G. S. Barney, J. D. Navratil, and W. W. Schultz (eds.). ACS Symposium Series 246, American Chemical Society, Washington, D.C.

Barton, K.R.O., L. A. Doremus, T. J Gilmore, G. V. Last, and J. V. Boreghese. 1990. *Borehole Completion Data Package for Low-Level Burial Grounds - 1990*. WHC-MR-0205, prepared by Pacific Northwest Laboratory for Westinghouse Hanford Company, Richland, Washington.

Bauer, H. H., and J. J. Vaccaro. 1990. *Estimates of Ground-Water Recharge to the Columbia Plateau Regional Aquifer System, Washington, Oregon, and Idaho for Predevelopment and current Land Use Conditions*. Water Resources Investigation Report 88-4108, U.S. Geological Survey, Tacoma, Washington.

Bechtel Hanford, Inc. 1999. *Cleanup Verification Package for the 116-C-1 Process Effluent Trench*. CVP-98-00006, Rev. 0, Richland, Washington.

Bergeron, M. P. and S. K. Wurstner. 2000. *Groundwater Calculations Supporting the Immobilized Low-Activity Waste Disposal Facility Performance Assessment*. PNNL-13400, Pacific Northwest National Laboratory, Richland, Washington.

Bergsman, K. E., T. B. Bergman, D. W. Bergmann, G. E. Costley, M. T. Jansky, D. S. Leach, R. L. McCormick, M. J. Monthey, A. N. Praga, I. K. Ullah, W. L. Willis, and A. G. Hosler. 1995. *K-Basins Environmental Impact Statement Technical Input*. WHC-SD-SNF-TI-013, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Bergstrom, K. A., T. H. Mitchell, R. Randall, and R. Price. 2000. *Spectral Gamma Logging Investigations Using a Small-Diameter Geophysical Logging System at B Pond, 216-B-2-2 Ditch, and 126-F-1 Ash Pit.* BHI-01352, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Bierschenk, W. H. 1957. *Fluctuations of Hanford Water Levels*. HW-53599, General Electric Company, Richland, Washington.

Bierschenk, W. H. 1959. *Aquifer Characteristics and Ground-Water Movement at Hanford*. HW-60601, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Bierschenk, W. H. and M. W. McConiga. 1957. *Changes in the Hanford Water Table 1944 - 1957*. HW-51277, Hanford Atomic Products Operation, Richland, Washington.

Bisping, L. E. 2002. *Hanford Site Environmental Surveillance Data Report for Calendar Year 2001*. PNNL-13910, APP. 1, Pacific Northwest National Laboratory, Richland, Washington.

Bjornstad, B. N. 1984. *Suprabasalt Stratigraphy Within and Adjacent to the Reference Repository Location*. SD-BWI-DP-039, Rockwell Hanford Operations, Richland, Washington.

Bjornstad, B. N. 1990. *Geohydrology of the 218-W-5 Burial Ground, 200-West Area, Hanford Site*. PNL-7336, Pacific Northwest Laboratory, Richland, Washington.

Borghese, J. V., R. S. Edrington, and L. D. Walker. 1995. *N Springs Pump-and-Treat Well Design*. BHI-00147, Rev. 1, Bechtel Hanford, Inc., Richland, Washington.

Brown, D. J. 1963. *Status of the Ground Water Beneath Hanford Reactor Areas, January 1962 to January 1963*. HW-77170, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Brown, D. J. 1964. *Ground Water Travel Time Calculations for the 1301-N Crib*. HW-80558, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Brown, D. J., and J. R. Raymond. 1962. *Hanford Experience in the Radiological Monitoring of Ground Water*. HW-SA-2566, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Bryce, R. W., and S. M. Goodwin. 1989. *Borehole Summary Report for Five Ground-Water Monitoring Wells Constructed in the 1100 Area*. PNL-6824, Pacific Northwest Laboratory, Richland, Washington.

Bryce, R. W., C. T. Kincaid, P. W. Eslinger, and L. F. Morasch (eds.). 2002. *An Initial Assessment of Hanford Impact Performed with the System Assessment Capability*. PNNL-14027, Pacific Northwest National Laboratory, Richland, Washington.

Buske, N., and L. Josephson. 1988. *Water and Sediment Reconnaissance of the Hanford Shoreline*. Hanford Reach Project, Data Report No. 4, Fall 1988, SEARCH Technical Services, Davenport, Washington.

Callison, S. W. and S. W. Clark. 2002. *Protection of 300 Area Groundwater from Uranium Contaminated Soils at Remediated Sites*. BHI-01667, Rev. 0, prepared by CH2M HILL Hanford, Inc. for Bechtel Hanford, Inc., Richland, Washington.

Caggiano, J. A., Jr. 1992. *Borehole Completion Data Package for Single-Shell Tanks: CY 1990*. WHC-SD-EN-DP-041, Westinghouse Hanford Company, Richland, Washington.

Caggiano, J. A. 1993. *Borehole Completion Data Package for CY 1991 and CY 1992 RCRA Wells at Single-Shell Tanks*. WHC-SD-EN-DP-042, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Campbell, M. D. 1994. *Monitoring Groundwater and River Interaction Along the Hanford Reach of the Columbia River*. PNL-9437, Pacific Northwest Laboratory, Richland, Washington.

Campbell, M. D., G. W. Gee, M. J. Kanyid, and M. L. Rockhold. 1990. *Field Lysimeter Test Facility: Second Year (FY 1989) Test Results*. PNL-7209, Pacific Northwest National Laboratory, Richland, Washington.

Carpenter, R. W. 1993. *100-D Technical Baseline Report*. WHC-SD-EN-TI-181, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Carpenter, R. W., and S. L. Cotè. 1994. *100-K Area Technical Baseline Report*. WHC-SD-EN-TI-239, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Carpenter, R. W., S. L. Cotè, D. H. Deford, and M. W. Einan. 1994. *100-B/C Area Technical Baseline Report*. WHC-SD-EN-TI-220, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

CH2M HILL Hanford, Inc. 2001. *Borehole Completion Report - 216-Z-9 Trench Vadose Well Deepening and Characterization*. BHI-01552, Rev. 0, prepared for Bechtel Hanford, Inc., Richland, Washington.

Chamness, M. A., and J. K. Merz. 1993. *Hanford Wells*. PNL-8800, Pacific Northwest Laboratory, Richland, Washington.

Chamness, M. A., T. J Gilmore, and S. S. Teel. 1993. *Savage Island Project Borehole Completion Report*. PNL-8485, Pacific Northwest Laboratory, Richland, Washington.

Chamness, M. A., S. P. Luttrell, D. J. Bates, and W. J. Martin. 1990. *2101-M Pond Hydrogeologic Characterization Report*. PNL-7468, Pacific Northwest Laboratory, Richland, Washington.

Chapman, D. W. 1988. "Critical Review of Variables Used to Define Effects of Fines in Redds of Large Salmonids." *Transactions of the American Fisheries Society* 117:1-21.

Chiaramonte, G. R. 1997. *Decision Process for Hanford Sitewide Groundwater Remediation*. BHI-00455, Rev. 1, Bechtel Hanford, Inc., Richland, Washington.

Chou, C. J., and V. G. Johnson. 1996. *Effluent Variability Study Results for the 200 Area Effluent Disposal Facility (W-049H)*. WHC-SD-LEF-EV-001, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Clark, S. W. 2002. *116-F-14 Characterization Test Pit Results*. BHI-01613, Bechtel Hanford Inc., Richland, Washington.

Conaway, J. G., R. J. Luxmoore, J. M. Matuszek, and R. O. Patt. 1997. *Tank Waste Remediation System Vadose Zone Contamination Issue: Independent Expert Panel Status Report*. DOE/RL-97-49, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Connelly, M. P. 1997. *Assessment of the Chromium Plume West of the 100-D/DR Reactors.* BHI-00967, CH2M Hill Hanford, Inc. for Bechtel Hanford, Inc., Richland, Washington.

Connelly, M. P. 1997. *Chromium Plume West of the 100-D/DR Reactors--Data Supplement*. BHI-01131, CH2M Hill Hanford, Inc. for Bechtel Hanford, Inc., Richland, Washington.

Cotè, S. L. 1994. *100-N Technical Baseline Report*. WHC-SD-EN-TI-251, Westinghouse Hanford Company, Richland, Washington.

Crumpler, J. D. 2002. *Site-Specific SST Phase 1 RFI/CMS Work Plan Addendum for WMAs T and TX-TY*. RPP-7578, Rev. 2, CH2M HILL Hanford Group, Inc., Richland Washington.

Cushing, C. E. (ed.) 1995. *Hanford Site National Environmental Policy Act (NEPA) Characterization*. PNL-6415, Rev. 7, Pacific Northwest Laboratory, Richland, Washington.

Dauble, D. D., and D. G. Watson. 1990. *Spawning and Abundance of Fall Chinook Salmon (Oncorhynchus tshawytscha) in the Hanford Reach of the Columbia River, 1948-1988*. PNL-7289, Pacific Northwest Laboratory, Richland, Washington.

Davis, J. D. 1993. *Site Characterization Report, Results of Detailed Evaluation of the Suitability of the Site Proposed for Disposal of 200 Areas Treated Effluent*. WHC-SD-EN-SE-004, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Davis, J. D., D. B. Barnett, C. J. Chou, and P. B. Freeman. 1996. *Ground-Water Screening Evaluation/ Monitoring Plan -- 200 Area Effluent Treatment Facility (Project C-018H)*. WHC-SD-C018H-PLN-004, Rev. 1, Westinghouse Hanford Company, Richland, Washington.

Davis, J. D., D. B. Barnett, L. C. Swanson, W. J. McMahon, and C. D. Palomares. 1993. *Site Characterization Report: Results of Detailed Evaluation of the Suitability of the Site Proposed for Disposal of 200 Areas Treated Effluent*. WHC-SD-EN-ES-004, Westinghouse Hanford Company, Richland, Washington.

Deford, D., and M. W. Einan. 1995. *100-H Area Technical Baseline Report*. BHI-00127, Rev. 0, Bechtel Hanford Inc., Richland, Washington.

Deju, R. A., and W. K. Summers. 1975. *Transmissivity and Hydraulic Conductivity of Saturated Sedimentary Rocks in the Hanford Reservation*. CA-168-RA-D5, Atlantic Richfield Hanford Company, Richland, Washington.

Delaney, C. D. 1993. *Borehole Completion Data Package for the CY 1992 216-B-3 Pond Drilling Project*. WHC-SD-EN-DP-053, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Delaney, C. D., and S. M. Goodwin. 1992. *Borehole Completion Data Package for Calendar Year 1991: 216-B-3 Pond Drilling Project*. WHC-SD-EN-DP-046, Westinghouse Hanford Company, Richland, Washington.

Delaney, C. D., K. A. Lindsey, and S. P. Reidel. 1991. *Geology and Hydrology of the Hanford Site: A Standardized Text for Use in Westinghouse Hanford Company Documents and Reports*. WHC-SD-ER-TI-003, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Delegard, C. H., R. L. Weiss, R. T. Kimura, A. G. Law, and R. C. Routson. 1986. "Characterization and Anion Exchange Removal of Uranium from Hanford Ground Water." In: *Waste Management '86, Proceedings of the Symposium on Waste Management*, Vol. 1 General Interest, R. G. Post (ed.). University of Arizona Press, Tucson, Arizona. (RHO-RE-SA-116P)

Dirkes, R. L. 1990. *1988 Hanford Riverbank Springs Characterization Report*. PNL-7500, Pacific Northwest Laboratory, Richland, Washington.

Dirkes, R. L., R. W. Hanf, and T. M. Poston (eds.). 1999. *Hanford Site 1998 Environmental Report*. PNNL-12088, Pacific Northwest National Laboratory, Richland, Washington.

Dirkes, R. L., R. W. Hanf, and T. M. Poston (eds.). 2000. *Hanford Site Environmental Report for Calendar Year 1999*. PNNL-13230, Pacific Northwest National Laboratory, Richland, Washington.

Doremus, L. A. 1990. *Borehole Completion Data Package for the Liquid Effluent Retention Facility*. WHC-MR-0235, Westinghouse Hanford Company, Richland, Washington.

Dresel, P. E., B. A. Williams, J. C. Evans, R. M. Smith, C. J. Thompson, and L. C. Hulstrom. 2000. *Evaluation of Elevated Tritium Levels in Groundwater Downgradient from the 618-11 Burial Grounds Phase I Investigations*. PNNL-13228, Pacific Northwest National Laboratory, Richland, Washington.

Drost, B. W., S. E. Cox, and K. M. Schurr. 1997. *Changes in Ground-Water Levels and Ground-Water Budgets, from Predevelopment to 1986, in Parts of the Pasco Basin, Washington*. Water-Resources Investigations Report 96-4086, U.S. Geological Survey, Tacoma, Washington.

Drost, B. W., K. M. Schurr, and W. E. Lum II. 1989. *Selected Ground-Water Information for the Pasco Basin and Adjacent Areas, Washington, 1986-1989*. Open-File Report 89-228, U.S. Geological Survey, Tacoma, Washington.

Drummond, M. E. 1992. *The Future for Hanford: Uses and Cleanup. A Final Report of the Hanford Future Site Uses Working Group*. Eastern Washington University, Cheney, Washington.

DynCorp Tri-Cities Services, Inc. *Hanford Solid Waste Landfill Closure Plan*. HNF-7173, Rev. 0, DynCorp Tri-Cities Services, Inc., Richland, Washington.

Ebbert, J. C., S. E. Cox, B. W. Drost, and K. M. Shurr. 1995. *Distribution and Sources of Nitrate and Presence of Fluoride and Pesticides in Parts of the Pasco Basin, Washington, 1986-1988*. Water-Resources Investigations Report 93-4197, U.S. Geological Survey, Washington, D.C., 173 pp.

Ecology and EPA. 1986. *Consent Agreement and Compliance Order*. DE86-133, PCHB No. 86-44, State of Washington Department of Ecology and U.S. Environmental Protection Agency, Olympia, Washington.

Eddy, P. A., D. A. Myers, and J. R. Raymond. 1978. *Vertical Contamination in the Unconfined Ground Water at the Hanford Site, Washington*. PNL-2724, Pacific Northwest Laboratory, Richland, Washington.

Eddy, P. A., S. S. Teel, J. R. Raymond, and W. H. Bierschenk. 1988. *Water Quality: Historic Values and Impact of Drilling Activities During FY 1988 at the Reference Repository Location in Southeastern Washington*. PNL-6497, Pacific Northwest Laboratory, Richland, Washington.

Eliason, J. R., and B. F. Hajek. 1967. *Ground Disposal of Reactor Coolant Effluent*. BNWL-CC-1352, Battelle Northwest, Richland, Washington.

Evans, J. C. 1989. *1100-EM-1 Soil Gas Survey Final Report*. WHC-MR-0072, Westinghouse Hanford Company, Richland, Washington.

Evans, J. C., R. M. Fruland, D. W. Glover, and C. Veverka. 1989. *Final Soil-Gas Survey at the Solid Waste Landfill*. PNL-7147, Pacific Northwest Laboratory, Richland, Washington.

Fancher, J. D. 1993. *200 West Carbon Tetrachloride Expedited Response Action Baseline Monitoring Data Package*. WHC-SD-EN-DP-063, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Faurote, J. M. 2000. *Groundwater Monitoring and Sampling at the Environmental Restoration Disposal Facility, Calendar Year 1996 Through 1999*. BHI-01382, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Faroute, J. M. 2001. *Borehole Summary Report for the 618-11 Burial Ground Tritium Investigation*. BHI-01567, CH2M HILL Hanford, Inc., Richland, Washington.

Fayer, M. J., and T. B. Walters. 1995. *Estimated Recharge Rates at the Hanford Site*. PNL-10285, Pacific Northwest Laboratory, Richland, Washington.

Fayer, M. J., E. M. Murphy, J. L. Downs, F. O. Khan, C. W. Lindenmeier, and B. N. Bjornstad. 1999. *Recharge Data Package for the Immobilized Low-Activity Waste 2001 Performance Assessment*. PNNL-13033, Pacific Northwest National Laboratory, Richland, Washington.

Fayer, M. J., J. B. Sisson, W. A. Jordan, A. H. Lu, and P. R. Heller. 1993. *Subsurface injection of radioactive tracers: Field experiment for model validation testing*. NUREG/CR-5996, U.S. Nuclear Regulatory Commission, Washington, D.C.

Fecht, K. R.. 1978. *Geology of Gable Mountain - Gable Butte Area*. RHO-BWI-LD-5, Rockwell Hanford Operations, Richland, Washington.

Fecht, K. R., and D. C. Weekes. 1996. *Geologic Field Inspection of the Sedimentary Sequence at the Environmental Restoration Disposal Facility*. BHI-00230, Bechtel Hanford, Inc., Richland, Washington.

Fecht, K. R., G. V. Last, and K. R. Price. 1977. *Evaluation of Scintillation Probe Profiles from 200 Area Crib Monitoring Wells*. ARH-ST-156, Atlantic Richfield Hanford Company, Richland, Washington.

Fecht, K. R., S. P. Reidel, and A. M. Tallman. 1987. "Paleodrainage of the Columbia River System on the Columbia Plateau of Washington State - A Summary." In *Selected Papers on the Geology of Washington*. J. E. Schuster (ed.), Washington State Division of Geology and Earth Resources, Bulletin 77, p. 219-248.

Fecht, K. R., D. B. Barnett, A. G. Law, K. A. Lindsey, and V. J. Rohay. 1994. "Pleistocene Clastic Dikes and Their Influence on Moisture Flow in the Vadose Zone of South-Central Washington State." *Geological Society of America, Abstracts with Programs* 26(7):A204.

Fecht, K. R., B. N. Bjornstad, D. G. Horton, G. V. Last, S. P. Reidel, and K. A. Lindsey. 1999. *Clastic Injection Dikes of the Pasco Basin and Vicinity*. BHI-01103, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Ford, B. H., and C. W. Denslow. 1996. *Methodology for Evaluating Groundwater Analytical Data*. BHI-00757, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Ford, B. H. 1996. *Description of Work for Routine Groundwater Sampling at the Environmental Restoration Disposal Facility*. BHI-00873, Bechtel Hanford, Inc., Richland, Washington.

Freeman, E. J., R. Khaleel, and P. R. Heller. 2001. *A Catalog of Vadose Zone Hydraulic Properties for the Hanford Site*. PNNL-13672, Pacific Northwest National Laboratory, Richland, Washington.

Freshley, M. D. 1989. "Estimation of Ground-Water Travel Time at the Hanford Site, Washington." In: *Abstracts, Fall Meeting, American Geophysical Union, December 4-8*, San Francisco, California. American Geophysical Union 70(43):1098.

Freshley, M. D., and P. D. Thorne. 1991. "Reconstruction of Radionuclide Movement in Groundwater at the Hanford Site." *Trans. Am. Nuc. Soc*. 63:47-49.

Freshley, M. D., and P. D. Thorne. 1992. *Ground-Water Contribution to Dose from Past Hanford Operations*. PNWD-1974 HEDR, Battelle Pacific Northwest Laboratories, Richland, Washington.

Fruchter, J. S., J. E. Amonette, C. R. Cole, Y. A. Gorby, M. D. Humphrey, J. D. Isok, F. A. Spane, J. E. Szecsody, S. S. Teel, V. R. Vermeul, M. D. Williams, and S. B. Yabusaki. 1996. *In Situ Redox Manipulation Field Injection Test Report - Hanford 100-H Area*. PNNL-11372, Pacific Northwest National Laboratory, Richland, Washington.

Fruland, R. M., R. A. Hagen, C. S. Cline, D. J. Bates, J. C. Evans, and R. L. Aaberg. 1989. *Interim Site Characterization Report and Ground Water Monitoring Program for the Hanford Site Solid Waste Landfill*. PNL-6823, Pacific Northwest Laboratory, Richland, Washington.

Galgoul, M. J. and C. Sump. 2002. *Alternative Fine-Grained Soil Borrow Source Study Final Report*. BHI-01551, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Gamerdinger, A. P., D. I. Kaplan, and C. T. Resch. 1998. *Uranium (VI) Sorption and Transport in Unsaturated, Subsurface Hanford Sediments: Effect of Moisture Content and Sediment Texture*. PNNL-11975, Pacific Northwest National Laboratory, Richland, Washington.

Gaylord, D. R., and E. P. Poeter. 1991. *Geology and Hydrology of the 300 Area and Vicinity, Hanford Site, South Central Washington*. WHC-EP-0500, Westinghouse Hanford Company, Richland, Washington.

Gee, G. W. 1987. *Recharge at the Hanford Site: Status Report*. PNL-6403, Pacific Northwest Laboratory, Richland, Washington.

Gee, G. W. 1991. *Tracking the Movement of Contaminants into Groundwater*. Geophysics News, pp. 14-15. American Geophysical Union. Washington, D.C.

Gee, G. W., and R. R. Kirkham. 1984. *Arid Site Water Balance: Evapotranspiration Modeling and Measurements*. PNL-5177, Pacific Northwest Laboratory, Richland, Washington.

Gee, G. W., and P. R. Heller. 1985. *Unsaturated Water Flow at the Hanford Site: A Review of Literature and Annotated Bibliography*. PNL-5428, Pacific Northwest Laboratory, Richland, Washington.

Gee, G. W. and A. L. Ward. 2001. V*adose Zone Transport Field Study: Status Report*. PNNL-13679, Pacific Northwest National Laboratory, Richland, Washington.

Gee, G. W., M. J. Fayer, M. L. Rockhold, and M. D. Campbell. 1992. "Variations in Recharge at the Hanford Site." *Northwest Sci*. 66:237-250.

Gee, G. W., L. L. Cadwell, H. D. Freeman, M. W. Ligotke, S. O. Link, R. A. Romine, and W. H. Walters. 1993. *Testing and Monitoring Plan for the Permanent Isolation Surface Barrier Prototype.* PNL-8391, Jr., Pacific Northwest Laboratory, Richland, Washington.

Gee, G. W., A. L. Ward, B. G. Gilmore, S. O. Link, G. W. Dennis, and T. K. O'Neil. 1996. *Hanford Protective Barrier Status Report. FY 1996*. PNNL-11367, Pacific Northwest National Laboratory, Richland, Washington.

Gee, G. W., A. L. Ward, J. C. Riter, J. B. Sisson, J. M. Hubbel, and H. Sydnor. 2001. *Installation of a Hydrologic Characterization Network for Vadose Zone Monitoring of a Single-Shell Tank Farm at the U.S. Department of Energy Hanford Site*. PNNL-13712, Pacific Northwest National Laboratory, Richland, Washington.

Gee, G. W., A. L. Ward, J. B. Sisson, J. M. Hubbell, D. A. Myers, and H. A. Sydnor. 2002. *Hydrologic Characterization Using Vadose Zone Monitoring Tools: Status Report*. PNNL-14115, Pacific Northwest National Laboratory, Richland, Washington.

Geist, D. R., T. M. Poston, and D. D. Dauble. 1994. *Assessment of Potential Impacts of Major Ground-water Contaminants to Fall Chinook Salmon (Oncorhynchus tshawytscha) in the Hanford Reach, Columbia River*. PNL-9990, Pacific Northwest Laboratory, Richland, Washington.

General Accounting Office. 1998. *Understanding of Waste Migration at the Hanford Site is Inadequate for Key Decisions*. GAO/RCED-98-80, Report to Congressional Requesters, Washington, D.C.

General Electric Company. 1963. "Volume 3: Description of the 100-B, 100-C, 100-D, 100-DR, 100-F, and 100-H Production Reactor Plants," *Hazards Summary Report*. HW-74094, Hanford Atomics Products Division, Richland, Washington.

Geomatrix Consultants. 1996. *Probabilistic Seismic Hazard Analysis, DOE Hanford Site, Washington*. WHC-SD-W236A-TI-002, Rev. 1, prepared for Westinghouse Hanford Company, Richland, Washington.

Gephart, R. E., R. C. Arnett, R. G. Baca, L. S. Leonhart, and F. A. Spane, Jr. 1979. *Hydrologic Studies within the Columbia Plateau, Washington: An Integration of Current Knowledge*. RHO-BWI-ST-5, Rockwell Hanford Operations, Richland, Washington.

Gephart, R. E., F. A. Spane, L. S. Leonhart, D. A. Palombo, and S. R. Strait. 1979. "Pasco Basin Hydrology." In: *Hydrologic Studies Within the Columbia Plateau, Washington: An Integration of Current Knowledge*. RHO-BWI-ST-5, Rockwell Hanford Operations, Richland, Washington.

Gerber, M. S. 1993. *Manhattan Project Buildings and Facilities at the Hanford Site: A Construction History*. WHC-MR-0425, Westinghouse Hanford Company, Richland, Washington.

Gilmore, T. J. 1989. *The Installation of the Multiport Ground-Water Sampling System in the 3000 Area*. PNL-6910, Pacific Northwest Laboratory, Richland, Washington.

Gilmore, T. J, J. V. Borghese, J. P. McDonald, and D. R. Newcomer. 1990. "Effects of River Stage Fluctuations on an Unconfined Aquifer Beneath Waste-Water Disposal Facilities." *Ground-Water* 28(5):793-794.

Gilmore, T. J, J. V. Borghese, J. P. McDonald, and D. R. Newcomer. 1990. *Evaluations of the Effects of the Columbia River on the Unconfined Aquifer Beneath the 1301-N Liquid Waste Disposal Facility*. PNL-7341, Pacific Northwest Laboratory, Richland, Washington.

Gilmore, T. J, J. V. Borghese, and D. R. Newcomer. 1991. *Evaluations of the Effects of the Columbia River on the Unconfined Aquifer Beneath the 100-N Area*. PNL-7646, Pacific Northwest Laboratory, Richland, Washington.

Gilmore, T. J, J. V. Borghese, and D. R. Newcomer. 1993. "Effects of River Stage and Waste Water Discharges on the Unconfined Aquifer, Hanford, Washington." *Ground Water Monitoring and Remediation* XIII(1).

Gilmore, T. J, D. R. Newcomer, S. K. Wurstner, and F. A. Spane. 1992. *Calculation of Groundwater Discharge to the Columbia River in the 100-N Area*. PNL-8057, Pacific Northwest Laboratory, Richland, Washington.

Gilmore, T. J, F. A. Spane, Jr., D. R. Newcomer, and C. R. Sherwood. 1992. *Applications of Three Aquifer Test Methods for Estimating Hydraulic Properties Within the 100-N Area*. PNL-8335, Pacific Northwest Laboratory, Richland, Washington.

Gleckler, B. P. 1995. *Environmental Releases for Calendar Year 1994*. WHC-EP-0527-04, Westinghouse Hanford Company, Richland, Washington.

Goodwin, S. M. 1990. *200-East and 200-West Areas Low-Level Burial Grounds Borehole Summary Report*. WHC-MR-0204, Westinghouse Hanford Company, Richland, Washington.

Goodwin, S. M. 1990. *Borehole Completion Data Package for the 216-B-63 Trench--1990*. WHC-MR-0207, Westinghouse Hanford Company, Richland, Washington.

Goodwin, S. M. 1990. *Borehole Completion Data Package for the 216-U-12 Crib*. WHC-MR-0208, Westinghouse Hanford Company, Richland, Washington.

Graham, M. J., G. V. Last, and K. R. Fecht. 1984. *An Assessment of Aquifer Intercommunication in the B Pond-Gable Mountain Pond Area of the Hanford Site*. RHO-RE-ST-12 P, Rockwell Hanford Operations, Richland, Washington.

Graham, M. J., M. D. Hall, S. R. Strait, and W. R. Brown. 1981. *Hydrology of the Separations Area*. RHO-ST-42, Rockwell Hanford Operations, Richland, Washington.

Graham, M. J., M. D. Hall, S. R. Strait, and W. R. Brown. 1981. *Hydrology of the Separations Area*. RHO-ST-42, Rockwell Hanford Operations, Richland, Washington.

Gutknecht, P. J., W. A. Rice, C. R. Cole, and M. D. Freshley. 1980. *Pasco Basin Hydrometeorological Study*. PNL-3855, prepared for Rockwell Hanford Operations (RHO-BWI-C-98) by Pacific Northwest Laboratory, Richland, Washington.

Hall, S. H. 1989. *Evaluations of the Ground-Water Contaminant Plume Extending from the 183-H Solar Evaporation Basins*. PNL-7130, Pacific Northwest Laboratory, Richland, Washington.

Hall, S. H. 1990. "Resolving Superimposed Ground-Water Contaminant Plumes Characterized by Chromium, Nitrate, Uranium, and Technetium-99." In: *Proceedings, Ground-Water Geochemistry, February 20-22, 1990*, Kansas, Missouri. National Well Water Association, Dublin, Ohio.

Haney, W. A. 1957. *Disposal of High Cobalt-60 Scavenged Wastes*. HW-48862, Hanford Atomic Products Operation, Richland, Washington.

Haney, W. A., D. J. Brown, and A. E. Reisenauer. 1962. *Fission Product Tritium in Separations Wastes and in the Ground Water.* HW-74536, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Hanlon, B. M. 2001. *Waste Tank Summary Report for Month Ending January 31, 2001*. HNF-EP-0182, Rev. 154, CH2M HILL Hanford Group, Inc., Richland, Washington.

Hartman, M. J. (ed.). 1999. *Hanford Site Groundwater: Settings, Sources, and Methods*. PNNL-13080, Pacific Northwest National Laboratory, Richland, Washington.

Hartman, M. J. 1990. *Interim Hydrogeologic Characterization Report for the 216-B-3 Pond*. WHC-SD-EN-EV-002, Westinghouse Hanford Company, Richland, Washington.

Hartman, M. J. 1992. *Borehole Completion Data Package, 100-D Ponds Wells: CY 1992*. WHC-SD-EN-DP-043, Westinghouse Hanford Company, Richland, Washington.

Hartman, M. J. 1992. *Borehole Completion Data Package for Wells 199-N-71, 199-N-72, 199-N-73, and 199-N-74*. WHC-SD-EN-DP-040, Westinghouse Hanford Company, Richland, Washington.

Hartman, M. J. 1993. *Borehole Completion Data Package for Wells 199-N-75, 199-N-76, and 199-N-77*. WHC-SD-EN-DP-056, Westinghouse Hanford Company, Richland, Washington.

Hartman, M. J. 1993. *Borehole Completion Data Package for Wells 199-N-75, 199-N-76, and 199-N-77*. WHC-SD-EN-DP-056, Rev. 0-A, Westinghouse Hanford Company, Richland, Washington.

Hartman, M. J. 1994. *Borehole Completion Data Package for Well 199-N-81*. WHC-SD-EN-DP-082, Westinghouse Hanford Company, Richland, Washington.

Hartman, M. J., and K. A. Lindsey. 1993. *Hydrogeology of the 100-N Area, Hanford Site, Washington*. WHC-SD-EN-EV-027, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Hartman, M. J., and R. E. Peterson. 1992. *Hydrologic Information Summary for the Northern Hanford Site*. WHC-SD-EN-TI-023, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Hartman, M. J., L. F. Morasch, and W. D. Webber (eds.). 2000. *Hanford Site Groundwater Monitoring for Fiscal Year 1999*. PNNL-13116, Pacific Northwest National Laboratory, Richland, Washington.

Hartman, M. J., P. E. Dresel, J. P. McDonald, R. B. Mercer, D. R. Newcomer, and E. C. Thornton. 1998. *Integrated Monitoring Plan for the Hanford Groundwater Monitoring Project*. PNNL-11989, Pacific Northwest National Laboratory, Richland, Washington.

Hartman, M. J., P. E. Dresel, J. W. Lindberg, D. R. Newcomer, and E. C. Thornton. 2000. *Integrated Monitoring Plan for the Hanford Groundwater Monitoring Project*. PNNL-11989, Rev. 2, Pacific Northwest National Laboratory, Richland, Washington.

Hartman, M. J., P. E. Dresel, J. W. Lindberg, D. R. Newcomer, and E. C. Thornton. 2001. *FY 2002 Integrated Monitoring Plan for the Hanford Groundwater Monitoring Project*. PNNL-13698, Pacific Northwest National Laboratory, Richland, Washington.

Hartman, M. J., P. E. Dresel, J. W. Lindberg, J. P. McDonald, D. R. Newcomer, and E. C. Thornton. 2002. *Fiscal Year 2003 Integrated Monitoring Plan for the Hanford Groundwater Monitoring Project*. PNNL-14111, Pacific Northwest National Laboratory, Richland, Washington.

Hodges, F. N. 1993. *Borehole Completion Data Package for Non-Radioactive Dangerous Waste Landfill Facility Monitoring Wells 699-25-34D and 699-26-34B*. WHC-SD-EN-DP-055, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Hodges, F. N. and C. J. Chou. 2000. *Groundwater Quality Assessment Plan for Single-Shell Tank Waste Management Area U at the Hanford Site*. PNNL-13185, Pacific Northwest National Laboratory, Richland, Washington.

Hodges, F. N. and C. J. Chou. 2000. *Groundwater Quality Assessment for Waste Management Area U: First Determination*. PNNL-13282, Pacific Northwest National Laboratory, Richland, Washington.

Hoitink, D. J., K. W. Burk, and J. V. Ramsdell. 1999. *Hanford Site Climatological Data Summary 1998 With Historical Data*. PNNL-12087, Pacific Northwest National Laboratory, Richland, Washington.

Hoitink, D. J., K. W. Burk, and J. V. Ramsdell. 2000. *Hanford Site Climatological Data Summary 1999 With Historical Data*. PNNL-13117, Pacific Northwest National Laboratory, Richland, Washington.

Honstead, J. F., M. W. McConiga, and J. R. Raymond. 1955. *Gable Mountain Groundwater Tests*. HW-34532, General Electric Company, Richland, Washington.

Hoover, J. D., and T. LeGore. 1991. *Characterization and Use of Soil and Groundwater Background for the Hanford Site*. WHC-MR-0246, Westinghouse Hanford Company, Richland, Washington.

Hope, S. J. 1996. *1907-DR Process Sewer Outfall Site Soil Characterization*. BHI-00860, Rev. 0, prepared by CH2M Hill Hanford, Inc. for Bechtel Hanford, Inc., Richland, Washington.

Hope, S. J., and R. E. Peterson. 1996. *Pore Water Chromium Concentrations at 100-H Reactor Area Adjacent to Fall Chinook Salmon Spawning Habitat of the Hanford Reach, Columbia River*. BHI-00345, Rev. 1, prepared by CH2M Hill Hanford, Inc. for Bechtel Hanford, Inc., Richland, Washington.

Hope, S. J., and R. E. Peterson. 1996. *Chromium in River Substrate Pore Water and Adjacent Groundwater: 100-D/DR Area, Hanford Site, Washington*. BHI-00778, Rev. 0, prepared by CH2M Hill Hanford, Inc. for Bechtel Hanford, Inc., Richland, Washington.

Horton, D. G. 1999. *Monitoring Plan for Fiscal Year 1999 Borehole Logging at 200 East Area Specific Retention Facilities.* PNNL-12222, Pacific Northwest National Laboratory, Richland, Washington.

Horton, D. G. 2002. *Groundwater Conditions at Single-Shell Tank Waste Management Area TX-TY (January 1998 through December 2001).* PNNL-14099, Pacific Northwest National Laboratory, Richland, Washington.

Horton, D. G., and F. N. Hodges. 1999. *Borehole Data Package for 1998 Wells Installed at Single-Shell Tank Waste Management Area T.* PNNL-12125, Pacific Northwest National Laboratory, Richland, Washington.

Horton, D. G. and F. N. Hodges. 1999. *Borehole Data Packages for 1998 Wells Installed at Single-Shell Tank Waste Management Area TX-TY.* PNNL-12124, Pacific Northwest National Laboratory, Richland, Washington.

Horton, D. G. and F. N. Hodges. 2001. *Borehole Data Packages for Calendar Year 2000-2001 RCRA Wells at Single-Shell Tank Waste Management Area TX-TY.* PNNL-13591, Pacific Northwest National Laboratory, Richland, Washington.

Horton, D. G. and F. N. Hodges. 2001. *Borehole Data Package for Well 299-W15-41 at Single-Shell Tank Waste Management Area TX-TY at the Hanford Site*. PNNL-13201, Pacific Northwest National Laboratory, Richland, Washington.

Horton, D. G., and R. R. Randall. 1998. *Results of 1998 Spectral Gamma-Ray Monitoring of Boreholes at the 216-Z-1A Tile Field, 216-Z-9 Trench, and 216-Z-12 Crib*. PNNL-11978, Pacific Northwest National Laboratory, Richland, Washington.

Horton, D. G., and R. R. Randall. 1999. *Results of 1999 Spectral Gamma-Ray and Neutron Moisture Monitoring of Boreholes at Specific Retention Facilities in the 200 East Area, Hanford Site*. PNNL-13077, Pacific Northwest National Laboratory, Richland, Washington.

Horton, D. G., G. V. Last, T. J Gilmore, and B. N. Bjornstad. 2001. *A Catalog of Geologic Data for the Hanford Site*. PNNL-13653, Pacific Northwest National Laboratory, Richland, Washington.

Horton, D. G., S. P. Reidel, and G. V. Last. 1999. *Monitoring Guidance for Vadose Zone Monitoring of Liquid Waste Disposal Facilities for the Hanford Groundwater Project*. PNNL-11958, Rev. 2, Pacific Northwest National Laboratory, Richland, Washington.

Horton, D. G., C. S. Cearlock, and B. A. Williams. 2000. *Borehole Data Package for the 216-S-10 Pond and Ditch Well 299-W26-13*. PNNL-13198, Pacific Northwest National Laboratory, Richland, Washington.

Hunter, C. R., and A. J. Busacca. 1990. *Feasibility Study of Modeling Pedogenic Carbonates in Soils and Sediments at the U.S. Department of Energy's Hanford Site*. PNL-7413, Pacific Northwest Laboratory, Richland, Washington.

ICF Northwest. 1987. *Hydrogeologic Study of North Richland Well Field and Ground-Water Recharge Basins*. Prepared for the City of Richland, Richland, Washington.

Jackson, R. L., C. M. Einberger, R. B. Mercer, and C. R. Wilson. 1991. *Efficiency-Based Groundwater Monitoring Network Design for Hazardous-Waste Sites*. WHC-SA-1157-FP, Westinghouse Hanford Company, Richland, Washington.

Jacobson, E. A., and M. D. Freshley. 1990. *An Initial Inverse Calibration of the Ground-Water Flow Model for the Hanford Unconfined Aquifer*. PNL-7144, Pacific Northwest Laboratory, Richland, Washington.

Jacques, I. D., and R. D. Kerkow. 1993. *Nonradioactive Dangerous Waste Landfill Soil-Gas Survey: Final Data Report*. WHC-SD-EN-TI-199, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Jenkins, O. P. 1922. *Underground Water Supply of the Region About White Bluffs and Hanford*. Bulletin No. 26, State of Washington Department of Conservation and Development, Division of Geology, Olympia, Washington.

Jensen, E. J. 1987. *An Evaluation of Aquifer Intercommunication Between the Unconfined and Rattlesnake Ridge Aquifers on the Hanford Site*. PNL-6313, Pacific Northwest Laboratory, Richland, Washington.

Johnson, V. G. 1993. *Westinghouse Hanford Company Operational Groundwater Status Report, 1990-1992*. WHC-EP-0595, Westinghouse Hanford Company, Richland, Washington.

Johnson, V. G. 1993. *Groundwater Impact Assessment Report for 216-Z-20 Crib, 200 West Area*. WHC-EP-0674, Westinghouse Hanford Company, Richland, Washington.

Johnson, V. G., and F. N. Hodges. 1997. "Mobile Transuranics: A Hanford Site Case History." Presented at *The 2nd Symposium on the Hydrogeology of Washington State*. *Abstracts, August 25, 26, & 27th, 1997, The Evergreen State College*. State of Washington Department of Ecology, Olympia, Washington.

Johnson, V. G. and F. A. Spane. 2001. *Contaminant Dispersion in a Heterogeneous Alluvial Aquifer: A Case History of a Hazardous Waste Tank Leak at the Hanford Site, USA*. PNNL-SA-35433, Pacific Northwest National Laboratory, Richland, Washington.

Johnson, V. G., C. J. Chou, and F. N. Hodges. 1994. *Some Statistical Aspects of Background Based Groundwater Standards at an Arid Hazardous Waste Site*. Poster demonstration at *Nuclear Materials Management, 35th Annual Meeting, Naples, Florida, July 17-20, 1994*. Published in Volume XXIII, Institute of Nuclear Materials Management, Northbrook, Illinois. Also known as WHC-SA-2358-FP, Westinghouse Hanford Company, Richland, Washington.

Johnson, V. G., D. L. Graham, and S. P. Reidel. 1993. "Methane in Columbia River Basalt Aquifers: Isotopic and Geohydrologic Evidence for a Deep Coal-Bed Gas Source in the Columbia Basin, Washington." *Bulletin of the American Association of Petroleum Geologists* 77(7):1192-1207.

Johnson, V. G., T. E. Jones, S. P. Reidel, and M. I. Wood. 1999. *Subsurface Physical Conditions Description of the S-SX Waste Management Area*. HNF-4936, Rev. 0, prepared for Lockheed Martin Hanford Corporation, Richland, Washington.

Johnson, V. M., K. A. Lindsey, R. J. Serne, R. S. Edrington, and T. H. Mitchell. 1995. *N-Springs Barrier Wall Drilling Program Data Package*. BHI-00135, Rev. 1, Bechtel Hanford, Inc., Richland, Washington.

Johnson, V. M., M. Mehlhorn, D. A. Myers, and L. D. Walker. 1996. *Well Summary Report: 100-HR-3 and 100-KR-4 Interim Remedial Action Wells*. BHI-00953, Rev. 0, prepared by CH2M Hill Hanford, Inc. for Bechtel Hanford, Inc., Richland, Washington.

Jones, T. E., B. C. Simpson, M. I. Wood, and R. A. Corbin. 2001. *Preliminary Inventory Estimates for Single Shell Tank Leaks in B-BX-BY Tank Farms*. RPP-7389, Rev. 0, CH2M HILL Hanford Group, Inc., Richland, Washington.

Kaplan, D. I. and R. J. Serne. 2000. *Geochemical Data Package for the Hanford Immobilized Low-Activity Tank Waste Performance Assessment (ILAW PA)*. PNNL-13037, Rev. 1, Pacific Northwest National Laboratory, Richland, Washington.

Kaplan, D. I., K. E. Parker, and I. V. Kutynakov. 1998. *Radionuclide Distribution Coefficients for Sediments Collected from Borehole 299-E17-21: Final Report for Subtask 1a*. PNNL-11966, Pacific Northwest National Laboratory, Richland, Washington.

Kasper, R. B. 1982. *216-Z-12 Transuranic Crib Characterization: Operational History and Distribution of Plutonium and Americium*. RHO-ST-44, Rockwell Hanford Operations, Richland, Washington.

Kasza, G. L. 1992. *Borehole Completion Data Package for the 216-A-29 Ditch: CY 1991*. WHC-SD-EN-DP-047, Westinghouse Hanford Company, Richland, Washington.

Kasza, G. L. 1993. *Borehole Completion Data Package for 216-A-29 RCRA Facility Monitoring Wells 299-E25-47 and 299-E25-48*. WHC-SD-EN-DP-054, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Kasza, G. L. 1995. *In Situ Flowmeter Results and Analysis for the 216-BY Cribs Vicinity*. BHI-00442, Rev. 0, Bechtel Hanford Company, Richland, Washington.

Khaleel, R. 1999. *Far-Field Hydrology Data Package for Immobilized Low-Activity Tank Waste*. HNF-4769, Rev. 1. Fluor Daniel Northwest, Inc., Richland, Washington.

Khaleel, R., and E. J. Freeman. 1995. *Variability and Scaling of Hydraulic Properties for 200 Area Soils, Hanford Site*. WHC-EP-0883, Westinghouse Hanford Company, Richland, Washington.

Khaleel, R., T. E. Jones, A. J. Knepp, F. M. Mann, D. A. Myers, P. M. Rogers, R. J. Serne, and M. I. Wood. 2000. *Modeling Data Package for S-SX Field Investigation Report (FIR)*. RPP-2696, CH2M HILL Hanford Group, Inc., Richland, Washington.

Kious, J. J. 2001. *116-H-1 Characterization Borehole Results*. BHI-01541, Bechtel Hanford, Inc., Richland, Washington.

Kipp, K. L., and R. D. Mudd. 1973. *Collection and Analysis of Pump Test Data for Transmissivity Values*. BNWL-1709, Pacific Northwest Laboratory, Richland, Washington.

Knepp, A. J. 2003. *Field Investigation Report for Waste Management Area B-BX-BY*. RPP-10098, Rev. 0, CH2M HILL Hanford Group, Inc., Richland, Washington.

Krupka, K. M., and R. J. Serne. 1995. *Performance Assessment of Low-Level Radioactive Waste Disposal Facilities: Effects on Radionuclide Concentrations by Cement/Ground-Water Interactions*. NUREG/CR-6377, U.S. Nuclear Regulatory Commission, Washington, D.C.

Kupfer, M. J., A. L. Boldt, B. A. Higley, K. M. Hodgson, L. W. Shelton, B. C. Simpson, R. A. Watrous, M. D. LeClair, G. L. Borsheim, R. T. Winward, R. M. Orme, N. G. Colton, S. L. Lambert, D. E. Place, and W. W. Schulz. 1997. *Standard Inventories of Chemicals and Radionuclides in Hanford Site Tank Wastes*. HNF-SD-WM-TI-740, Fluor Daniel Hanford, Inc., Richland, Washington.

Last, G. V., and V. J. Rohay. 1991. *Carbon Tetrachloride Contamination, 200 West Area, Hanford Site*. PNL-SA-19564, Pacific Northwest Laboratory, Richland, Washington.

Last, G. V., and V. J. Rohay. 1993. *Refined Conceptual Model for the Volatile Organic Compounds-Arid Integrated Demonstration and 200 West Area Carbon Tetrachloride Expedited Response Action*. PNL-8597, Pacific Northwest Laboratory, Richland, Washington.

Last, G. V., B. N. Bjornstad, M. P. Bergeron, D. W. Wallace, D. R. Newcomer, J. A. Schramke, M. A. Chamness, C. S. Cline, S. P. Airhart, and J. S. Wilbur. 1989. *Hydrogeology of the 200 Areas Low-Level Burial Grounds - An Interim Report*. PNL-6820, 2 Volumes, Pacific Northwest Laboratory, Richland, Washington.

Laul, J. C., M. R. Smith, V. G. Johnson, and R. M. Smith. 1985. "Disequilibrium of Natural Radionuclides in Hanford Site Groundwater." In: *High-Level Nuclear Waste Disposal*, H. C. Burkholder (ed.), pp. 401-410. Battelle Press, Richland, Washington.

Lerch, J. A. 1998. *100-D Area Chromium Study Report*. BHI-01185, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Liikala, T. L. 1994. *Hydrogeology Along the Southern Boundary of the Hanford Site Between the Yakima and Columbia Rivers, Washington*. PNL-10094, Pacific Northwest Laboratory, Richland, Washington.

Liikala, T. L., D. S. Daly, and A. P. Toste. 1988. *An Evaluation of the Effects of Well Construction Materials and Ground-Water Sampling Equipment on Concentrations of Volatile Organic Compounds*. PNL-6585, Pacific Northwest Laboratory, Richland, Washington.

Liikala, T. L., R. L. Aaberg, N. J. Aimo, D. J. Bates, T. J. Gilmore, E. J. Jensen, G. V. Last, P. L. Oberlander, K. B. Olsen, K. R. Oster, L. R. Roome, J. C. Simpson, S. S. Teel, and E. J. Westergard. 1988. *Geohydrologic Characterization of the Area Surrounding the 183-H Solar Evaporation Basins*. PNL-6728, Pacific Northwest Laboratory, Richland, Washington.

Lindberg, J. W. 1993. *Geology of the 100-B/C Area, Hanford Site, South-Central Washington*. WHC-SD-EN-TI-133, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Lindberg, J. W. 1993. *Geology of the 100-K Area, Hanford Site, South-Central Washington*. WHC-SD-EN-TI-155, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Lindberg, J. W. 1995. *Hydrogeology of the 100-K Area, Hanford Site, South-Central Washington*. WHC-SD-EN-TI-294, Westinghouse Hanford Company, Richland, Washington.

Lindberg, J. W., and F. W. Bond. 1979. *Geohydrology and Ground-Water Quality Beneath the 300 Area, Hanford Site, Washington*. PNL-2949, Pacific Northwest Laboratory, Richland, Washington.

Lindberg, J. W., J. V. Borghese, B. N. Bjornstad, and M. P. Connelly. 1993. *Geology and Aquifer Characteristics of the Grout Treatment Facility*. WHC-SD-EN-TI-071, Westinghouse Hanford Company, Richland, Washington.

Lindberg, J. W., B. A. Williams, and F. A. Spane. 1997. *Borehole Data Package for Well 699-37-47A, PUREX Plant Cribs, CY 1996*. PNNL-11515, Pacific Northwest National Laboratory, Richland, Washington.

Lindsey, K. A. 1991. *Revised Stratigraphy for the Ringold Formation, Hanford Site, South-Central Washington*. WHC-SD-EN-EE-004, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Lindsey, K. A. 1992. *Geology of the Northern Part of the Hanford Site: An Outline of Data Sources and the Geologic Setting of the 100 Areas*. WHC-SD-EN-TI-011, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Lindsey, K. A. 1995. *Miocene- to Pliocene-Aged Suprabasalt Sediments of the Hanford Site, South-Central Washington*. BHI-00184, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Lindsey, K. A. 1996. *The Miocene to Pliocene Ringold Formation and Associated Deposits of the Ancestral Columbia River System, South-Central Washington and North-Central Oregon*. Open File Report 96-8, Washington Divisions of Geology and Earth Resources, Washington State Department of Natural Resources, Olympia, Washington.

Lindsey, K. A., B. N. Bjornstad, J. W. Lindberg, and K. M. Hoffman. 1992. *Geologic Setting of the 200 East Area: An Update*. WHC-SD-EN-TI-012, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Lindsey, K. A., M. P. Connelly, and B. N. Bjornstad. 1991. *Geologic Setting of the 200 West Area: An Update*. WHC-SD-EN-TI-008, Rev. 0, Richland, Washington.

Lindsey, K. A., and G. K. Jaeger. 1993. *Geologic Setting of the 100-HR-3 Operable Unit, Hanford Site, South-Central Washington*. WHC-SD-EN-TI-132, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Lindsey K. A., S. P. Reidel, K. R. Fecht, J. L. Slate, A. G. Law, and A. M. Tallman. 1994. "Geohydrologic Setting of the Hanford Site, South-Central Washington" in *Field Trips in the Pacific Northwest: 1994 Geologic Society of America Meeting*, Chapter 1C, D. A. Swanson and R. A. Hagerud (eds.), pp. 1C-1 to 1C-16, Geological Society of America, Boulder, Colorado.

Lindsey, K. A., J. L. Slate, G. K. Jaeger, K. J. Swett, and R. B. Mercer. 1994. *Geologic Setting of the Low-Level Burial Grounds*. WHC-SD-EN-TI-290, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Link, S. O., N. R. Wing, and G. W. Gee. 1995. "The Development of Permanent Isolation Barriers for Buried Wastes in Cool Deserts: Hanford Washington." *J. Arid Land Studies* 4:215-224.

Lockheed Martin Hanford Corporation. 1999. *Preliminary Site-Specific SST Phase 1 RFI/CMS Work Plan Addendum for WMA S-SX*. HNF-4380, Rev. 1, prepared for the U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Lockheed Martin Hanford Corporation. 1999. *Site-Specific SST Phase I RFI/CMS Work Plan Addendum for WMA S-SX*. HNF-5058, Rev. 0, prepared for the U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Ludowise, J. D. 1978. *Report on Plutonium Mining Activities at 216-Z-9 Enclosed Trench*. RHO-ST-21, Rockwell Hanford Operations, Richland, Washington.

Ludowise, J. D. 1998. *Data Summary Report for 116-N-1 and 116-N-3 Facility Soil Sampling to Support Remedial Design*. BHI-01271, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Luttrell, S. P., D. R. Newcomer, S. S. Teel, and V. R. Vermeul. 1992. *Hydrogeologic Controls on Ground-Water and Contaminant Discharge to the Columbia River in the Hanford Townsite Vicinity*. PNL-8167, Pacific Northwest Laboratory, Richland, Washington.

Mann, F. M. and R. J. Puigh. 2000. *Data Packages for the Hanford Immobilized Low-Activity Tank Waste Performance Assessment: 2001 Version*. HNF-5636, Rev. 0, Fluor Federal Services, Richland, Washington.

Mann, F. M., R. J. Puigh, II, P. D. Rittmann, N. W. Kline, J. A. Voogd, Y. Chen, C. R. Eiholzer, C. T. Kincaid, B. P. McGrail, A. H. Lu, G. F. Williamson, N. R. Grown, and P. E. LaMont. 1998. *Hanford Immobilized Low-Activity Tank Waste Performance Assessment*. DOE/RL-97-69, U.S. Department of Energy, Richland Operations, Richland, Washington.

Maxfield, H. L. 1979. *Handbook 200 Areas Waste Sites. Vols. 1 and 3*. RHO-CD-673, Rockwell Hanford Operations, Richland, Washington.

McCormack, W. D., and J. M. V. Carlile. 1984. *Investigation of Ground-Water Seepage from the Hanford Shoreline of the Columbia River*. PNL-5289, Pacific Northwest Laboratory, Richland, Washington.

McDonald, J. P., M. A. Chamness, and D. R. Newcomer. 1999. *Water-Level Monitoring Plan for the Hanford Groundwater Monitoring Project*. PNNL-13021, Pacific Northwest National Laboratory, Richland, Washington.

McGhan, V. L. 1989. *Hanford Wells*. PNL-6907, Pacific Northwest Laboratory, Richland, Washington.

McKinley, J. P., C. J. Zeissler, J. M. Zachara, R. Serne, R. M. Lindstrom, J. Schaef, and R. D. Orr. 2001. "Distribution and Retention of ^{137}Cs in Sediments at the Hanford Site, Washington." *Environmental Sciences and Technology*, 35(17):3433-3441.

McMahon, W. J., and R. E. Peterson. 1992. *Estimating Aquifer Hydraulic Properties Using the Ferris Method, Hanford Site, Washington*. DOE/RL-92-64, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Mercer, R. B. 1993. *1991 Borehole Completion Data Package for the Low-Level Burial Grounds*. WHC-SD-EN-DP-044, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Mercer, R. B. 1993. *1992 Borehole Completion Data Package for the Low-Level Burial Grounds*. WHC-SD-EN-DP-049, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Mercer, R. B. 1994. *1993 Borehole Completion Data Package for the Low-Level Burial Grounds*. WHC-SD-EN-DP-086, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Meyer, P. D. 1993. *A Quantitative Method for Ground-Water Surveillance Monitoring Network Design at the Hanford Site*. PNL-8868, Pacific Northwest Laboratory, Richland, Washington.

Mitchell, P. J., R. S. Argo, S. L. Bradymire, and C. A. Newbill. 1985. *Hanford Ground-Water Data Base Management Guide and User's Manual*. PNL-5486, Pacific Northwest Laboratory, Richland, Washington.

Mitchell, T. H., K. A. Bergstrom, and D. J. Hoff. 1993. *Geophysical Investigation of the Nonradioactive Dangerous Waste Landfill*. WHC-SD-EN-TI-116, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Murray, C. J., G. V. Last, and Y. Chien. 2001. *Enhanced Site Characterization of the 618-4 Burial Ground*. PNNL-13656, Pacific Northwest National Laboratory, Richland, Washington.

Myers, C. W., S. M. Price, J. A. Caggiano, M. P. Cochran, W. J. Czimer, N. J. Davidson, R. C. Edwards, K. R. Fecht, G. E. Holmes, M. G. Jones, J. R. Kunk, R. D. Landon, R. K. Ledgerwood, J. T. Lillie, P. E. Long, T. H. Mitchell, E. H. Price, S. P. Reidel, and A. M. Tallman. 1979. *Geologic Studies of the Columbia Plateau: A Status Report*. RHO-BWI-ST-4, Rockwell Hanford Operations, Richland, Washington.

Myers, C. W. and S. M. Price (eds.). 1981. *Subsurface Geology of the Cold Creek Syncline*. RHO-BWI-ST-14, Rockwell Hanford Operations, Richland, Washington.

Myers, D. A., D. L. Parker, G. W. Gee, V. G. Johnson, G. V. Last, R. J. Serne, and D. J. Moak. 1998. *Findings of the Extension of Borehole 41-09-39, 241-SX Tank Farm*. HNF-2855, MACTEC-ERS, Pacific Northwest National Laboratory, and Waste Management Northwest for Lockheed Martin Hanford Corporation, Richland, Washington.

Narbutovskih, S. M. 1995. *Electrical Resistivity Tomography and Seismic Tomography for Early Vadose Leak Detection*. WHC-SD-EN-TP-053, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Narbutovskih, S. M. 1996. *Electrical Resistivity Tomography for Early Vadose Leak Detection Under Single-Shell Tanks*. WHC-SD-EN-TP-056, Westinghouse Hanford Company, Richland, Washington.

Narbutovskih, S. M., D. F. Iwatate, M. D. Sweeney, A. L. Ramirez, W. Daily, R. M. Morey, and L. Christensen. 1996. *Feasibility of CPT-Deployed Vertical Electrode Array in Single Shell Tank Farms*. WHC-SD-EN-TA-004, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Narbutovskih, S. M., W. Daily, A. L. Ramirez, T. D. Halter, and M. D. Sweeney. 1996. "Electrical Resistivity Tomography at the DOE Hanford Site." In: *Proceedings of the Symposium of the Application of Geophysics to Engineering and Environmental Problems*. Keystone, Colorado, pp. 773-782; also WHC-SA-3035-FP, Westinghouse Hanford Company, Richland, Washington.

Narbutovskih, S. M., J. P. McDonald, R. Schalla, and M. D. Sweeney. 2002. "Application of the Colloidal Borescope to Determine a Complex Groundwater Flow Pattern." *Evaluation and Remediation of Low Permeability and Dual Porosity Environments*, ASTM STP1415, M. N. Sara and L. G. Everett (eds.), ASTM International, West Conshohocken, Pennsylvania.

Newcomb, R. C. 1958. "Ringold Formation of the Pleistocene Age in the Type Locality, The White Bluffs, Washington." *American Journal of Science* 256:328-340.

Newcomb, R. C., and S. G. Brown. 1961. *Evaluation of Bank Storage Along the Columbia River Between Richland and China Bar, Washington*. Geological Water-Supply Paper 1539-I, U.S. Geological Survey, Washington, D.C.

Newcomb, R. C., and J. R. Strand. 1953. *Geology and Ground-Water Characteristics of the Hanford Reservation of the Atomic Energy Commission, Washington: U.S. Geological Survey*. Working Paper 8, U.S. Geological Survey, Washington, D.C.

Newcomb, R. C., J. R. Strand, and F. J. Frank. 1972. *Geology and Ground-Water Characteristics of the Hanford Reservation of the U.S. Atomic Energy Commission, Washington*. Professional Paper 717, U.S. Geological Survey, Washington, D.C.

Newcomer, D. R., J. V. Borghese, and W. E. Cronin. 1990. *Hydrologic Testing at the Single-Shell Tanks, 1989*. WHC-SD-EN-TI-147, Rev. 0, An Informal Report by Pacific Northwest Laboratory, released on April 9, 1993 by Westinghouse Hanford Company, Richland, Washington.

Newcomer, D. R., L. A. Doremus, S. H. Hall, M. J. Truex, V. R. Vermeul, and R. E. Engelman. 1995. *Geology, Hydrology, Chemistry, and Microbiology of the In Situ Bioremediation Demonstration Site*. PNL-10422, Pacific Northwest Laboratory, Richland, Washington.

Newcomer, D. R., M. A. Chamness, D. L. McAlister, R. J. Brockman, A. W. Pearson, and S. S. Teel. 1992. *Unconfined Aquifer Hydrologic Test Data Package for the 200 East Area*. WHC-SD-EN-DP-030, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Newcomer, D. R., E. C. Thornton, and T. L. Liikala. 2002. *Groundwater Chemistry and Hydrogeology of the Upper Saddle Mountains Basalt-Confined Aquifer South and Southeast of the Hanford Site*. PNNL-14107, Pacific Northwest National Laboratory, Richland, Washington.

Nielsen, J. M., and R. W. Perkins. 1957. *The Depletion of Radioisotopes from the Columbia River by Natural Causes*. HW-52908, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Olsen, K. B., G. W. Patton, R. Poreda, P. E. Dresel, and J. C. Evans. 2000. *Measurement of Tritium in Gas Phase Soil Moisture and Helium-3 in Soil Gas at the Hanford Townsite and 100 K Area*. PNNL-13217, Pacific Northwest National Laboratory, Richland, Washington.

Olsen, K. B., P. E. Dresel, and J. C. Evans. 2001. *Measurement of Helium-3/Helium-4 Ratios in Soil Gas at the 618-11 Burial Ground*. PNNL-13675, Pacific Northwest National Laboratory, Richland, Washington.

Pacific Northwest Laboratory. 1986. *Environmental Monitoring Procedures*. PNL-MA-580, Richland, Washington.

Pacific Northwest Laboratory. 1989. *Procedures for Ground-Water Investigations*. PNL-6894, Richland, Washington.

Pacific Northwest Laboratory. 1990. *Hanford Ground-Water Data Base Management Guide*. PNL-7003, Richland, Washington.

Parker, H. M. 1959. *Hearings Before the Special Subcommittee on Radiation of the Joint Committee on Atomic Energy Congress of the United States Eighty-Sixth Congress First Session on Industrial Radioactive Waste Disposal*. January 28-February 3, 1959, Vol. 1, pp. 202-235, 330-391.

Patton, G. W., B. L. Tiller, E. J. Antonio, T. M. Poston, and S. P. Van Verst. 2002. *Survey of Radiological and Chemical Contaminants in the Near-Shore Environment at the Hanford Site 300 Area*. A Cooperative Environmental Monitoring Project involving the Hanford Site Public Safety and Resource Protection Program (PSRPP) and Washington State Department of Health. PNNL-13692A, Pacific Northwest National Laboratory, Richland, Washington.

Pearson, A. W. 1990. *Borehole Summary Report for Twelve Single-Shell Tank Wells Installed in 1989*. WHC-MR-0209, Westinghouse Hanford Company, Richland, Washington.

Perkins, C. J. 1992. *Westinghouse Hanford Company Environmental Surveillance Annual Report – 100 Areas, Calendar Year 1990*. WHC-EP-0258-2, Westinghouse Hanford Company, Richland, Washington.

Perkins, C. J., B. M. Markes, S. M. McKinney, R. M. Mitchell, and R. C. Roos. 2002. *Hanford Site Near-Facility Environmental Monitoring Data Report for Calendar Year 2001*. PNNL-13910, Appendix 2, Duratek Federal Services, Inc., Northwest Operations, Richland, Washington.

Peterson, R. E. 1992. *Hydrologic and Geologic Data Available for the Region North of Gable Mountain, Hanford Site, Washington*. WHC-SD-EN-TI-006, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Peterson, R. E. 1997. "Columbia River Influence on Groundwater, Hanford Site, Washington." Presented at the *2nd Symposium on the Hydrogeology of Washington State, August 25-27, 1997, The Evergreen State College, Olympia, Washington*. Washington State Department of Ecology, Washington Hydrologic Society, U.S. Geological Survey, and Washington State Department of Natural Resources, Olympia, Washington.

Peterson, R. E., and M. P. Connelly. 1992. "Characterization of Chromium Plume in Groundwater Along the Columbia River Shoreline, Hanford Site, Washington." Abs. *EOS, Transactions of the American Geophysical Union* 73(43):225; presented at the 1992 Fall Meeting, American Geophysical Union, San Francisco, California, December 7-11, 1992; also WHC-SA-1674-VA, Westinghouse Hanford Company, Richland, Washington.

Peterson, R. E. and M. P. Connelly. 2001. *Zone of Interaction Between Hanford Site Groundwater and Adjacent Columbia River*. PNNL-13674, Pacific Northwest National Laboratory, Richland, Washington.

Peterson, R. E., and V. G. Johnson. 1992. *Riverbank Seepage of Groundwater Along the 100 Areas Shoreline, Hanford Site*. WHC-EP-0609, Westinghouse Hanford Company, Richland, Washington.

Peterson, R. E. and T. M. Poston. 2000. *Strontium-90 at the Hanford Site and its Ecological Implications*. PNNL-13127, Pacific Northwest National Laboratory, Richland, Washington.

Peterson, R. E., and T. M. Poston. 2000. *Hanford-Derived Strontium-90 Contamination and its Potential for Ecological Impacts*. PNNL-13177, Pacific Northwest National Laboratory, Richland, Washington.

Peterson, R. E., K. L. Singleton, and J. V. Borghese. 1997. *Description of Work for Installing Aquifer Sampling Tubes Along the 100 Area and Hanford Townsite Shorelines.* BHI-01090, CH2M Hill Hanford, Inc. for Bechtel Hanford, Inc., Richland, Washington.

Peterson, R. E., J. V. Borghese, and D. B. Erb. 1998. *Aquifer Sampling Tube Completion Report: 100 Area and Hanford Townsite Shorelines*. BHI-01153, CH2M Hill Hanford, Inc. for Bechtel Hanford, Inc., Richland, Washington.

Peterson, R. E., F. A. Spane, K. B. Olsen, and M. D. Williams. 2002. *Evaluation of Potential Sources for Tritium Detected in Groundwater at Well 199-K-111A, 100-K Area*. PNNL-14031, Pacific Northwest National Laboratory, Richland, Washington.

Poeter, E., and D. R. Gaylord. 1990. "Influence of Aquifer Heterogeneity on Contaminant Transport at the Hanford Site." *Ground Water* 28:900-909.

Poston, T. M., K. R. Price, and D. R. Newcomer. 1991. *An Evaluation of the Chemical, Radiological, and Ecological Conditions of West Lake on the Hanford Site*. PNL-7662, Pacific Northwest Laboratory, Richland, Washington.

Poston, T. M., R. W. Hanf, R. L. Dirkes, and L. F. Morasch (eds.). 2001. *Hanford Site Environmental Report for Calendar Year 2000*. PNNL-13487, Pacific Northwest National Laboratory, Richland, Washington.

Praga, A. N. 1998. *105-K Basin Material Design Basis Feed Description for Spent Nuclear Fuel Project Facilities, Vol. 1, Spent Nuclear Fuel*. HNF-SD-SNF-TI-009, Duke Engineering & Services Hanford, Richland, Washington.

Price, R. K. 1995. *Vadose Zone Monitoring Plan Using Geophysical Nuclear Logging for Radionuclides Discharged to Hanford Liquid Waste Disposal Facilities*. WHC-SD-EN-AP-087, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Price, R. K., J. E. Meisner, and R. R. Randall. 1996. *Radionuclide Logging System In Situ Vadose Zone Moisture Measurement Calibration*. WHC-SD-EN-TI-306, Westinghouse Hanford Company, Richland, Washington.

Price, S. M., and L. L. Ames. 1976. "Characterization of Actinide-Bearing Sediments Underlying Liquid Waste Disposal Facilities at Hanford." In *Transuranium Nuclides in the Environment*, International Atomic Energy Agency, Vienna, Austria. Also known as ARH-SA-232, Atlantic Richfield Hanford Company, Richland, Washington.

Price, S. M., R. B. Kasper, M. K. Additon, R. M. Smith, and G. V. Last. 1979. *Distribution of Plutonium and Americium Beneath the 216-Z-1A Crib: Status Report*. RHO-ST-17, Rockwell Hanford Operations, Richland, Washington.

Price, W. H., and K. R. Fecht. 1976. *Geology of the 241-A Tank Farm*. ARH-LD-127, Atlantic Richfield Hanford Company, Richland, Washington.

Price, W. H., and K. R. Fecht. 1976. *Geology of the 241-AX Tank Farm*. ARH-LD-128, Atlantic Richfield Hanford Company, Richland, Washington.

Price, W. H., and K. R. Fecht. 1976. *Geology of the 241-B Tank Farm*. ARH-LD-129, Atlantic Richfield Hanford Company, Richland, Washington.

Price, W. H., and K. R. Fecht. 1976. *Geology of the 241-BX Tank Farm*. ARH-LD-130, Atlantic Richfield Hanford Company, Richland, Washington.

Price, W. H., and K. R. Fecht. 1976. *Geology of the 241-BY Tank Farm*. ARH-LD-131, Atlantic Richfield Hanford Company, Richland, Washington.

Price, W. H., and K. R. Fecht. 1976. *Geology of the 241-C Tank Farm*. ARH-LD-132, Atlantic Richfield Hanford Company, Richland, Washington.

Puget Sound Power and Light Company. 1982. *Skagit/Hanford Nuclear Project, Preliminary Safety Analysis Report, Appendix 20, Amendment 23*. Bellevue, Washington.

Raidl, R. F. 2002. *Aquifer Sampling Tubes Data Summary, Fall 2001*. BHI-01624, Bechtel Hanford, Inc., Richland, Washington.

Randall, R. R., and R. K. Price. 1998. *Monitoring Results for the SX Single Shell Tank Farm Dry Well Gamma Ray Surveillance Log Surveys*. WMNW/TRS-ES-VZMA-002, Waste Management Federal Services Inc., Northwest Operations, Richland, Washington.

Raymond, J. R., and D. J. Brown. 1963. *Ground Water Exchange with Fluctuating Rivers, Hanford Laboratories*. HW-SA-3198, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Raymond, J. R., and E. G. Shdo. 1966. *Characterization of Subsurface Contamination in the SX Tank Farm*. BNWL-CC-701, Battelle Northwest Laboratories, Richland, Washington.

Reidel, S. P., and E. C. Thornton. 1992. *Characterization Report, C-018H Disposal Siting Evaluation*. WHC-SD-C018H-RPT-001, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Reidel, S. P. and D. G. Horton. 1999. *Geologic Data Package for 2001 Immobilized Low-Activity Waste Performance Assessment*. PNNL-12257, Rev. 1, Pacific Northwest National Laboratory, Richland, Washington.

Reidel, S. P., K. A. Lindsey, and K. R. Fecht. 1992. *Field Trip Guide to the Hanford Site*. WHC-MR-0391, Westinghouse Hanford Company, Richland, Washington.

Reidel, S. P., and K. R. Fecht. 1994. *Geologic Map of the Richland 1:100,000 Quadrangle, Washington*. Open File Report 94-8, Washington Division of Geology and Earth Resources, Washington State Department of Natural Resources, Olympia, Washington.

Reidel, S. P., and K. R. Fecht. 1994. *Geologic Map of the Priest Rapids 1:100,000 Quadrangle, Washington*. Open File Report 94-13, Washington Division of Geology and Earth Resources, Washington State Department of Natural Resources, Olympia, Washington.

Reidel, S. P. and A. M. Ho. 2002. *Geologic and Wireline Summaries from Fiscal Year 2002 ILAW Boreholes*. PNNL-14029, Pacific Northwest National Laboratory, Richland, Washington.

Reidel, S. P., K. D. Reynolds, and D. G. Horton. 1998. *Immobilized Low-Activity Waste Site Borehole 299-E17-21*. PNNL-11957, Pacific Northwest National Laboratory, Richland, Washington.

Reidel, S. P., D. G. Horton, and M. M. Valenta. 2001. *Geologic and Wireline Borehole Summary from the Second ILAW Borehole (299-E24-21)*. PNNL-13652, Rev. 1, Pacific Northwest National Laboratory, Richland, Washington.

Reynolds, K. D. 2001. *BX-102 Borehole Completion Report*. RPP-7921, Duratek Federal Services, Inc., Northwest Operations, Richland, Washington.

Reynolds, K. D. 2001. *Summary Report 241-B-110 Well (C3360) 299-E33-46*. RPP-8633, Duratek Federal Services, Inc., Northwest Operations, Richland, Washington.

Rhoads, K., B. N. Bjornstad, R. E. Lewis, S. S. Teel K. J. Cantrell, R. J. Serne, J. L. Smoot, C. T. Kincaid, and S. K. Wurstner. 1993. *Estimation of the Release and Migration of Lead through Soils and Groundwater at the Hanford Site 218-E-12B Burial Ground*. PNL-8356, Vol. 1, Pacific Northwest Laboratory, Richland, Washington.

Rhoads, K., B. N. Bjornstad, R. E. Lewis, S. S. Teel, K. J. Cantrell, R. J. Serne, L. H. Sawyer, J. L. Smoot, J. E. Szecsody, M. S. Wigmosta, and S. K. Wurstner. 1994. *Estimation of the Release and Migration of Nickel Through Soils and Groundwater at the Hanford Site 218-E-12B Burial Ground*. PNL-9791, Pacific Northwest Laboratory, Richland, Washington.

Rickard, W. H., and K. R. Price. 1989. "Uptake of Tritiated Groundwater by Black Locust Trees." *Northwest Sci*. 63(3):87-89.

Ridgway, K. R., M. D. Veatch, and D. T. Crawley. 1971. *216-Z-9 Crib History and Safety Analysis*. ARH-2207, Atlantic Richfield Hanford Company, Richland, Washington.

Rieger, J. T., and R. W. Bryce. 1990. "Effective Sample Labeling," pp. 327-329. In: *Environmental Monitoring, Restoration and Assessment: What Have We Learned? Proceedings, 28th Hanford Symposium on Health and the Environment, October 16-19, 1989*. R. H. Gray (ed.), Richland, Washington. Battelle Press, Columbus, OH.

Rockhold, M. L., M. J. Fayer, and G. W. Gee. 1988. *Characterization of Unsaturated Hydraulic Conductivity at the Hanford Site*. PNL-6488, Pacific Northwest Laboratory, Richland, Washington.

Rockhold, M. L., M. J. Fayer, G. W. Gee, and M. J. Kanyid. 1989. *Natural Groundwater Recharge and Soil-Water Balance at the Hanford Site*. PNL-7215, Pacific Northwest Laboratory, Richland, Washington.

Rockhold, M. L., M. J. Fayer, C. T. Kincaid, and G. W. Gee. 1995. *Estimation of Natural Ground Water Recharge for the Performance Assessment of a Low-Level Waste Disposal Facility at the Hanford Site*. PNL-10508, Pacific Northwest Laboratory, Richland, Washington.

Rohay, V. J. 1990. *Liquid Effluent Study Final Project Report*. WHC-EP-0367, Westinghouse Hanford Company, Richland, Washington.

Rohay, V. J. 1996. *Field Tests of Passive Soil Vapor Extraction Systems at the Hanford Site, Washington*. BHI-00766, Bechtel Hanford, Inc., Richland, Washington.

Rohay, V. J. 1997. *Conceptual Model for the Solid Waste Landfill*. BHI-01063, Bechtel Hanford, Inc., Richland, Washington.

Rohay, V. J. 1997. *Evaluation of the Soil-Gas Survey at the Nonradioactive Dangerous Waste Landfill*. BHI-01115, Bechtel Hanford, Inc., Richland, Washington.

Rohay, V. J. 1997. *Rebound Study Report for the Carbon Tetrachloride Soil Vapor Extraction Site, Fiscal Year 1997*. BHI-01105, Bechtel Hanford, Inc., Richland, Washington.

Rohay, V. J. 1998. *Performance Evaluation Report for Soil Vapor Extraction Operations at the Carbon Tetrachloride Site, February 1992 - September 1997.* BHI-00720, Rev. 2, Bechtel Hanford, Inc., Richland, Washington.

Rohay, V. J. 1999. *Performance Evaluation Report for Soil Vapor Extraction Operations at the Carbon Tetrachloride Site, February 1992 - September 1998*. BHI-00720, Rev. 3, Bechtel Hanford, Inc., Richland, Washington.

Rohay, V. J. 2000. *Performance Evaluation Report for Soil Vapor Extraction Operations at the Carbon Tetrachloride Site, February 1992 - September 1999.* BHI-00720, Rev. 4, Bechtel Hanford, Inc., Richland, Washington.

Rohay, V. J., and D. C. Weekes. 1998. *Borehole Summary Report for the 216-B-2-2 Ditch*. BHI-01177, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Rohay, V. J., G. V. Last, V. L. King, and L. A. Doremus. 1992. *FY92 Site Characterization Status Report and Data Package for the Carbon Tetrachloride Site*. WHC-SD-EN-EI-063, Rev. 0, prepared by V. J. Rohay and V. L. King, Westinghouse Hanford Company, and G. V. Last and L. A. Doremus, Pacific Northwest Laboratory, for Westinghouse Hanford Company, Richland, Washington.

Rohay, V. J., D. C. Weekes, W. J. McMahon, and J. V. Borghese. 1999. *The Chromium Groundwater Plume West of the 100-D/DR Reactors: Summary and Fiscal Year 1999 Update.* BHI-01309, Rev 0, Bechtel Hanford, Inc., Richland, Washington.

V. J. Rohay, J. M. Faurote, and C. W. Miller. 2002. *Carbon Tetrachloride Field Investigation Report for Drilling in the Vicinity of the PFP and the 216-Z-9 Trench.* BHI-01631, Rev. 0, CH2M HILL Hanford, Inc., Richland, Washington.

Rust Geotech. 1995. *Vadose Zone Characterization Project at the Hanford Tank Farms, Calibration of Two Spectral Gamma-Ray Logging Systems for Baseline Characterization Measurements in the Hanford Tank Farms*. GJPO-HAN-1, Grand Junction Projects Office, U.S. Department of Energy, Grand Junction, Colorado.

Rust Geotech. 1995. *Vadose Zone Characterization Project at the Hanford Tank Farms, Project Management Plan*. P-GJPO-1780, Grand Junction Projects Office, U.S. Department of Energy, Grand Junction, Colorado.

Rust Geotech. 1995. *Vadose Zone Characterization Project at the Hanford Tank Farms, Spectral Gamma-Ray Borehole Geophysical Logging Characterization and Baseline Monitoring Plan for the Hanford Single-Shell Tanks*. P-GJPO-1786, Grand Junction Projects Office, U.S. Department of Energy, Grand Junction, Colorado.

Rust Geotech. 1996. *Vadose Zone Characterization Project at the Hanford Tank Farms, Biannual Recalibration of Two Spectral Gamma-Ray Logging Systems for Baseline Characterization Measurements in the Hanford Tank Farms*. GJPO-HAN-3, Grand Junction Projects Office, U.S. Department of Energy, Grand Junction, Colorado.

Schalla, R., R. W. Wallace, R. L. Aaberg, S. P. Airhart, D. J. Bates, J.V.M. Carlile, C. S. Cline, D. I. Dennison, M. D. Freshley, P. R. Heller, E. J. Jensen, K. B. Olsen, R. G. Parkhurst, J. T. Rieger, and E. J. Westergard. 1988. *Interim Characterization Report for the 300 Area Process Trenches*. PNL-6716, Pacific Northwest Laboratory, Richland, Washington.

Serne, R. J., and M. I. Wood. 1990. *Hanford Waste-Form Release and Sediment Interaction*. PNL-7297, Pacific Northwest Laboratory, Richland, Washington.

Serne, R. J., and V. L. LeGore. 1996. *Strontium-90 Adsorption-Desorption Properties and Sediment Characterization at 100-N Area*. PNL-10899, Pacific Northwest Laboratory, Richland, Washington.

Serne, R. J., A. R. Felmy, K. J. Cantrell, K. M. Krupka, J. A. Campbell, H. Bolton, Jr., and J. K. Fredrickson. 1996. *Characterization of Radionuclide-Chelating Agency Complexes Found in Low-Level Radioactive Decontamination Waste*. NUREG/CR-6124, U.S. Nuclear Regulatory Commission, Washington, D.C.

Serne, R. J., J. L. Conca, V. L. LeGore, K. J. Cantrell, C. W. Lindenmeier, J. A. Campbell, J. E. Amonette, and M. I. Wood. 1993. *Solid-Waste Leach Characteristics and Contaminant-Sediment Interactions, Volume 1: Batch Leach and Adsorption Tests and Sediment Characterization*. PNL-8889, Pacific Northwest Laboratory, Richland, Washington.

Serne, R. J., J. M. Zachara, and D. S. Burke. 1998. *Chemical Information on Tank Supernatants, Cs Adsorption from Tank Liquids onto Hanford Sediments, and Field Observations of Cs Migration from Past Tank Leaks*. PNNL-11495, Pacific Northwest National Laboratory, Richland, Washington.

Serne, R. J., C. F. Brown, H. T. Schaef, E. M. Price, M. J. Lindberg, Z. Wang, P. L. Gassman, and J. G. Catalano. 2002. *300 Area Uranium Leach and Adsorption Project*. PNNL-14022, Pacific Northwest National Laboratory, Richland, Washington.

Serne, R. J., G. V. Last, H. T. Schaef, D. C. Lanigan, C. W. Lindenmeier, C. C. Ainsworth, R. E. Clayton, V. L. LeGore, M. J. O'Hara, C. F. Brown, R. D. Orr, I. V. Kutnyakov, T. C. Wilson, K. B. Wagnon, B. A. Williams, and D. S. Burke. 2002. *Characterization of Vadose Zone Sediment: Borehole 41-09-39 in the S-SX Waste Management Area*. PNNL-13757-3, Pacific Northwest National Laboratory, Richland, Washington.

Serne, R. J., G. V. Last, H. T. Schaef, D. C. Lanigan, C. W. Lindenmeier, C. C. Ainsworth, R. E. Clayton, V. L. LeGore, M. J. O'Hara, C. F. Brown, R. D. Orr, I. V. Kutnyakov, T. C. Wilson, K. B. Wagnon, B. A. Williams, and D. S. Burke. 2002. *Characterization of Vadose Zone Sediment: Slant Borehole SX-108 in the S-SX Waste Management Area*. PNNL-13757-4, Pacific Northwest National Laboratory, Richland, Washington.

Serne, R. J., H. T. Schaef, B. N. Bjornstad, B. A. Williams, D. C. Lanigan, D. G. Horton, R. E. Clayton, V. L. LeGore, M. J. O'Hara, C. F. Brown, K. E. Parker, I. V. Kutnyakov, J. N. Serne, A. V. Mitroshkov, G. V. Last, S. C. Smith, C. W. Lindenmeier, J. M. Zachara, and D. S. Burke. 2002. *Characterization of Vadose Zone Sediment: Uncontaminated RCRA Borehole Core Samples and Composite Samples*. PNNL-13757-1, Pacific Northwest National Laboratory, Richland, Washington.

Serne, R. J., H. T. Schaef, B. N. Bjornstad, D. C. Lanigan, G. W. Gee, C. W. Lindenmeier, R. E. Clayton, V. L. LeGore, M. J. O'Hara, C. F. Brown, R. D. Orr, G. V. Last, I. V. Kutnyakov, D. S. Burke, T. C. Wilson, and B. A. Williams. 2002. *Characterization of Vadose Zone Sediment: Borehole 299-W23-19 [SX-115] in the S-SX Waste Management Area*. PNNL-13757-2, Pacific Northwest National Laboratory, Richland, Washington.

Sherwood, D. R., J. R. Evans, and R. W. Bryce. 1990. "Identification of Contaminants of Concern in Hanford Ground Waters," pp. 51-59. In: *Environmental Monitoring, Restoration and Assessment: What Have We Learned? Proceedings, 28th Hanford Symposium on Health and the Environment, October 16-19, 1989*, R. H. Gray (ed.), Richland, Washington. Battelle Press, Columbus, Ohio.

Smith, A. E. 1973. *Nuclear Reactivity Evaluations of 216-Z-9 Enclosed Trench.* ARH-2915, Atlantic Richfield Hanford Company, Richland, Washington.

Smith, R. M. 1980. *216-B-5 Reverse Well Characterization Study*. RHO-ST-37, Rockwell Hanford Operations, Richland, Washington.

Smith, R. M., and R. B. Kasper. 1983. *Serviceability of Cribs Affected by PUREX Startup*. RHO-HS-EV-18, Rockwell Hanford Operations, Richland, Washington.

Smith, M. R., J. C. Laul, and V. G. Johnson. 1987. "Natural Radionuclides in Hanford Site Ground Waters." *Mater. Res. Soc. Symp. Proc*. 112:249-257.

Soler, L., G. V. Last, B. A. Napier, V. J. Rohay, and F. J. Schelling. 2001. *The Application of Feature, Event, and Processes Methodology the Hanford Site*. BHI-01573, Prepared by Bechtel Hanford, Inc. for the U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Spane, Jr., F. A. 1987. *Fresh-Water Potentiometric Map and Interred Flow Direction of Ground Water Within the Mabton Interbed, Hanford Site, Washington State - January 1987*. SD-BWI-TI-335, Rockwell Hanford Operations, Richland, Washington.

Spane, Jr., F. A. 1992. *Applicability of Slug Interference Tests under Hanford Site Test Conditions: Analytical Assessment and Field Test Evaluation*. PNL-8070, Pacific Northwest Laboratory, Richland, Washington.

Spane, Jr., F. A. 1992. *Hydraulic Test Results for Savage Island Wells: 699-32-22B, 699-42-E9A, and 699-42-E9B*. PNL-8173, Pacific Northwest Laboratory, Richland, Washington.

Spane, Jr., F. A. 1999. *Effects of Barometric Fluctuations on Well Water-Level Measurements and Aquifer Test Data*. PNNL-13078, Pacific Northwest National Laboratory, Richland, Washington.

Spane, Jr., F. A. 2000. *Analysis of the Hydrologic Response Associated with Shutdown and Restart of the 200-ZP-1 Pump-and-Treat System*. PNNL-13342, Pacific Northwest National Laboratory, Richland, Washington.

Spane, Jr., F. A., and R. G. Raymond. 1993. *Preliminary Potentiometric Map and Flow Dynamic Characteristics for the Upper-Basalt Confined Aquifer System*. PNL-8869, Pacific Northwest Laboratory, Richland, Washington.

Spane, Jr., F. A., and P. D. Thorne. 1992. "An Evaluation of Slug Interference Tests for Aquifer Characterization at the Hanford Site," pp. 387-392. In: *Proceedings, Nuclear and Hazardous Waste Management, Spectrum 92, Vol. 1, August 23-27*, Boise, Idaho. American Nuclear Society, La Grange Park, Illinois.

Spane, Jr., F. A., and P. D. Thorne. 1995. *Comparison of Constant-Rate Pumping Test and Slug Interference Test Results at the B-Pond Multi-Level Test Facility, Hanford Site*. PNL-10835. Pacific Northwest Laboratory, Richland, Washington.

Spane, Jr., F. A., and V. R. Vermeul. 1994. *Summary and Evaluation of Hydraulic Property Data Available for the Hanford Site Upper Basalt Confined Aquifer System*. PNL-10158, Pacific Northwest Laboratory, Richland, Washington.

Spane, Jr., F. A., and W. D. Webber. 1995. *Hydrochemistry and Hydrogeologic Conditions Within the Hanford Upper Basalt Confined Aquifer System*. PNL-10817, Pacific Northwest Laboratory, Richland, Washington.

Spane, Jr., F. A., D. L. Graham, and R. W. Bryce. 1982. *Hydrochemical and Isotopic Content of Basalt Groundwaters Beneath the Hanford Site, Washington*. RHO-BW-SA-190, Rockwell Hanford Operations, Richland, Washington.

Spane, Jr., F. A., P. D. Thorne, and D. R. Newcomer. 2001. *Results of Detailed Hydrologic Characterization Tests - Fiscal Year 1999*. PNNL-13378, Pacific Northwest National Laboratory, Richland, Washington.

Spane, Jr., F. A., P. D. Thorne, and D. R. Newcomer. 2001. *Results of Detailed Hydrologic Characterization Tests – Fiscal Year 2000*. PNNL-13514, Pacific Northwest National Laboratory, Richland, Washington.

Spane, Jr., F. A., P. D. Thorne, and D. R. Newcomer. 2002. *Results of Detailed Hydrologic Characterization Tests – Fiscal Year 2001*. PNNL-14113, Pacific Northwest National Laboratory, Richland, Washington.

State of Washington Department of Ecology. 1995. *State Waste Discharge Permit (216 Permit) for the 200 Area Effluent Treatment Facility (ETF)*. Permit No. ST 4500, issued in compliance with the provisions of Chapter 90.48 RCW, as amended, and Chapter 173-216 WAC, as amended, Olympia, Washington.

State of Washington Department of Ecology. 1995. *State Waste Discharge Permit (216 Permit) for the 200 Area Treated Effluent Disposal Facility (TEDF)*. Permit No. ST 4502, issued in compliance with the provisions of Chapter 90.48 RCW, as amended, and Chapter 173-216 WAC, as amended, Olympia, Washington.

State of Washington Department of Ecology. 1996. *State Waste Discharge Permit No. ST 4501 (400 Area Pond)*. Olympia, Washington.

State of Washington Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy. 1989. *Hanford Federal Facility Agreement and Consent Order Between the U.S. Environmental Protection Agency, the U.S. Department of Energy, and the State of Washington Department of Ecology, May 15, 1989*, as amended. Olympia, Seattle, and Richland, Washington.

State of Washington Department of Ecology. 2000. *State Waste Discharge Permit ST 4500*. Kennewick, Washington.

Stenner, R. D., K. H. Cramer, K. A. Higley, S. J. Jette, D. A. Lamar, T. J. McLaughlin, D. R. Sherwood, and N. C. VanHouten. 1988. *Hazard Ranking System Evaluation of CERCLA Inactive Waste Sites at Hanford. Volume 1, Evaluation Method and Results*. PNL-6456, Pacific Northwest Laboratory, Richland, Washington.

Stordeur, R. T., and D. L. Flyckt. 1988. *1988 Annual Status Report of the Plan and Schedule to Discontinue Disposal of Contaminated Liquids into the Soil Column at the Hanford Site*. WHC-EP-0196-1, Westinghouse Hanford Company, Richland, Washington.

Strait, S. R., and B. A. Moore. 1982. *Geohydrology of the Rattlesnake Ridge Interbed in the Gable Mountain Pond Area*. RHO-ST-38, Rockwell Hanford Operations, Richland, Washington.

Strait, S. R., and R. B. Mercer. 1987. *Hydrologic Property Data from Selected Test Zones on the Hanford Site*. SD-BWI-DP-051, Rev. 2, Rockwell Hanford Operations, Richland, Washington.

Stromswold, D. C. 1994. *Calibration Facilities at Hanford for Gamma-Ray and Fission-Neutron Well Logging*. PNL-9958, Pacific Northwest Laboratory, Richland, Washington.

Summers, W. K., and G. Schwab. 1980. *Hydrology and Isotopic Analyses of Water in a Recharge Area, Eastern Washington*. (Abstract) RHO-BWI-SA-71 A, Rockwell Hanford Operations, Richland, Washington.

Swanson, D. A., J. L. Anderson, R. D. Bentley, V. E. Camp, J. N. Gardner, and T. L. Wright. 1979. *Reconnaissance Geologic Map of the Columbia River Basalt Group in Washington and Adjacent Idaho*. Open-File Report 79-1363, U.S. Geological Survey, Washington, D.C.

Swanson, L. C. 1992. *Borehole Completion Data Package for the Grout Treatment Facility: CY 1991*. WHC-SD-EN-DP-048, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Swanson, L. C. 1993. *Borehole Completion Data Package for Grout Treatment Facility Wells 299-E25-44 and 299-E25-45*. WHC-SD-EN-DP-058, Westinghouse Hanford Company, Richland, Washington.

Swanson, L. C. 1993. *Grout Treatment Facility Borehole Summary Report for 1989-1993 Update*. WHC-SD-SD-EN-DP-070, Westinghouse Hanford Company, Richland, Washington.

Swanson, L. C. 1994. *1994 Characterization Report for the State Approved Land Disposal Site*. WHC-SD-C018H-RPT-003, Westinghouse Hanford Company, Richland, Washington.

Swanson, L. C., V. J. Rohay, and J. M. Faurote. 1999. *Hydrogeologic Conceptual Model for the Carbon Tetrachloride and Uranium/Technetium Plumes in the 200 West Area: 1994 Through 1999 Update*. BHI-01311, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Sweeney, M. D., K. A. Lindsey, J. S. Schmid, and J. V. Borghese. 1994. *Site Characterization Report for the Liquid Effluent Retention Facility*. WHC-SD-EN-EV-024, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Tallman, A. M., K. R. Fecht, M. C. Marratt, and G. V. Last. 1979. *Geology of the Separations Areas, Hanford Site, South-Central Washington*. RHO-ST-23, Rockwell Hanford Operations, Richland, Washington.

Teel, S. S. 1990. *Grout Treatment Facility Borehole Summary Report for 1989*. WHC-MR-0203, Westinghouse Hanford Company, Richland, Washington.

Thomas, C. W., D. L. Reid, and H. A. Treibe. 1956. *Cobalt-60 in Ground Water and Separations Plant Waste Streams*. HW-42612, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Thompson, K. M. 1991. *Hanford Past-Practice Strategy*. DOE/RL-91-40, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Thorne, P. 1998. *Upper Basalt-Confined Aquifer System in the Southern Hanford Site*. PNNL-12067, Pacific Northwest National Laboratory, Richland, Washington.

Thorne, P. D., and M. A. Chamness. 1992. *Status Report on the Development of a Three-Dimensional Conceptual Model for the Hanford Site Unconfined Aquifer System*. PNL-8332, Pacific Northwest Laboratory, Richland, Washington.

Thorne, P. D., and D. R. Newcomer. 1992. *Summary and Evaluation of Available Hydraulic Property Data for the Hanford Site Unconfined Aquifer System*. PNL-8337, Pacific Northwest Laboratory, Richland, Washington.

Thorne, P. D., M. A. Chamness, F. A. Spane, V. R. Vermeul, and W. B. Webber. 1993. *Three-Dimensional Conceptual Model for the Hanford Site Unconfined Aquifer System, FY 1993*. PNL-8971, Pacific Northwest Laboratory, Richland, Washington.

Thorne, P. D., M. A. Chamness, V. R. Vermeul, Q. C. Macdonald, and S. E. Schubert. 1994. *Three-Dimensional Conceptual Model for the Hanford Site Unconfined Aquifer System: FY 1994 Status Report*. PNL-10195, Pacific Northwest Laboratory, Richland, Washington.

Thornton, E. C. 1997. *Origin of Increased Sulfate in Groundwater at the ETF Disposal Site*. PNNL-11633, Pacific Northwest National Laboratory, Richland, Washington.

Thornton, E. C., K. J. Cantrell, J. M. Faurote, T. J. Gilmore, K. B. Olsen, and R. Schalla. 2000. *Identification of a Hanford Waste Site for Initial Deployment of the In Situ Gaseous Reduction Approach*. PNNL-13107, Pacific Northwest National Laboratory, Richland, Washington.

Thornton, E. C., T. J Gilmore, K. B. Olsen, R. Schalla, and K. J. Cantrell. 2001. *Characterization Activities Conducted at the 183-DR Site in Support of an In Situ Gaseous Reduction Demonstration*. PNNL-13486, Pacific Northwest National Laboratory, Richland, Washington.

Todd, M. E. and C. A. Kahler-Royer. 2002. *Borehole Summary Report for Borehole C3102 in the 216-T-26, 200-TW-1 Scavenged Waste Group Operable Unit*. BHI-01606, Bechtel Hanford, Inc., Richland, Washington.

Todd, M. E. and C. Trice. 2002. *Borehole Summary Report for Boreholes C3103 and C3104, and Drive Casings C3340, C3341, C3342, C3343, and C3344, in the 216-B-38 Trench and 216-B-7A Crib, 200-TW-2 Tank Waste Group Operable Unit*. BHI-01607, Bechtel Hanford Inc., Richland, Washington.

Truex, M. J., C. J. Murray, C. R. Cole, R. J. Cameron, M. D. Johnson, R. S. Skeen, and C. D. Johnson. 2001. *Assessment of Carbon Tetrachloride Groundwater Transport in Support of the Hanford Carbon Tetrachloride Innovative Technology Demonstration Program*. PNNL-13560, Pacific Northwest National Laboratory, Richland, Washington.

U.S. Department of Energy. 1982. *Site Characterization Report for the Basalt Waste Isolation Project*. DOE/RL-82-3, 3 vols., prepared by Rockwell Hanford Operations, Richland, Washington.

U.S. Department of Energy. 1988. *Consultation Draft, Site Characterization Plan, Reference Repository Location, Hanford Site, Washington*. DOE/RW-0164, Vols. 1 and 2, Richland, Washington.

U.S. Department of Energy. 1988. *Hanford Facility Dangerous Waste Part A Permit Application* (3 vols.). DOE/RL-88-21, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1989. *Low-Level Burial Grounds Dangerous Waste Permit Application*. DOE/RL-88-20, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1991. *Hanford Site Solid Waste Landfill Permit Application*. DOE/RL-90-38, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1991. *Hanford Site Waste Minimization and Pollution Awareness Program Plan*. DOE/RL-91-31, Rev. 1, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1991. *Environmental Monitoring Plan, United States Department of Energy, Richland Operations Office*. DOE/RL-91-50, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1991. *T Plant Source Aggregate Area Management Study*. DOE/RL-91-61, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1992. *Hanford Site Groundwater Background*. DOE/RL-92-23, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1991. *Groundwater Model Development Plan in Support of Risk Assessment*. DOE/RL-91-62, Decisional Draft, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1993. *PUREX Source Aggregate Area Management Study Report*. DOE/RL-92-04, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1993. *B-Plant Source Aggregate Area Management Study Report*. DOE/RL-92-05, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1993. *Columbia River Impact Evaluation Plan*. DOE/RL-92-28, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1993. *Hanford Site Solid Waste Landfill Interim Closure Plan*. DOE/RL-90-38, Rev. 1, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1994. *Hanford Remedial Action Draft Environmental Impact Statement*. DOE/DEIS-0222, 2 vols., Richland, Washington.

U.S. Department of Energy. 1994. *Environmental Monitoring Plan, United States Department of Energy, Richland Operations Office*. DOE/RL-91-50, Rev. 1, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1995. *Hanford Site Ground-Water Protection Management Plan*. DOE-RL-89-12, Rev. 2, Richland, Washington.

U.S. Department of Energy. 1995. *Hanford Site Risk Assessment Methodology*. DOE/RL-91-45, Rev. 3, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1995. *Hanford Site Background: Part 1, Soil Background for Nonradionuclide Analytes*. DOE/RL-92-24, Rev. 3, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1995. *Hanford Site Groundwater Remediation Strategy*. DOE/RL-94-95, Rev. 1, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1995. *Hanford Site Groundwater Remediation Strategy*. DOE/RL-94-95, Rev. 1, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1995. *Additional Monitoring Well Installation and Field Sampling Plan for Continued Groundwater Monitoring at the Horn Rapids Landfill*. DOE/RL-95-50, prepared by the Department of the Army, Walla Walla District, Corps of Engineers, Walla Walla Washington for the Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1995. *Vadose Zone Characterization Project at the Hanford Tank Farms, Spectral Gamma-Ray Borehole Geophysical Logging Characterization and Baseline Monitoring Plan for the Hanford Single-Shell Tanks*. P-GJPO-1786, prepared by Rust Geotech for the Grand Junction Projects Office, Grand Junction, Colorado.

U.S. Department of Energy. 1996. *Tank Waste Remediation System, Hanford Site, Final Environmental Impact Statement*. DOE/EIS-0189, Washington, D.C.

U.S. Department of Energy. 1996. *Hanford Remedial Action Environmental Impact Assessment and Comprehensive Land Use Plan*. DOE/EIS-0222D, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1996. *Vadose Zone Characterization Project at the Hanford Tank Farms: SX Tank Farm Report*. DOE/ID/12584-268, GJPO-HAN-4, prepared by Albuquerque Operations Office, Grand Junction Projects Office for Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1996. *Hanford Site Background: Part 2, Soil Background for Radionuclides*. DOE/RL-96-12, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1996. *Remedial Design Report/Remedial Action Work Plan for the 100 Areas*. DOE/RL-96-17, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1996. *200 Areas Soil Remediation Strategy - Environmental Restoration Program*. DOE/RL-96-67, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1996. *200-UP-1 Groundwater Remedial Design/Remedial Action Work Plan*. DOE/RL-97-36, Rev. 2, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1997. *Environmental Monitoring Plan, United States Department of Energy, Richland Operations Office*. DOE/RL-91-50, Rev. 2, prepared by personnel from Pacific Northwest National Laboratory, Fluor Daniel Hanford, Inc. and its subcontractor Waste Management Federal Services of Hanford, Inc., and Bechtel Hanford, Inc. for U.S. Department of Energy, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1997. *Hanford Sitewide Groundwater Remediation Strategy*. DOE/RL-94-95, Rev. 1, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1997. *Hanford Site Background: Part 3, Groundwater Background*. DOE/RL-96-61, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1997. *Waste Site Grouping for 200 Areas Soil Investigations*. DOE/RL-96-81, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1997. *Richland Environmental Restoration Project Baseline, Multi-Year Work Plan*. DOE/RL-96-105, Rev. 1, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1997. *N-Springs Pump and Treat System Optimization Study.* DOE/RL-97-34, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1997. *Vadose Zone Characterization Project at the Hanford Tank Farms: BY Tank Farm Report*. GJO-96-2-TAR, GJO-HAN-6, Albuquerque Operations Office and Grand Junction Office for Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1997. *Vadose Zone Characterization Project at the Hanford Tank Farms: U Tank Farm Report*. GJO-97-1-TAR, GJO-HAN-8, Albuquerque Operations Office and Grand Junction Office for Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1997. *Hanford Tank Farms Vadose Zone: TX Tank Farm Report*. GJO-97-13-TAR, GJO-HAN-11, Albuquerque Operations Office and Grand Junction Office for Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1997. *Vadose Zone Characterization Project at the Hanford Tank Farms: AX Tank Farm Report*. GJO-97-14-TAR, GJO-HAN-12, Albuquerque Operations Office and Grand Junction Office for Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1997. *Hanford Tank Farms Vadose Zone: Tank Summary Data Report for Tank BX-102.* GJO-HAN-89, Grand Junction Project Office, Grand Junction, Colorado.

U.S. Department of Energy. 1998. *Groundwater/Vadose Zone Integration Project Background Information and State of Knowledge*. DOE/RL-98-48, Vol. I, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1998. *Hanford Tank Farms Vadose Zone, TY Tank Farm Report*. GJO-97-30-TAR, GJO-HAN-16, Albuquerque Operations Office and Grand Junction Office for Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1998. *Hanford Tank Farms Vadose Zone, S Tank Farm Report*. GJO-97-31-TAR, GJO-HAN-17, Albuquerque Operations Office and Grand Junction Office for Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1998. *Hanford Tank Farms Vadose Zone, C Tank Farm Report*. GJO-98-39-TAR, GJO-HAN-18, Albuquerque Operations Office and Grand Junction Office for Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1998. *Hanford Tank Farms Vadose Zone, BX Tank Farm Report*. GJO-98-40-TAR, GJO-HAN-19, Albuquerque Operations Office and Grand Junction Office for Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1998. *Screening Assessment and Requirements for a Comprehensive Assessment, Columbia River Comprehensive Impact Assessment, Part II*. DOE/RL-96-16, Rev. 1, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1999. *Hanford Tank Farms Vadose Zone, Base Calibration of a High Rate Logging System for Characterization of Intense Radiation Zones in the Hanford Tank Farms*. GJO-99-118-TAR, GJO-HAN-29, Prepared by MACTEC-ERS for the U.S. Department of Energy, Grand Junction Projects Office, Grand Junction, Colorado.

U.S. Department of Energy. 1999. *Focused Feasibility Study for the K-Basins Interim Remedial Action*. DOE/RL-98-66, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1999. *Proposed Plan for the K-Basins Interim Remedial Action*. DOE/RL-98-71, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1999. *Prototype Barrier Treatability Test Report*. DOE/RL-99-11, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1999. *Phase I RCRA Facility Investigation/Corrective Measures Study Work Plan for Single-Shell Tank Waste Management Areas*. DOE/RL-99-36, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 2000. *Environmental Monitoring Plan, United States Department of Energy, Richland Operations Office*. DOE/RL-91-50, Rev. 3, Prepared by personnel from Pacific Northwest National Laboratory, Fluor Daniel Hanford, Inc. and its subcontractor Waste Management Federal Services of Hanford, Inc., and Bechtel Hanford, Inc. for the U.S. Department of Energy, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 2000. *Recommendations for Selection of a Site-Wide Groundwater Flow and Transport Model*. DOE/RL-2000-11, Rev. 1, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 2000. *Hanford Tank Farms Vadose Zone, B Tank Farm Report.* GJO-99-113-TAR, GJO-HAN-28, Prepared by MACTEC-ERS for the Grand Junction Office, Grand Junction, Colorado.

U.S. Department of Energy. 2000. *Hanford Tank Farms Vadose Zone, Seventh Recalibration of Spectral Gamma-Ray Logging Systems Used for Baseline Characterization Measurements in the Hanford Tank Farms*. GJO-2000-142-TAR, GJO-HAN-30, Prepared by MACTEC-ERS for the U.S. Department of Energy, Grand Junction Projects Office, Grand Junction, Colorado.

U.S. Department of Energy. 2001. *Hanford Tank Farms Vadose Zone Monitoring Project Baseline Monitoring Plan*. MAC-HGLP 1.8.1, Rev. 0, Grand Junction Office, Grand Junction, Colorado.

U.S. Department of Energy. 2002. Draft *Hanford Site Solid (Radioactive and Hazardous) Waste Program Environmental Impact Statement Richland, Washington*. DOE/EIS-0286D, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 2002. *Standardized Stratigraphic Nomenclature for Post-Ringold-Formation Sediments Within the Central Pasco Basin.* DOE/RL-2002-39, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 2002. *Hanford 200 Areas Spectral Gamma Baseline Characterization Project, Waste Site Summary Report: 216-B-35 to -42 Trenches*. GJO-2002-322, Prepared by MACTEC-ERS for the Grand Junction Office, Grand Junction, Colorado.

U.S. Department of Energy. 2002. *Hanford 200 Areas Spectral Gamma Baseline Characterization Project, Waste Site Summary Report: 216-B-8 Crib and Adjacent Sites*. GJO-2002-343, Prepared by S. M. Stoller Corporation for the Grand Junction Office, Grand Junction, Colorado.

U.S. Department of Energy. 2002. *Hanford 200 Area Spectral Gamma Baseline Characterization Project: 216-B-5 Injection Well and 216-B-9 Crib and Tile Field Waste Site Summary Report*. GJO-2002-358-TAC, Prepared by S. M. Stoller Corporation for the Grand Junction Office, Grand Junction, Colorado.

U.S. Environmental Protection Agency. 2001. *USDOE Hanford Site First Five Year Review Report*. U.S. Environmental Protection Agency, Region 10, Hanford Project Office, Seattle, Washington.

U.S. Geological Survey. 1987. *Subsurface Transport of Radionuclides in Shallow Deposits of the Hanford Nuclear Reservation, Washington - Review of Selected Previous Work and Suggestions for Further Study*. Open File Report 87-222, Tacoma, Washington.

Van Luik, A. R., R. M. Mitchell, G. V. Last, R. C. Routson, D. S. Landeen, and K. R. Fecht. 1980. *Characterization of the W-5 Burial Ground Expansion Site*. RHO-CD-941, Rockwell Hanford Operations, Richland, Washington.

Van Verst, S. P. 2000. *Hanford Site Shoreline Vegetation Study 1999*. WDOH/320-023, Washington State Department of Health, Division of Radiation Protection, Olympia, Washington.

Van Vleet, R. J. 1993. *Radionuclide and Chemical Inventories for the Single-Shell Tanks*. WHC-SD-WM-TI-565, Rev. 1, prepared by WASTREN, Inc. for Westinghouse Hanford Company, Westinghouse Hanford Company, Richland, Washington.

Vermeul, V. R., S. S. Teel, J. E. Amonette, C. R. Cole, J. S. Fruchter, Y. A. Gorby, F. A. Spane, J. E. Szecsody, M. D. Williams, and S. B. Yabusaki. 1995. *Geologic, Geochemical, Microbiologic, and Hydrologic Characterization at the In Situ Redox Manipulation Test Site*. PNL-10633, Pacific Northwest Laboratory, Richland, Washington.

Waite, J. L. 1991. *Tank Wastes Discharged Directly to the Soil at the Hanford Site*. WHC-MR-0227, Westinghouse Hanford Company, Richland, Washington.

Walker, L. D. 2001. *Borehole Summary Report for the 2001 ILAW Site Characterization Well*. BHI-01531, Bechtel Hanford, Inc., Richland, Washington.

Walters, K. L., and M. J. Grolier. 1960. *Geology and Ground-Water Resources of the Columbia Basin Project Area, Washington Volume I*, Division of Water Resources, State of Washington, Olympia, Washington.

Walters, W. H., M. C. Richmond, and B. G. Gilmore. 1994. *Reconstruction of Radionuclide Concentrations in the Columbia River from Hanford, Washington to Portland, Oregon, January 1950-January 1971*. PNWD-2225 HEDR, Pacific Northwest Laboratory, Richland, Washington.

Ward, A. L. and G. W. Gee. 2000. *Vadose Zone Transport Field Study: Detailed Test Plan for Simulated Leak Tests*. PNNL-13263, Pacific Northwest National Laboratory, Richland, Washington.

Ward, A. L. and G. W. Gee. 2000. *Vadose Transport Field Study: Detail Test Plan for Simulated Leak Tests*. PNNL-13240, Pacific Northwest National Laboratory, Richland, Washington.

Ward, A. L. and G. W. Gee. 2001. *Vadose Zone Transport Field Study: FY 2001 Test Plan*. PNNL-13451, Rev. 1, Pacific Northwest National Laboratory, Richland, Washington.

Ward, A. L., J. K. Linveille, G. W. Gee, and C. D. Wittreich. 2002. *200-BP-1 Prototype Hanford Barrier Annual Monitoring Report for Fiscal Year 2001*. BHI-100381, Bechtel Hanford, Inc., Richland, Washington.

Waste Management Federal Services, Northwest Operations, Inc. 1998. *Operational Environmental Monitoring*. WMNW-CM-004, Richland, Washington.

Webb, C. R. 1993. *Miscellaneous Information Regarding Operation and Inventory of 618-10 Burial Ground*. WHC-MR-0415, Westinghouse Hanford Company, Richland, Washington.

Weekes D. C., G. K. Jaeger, W. J. McMahon, and B. H. Ford. 1996. *Groundwater Protection Plan for the Environmental Restoration Disposal Facility*. BHI-00079, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Weekes, D. C., S. P. Luttrell, and M. R. Fuchs. 1987. *Interim Hydrogeologic Characterization Report and Groundwater Monitoring System for the Nonradioactive Dangerous Waste Landfill, Hanford Site, Washington*. WHC-EP-0021, Westinghouse Hanford Company, Richland, Washington.

Westinghouse Hanford Company. 1987. *Data Compilation: Iodine-129 in Hanford Groundwater*. WHC-EP-0037, Richland, Washington.

Westinghouse Hanford Company. 1990. *Liquid Effluent Study: Groundwater Characterization Data*. WHC-EP-0366, Westinghouse Hanford Company, Richland, Washington.

Westinghouse Hanford Company. 1992. *Geophysical Surveys Performed by the Automatic and Measurement Sciences Department of the Pacific Northwest Laboratory at Hanford Burial Grounds 619-4 and 618-5*. WHC-SD-EN-TI-061, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Westinghouse Hanford Company. 1995. *Summary Report of Hanford Site Well Remediation and Decommissioning Activities for Fiscal Year 1995*. WHC-SD-EN-PRS-003, Richland, Washington.

Williams, B. A. 1992. *Borehole Completion Data Package for the 216-S-10 Ditch and Pond: CY 1991*. WHC-SD-EN-DP-045, Westinghouse Hanford Company, Richland, Washington.

Williams, B. A. 1993. *Borehole Completion Data Package for the 216-B-63 Trench, CY 1992*. WHC-SD-EN-DP-051, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Williams, B. A. 1994. *Borehole Data Package for the 100-K Area Ground Water Wells, CY 1994*. WHC-SD-EN-DP-090, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Williams, B. A. 1995. *Borehole Data Package for the 216-U-12 Crib Well 699-36-70A, CY 1994*. WHC-SD-EN-DP-091, Westinghouse Hanford Company, Richland, Washington.

Williams, B. A., and D. B. Barnett. 1993. *Borehole Completion Data Package for the 216-S-10 Facility, CY 1992*. WHC-SD-EN-DP-052, Westinghouse Hanford Company, Richland, Washington.

Williams, B. A., B. N. Bjornstad, R. Schalla, and W. D. Webber. 2000. *Revised Hydrogeology for the Suprabasalt Upper Aquifer System, 200 East Area, Hanford Site, Washington*. PNNL-12261, Pacific Northwest National Laboratory, Richland, Washington.

Williams, M. D., V. R. Vermeul, J. E. Szecsody, J. S. Fruchter, and C. R. Cole. 1999. *100-D Area In Situ Redox Treatability Test for Chromate-Contaminated Groundwater: FY-1998 Year-End Report*. PNNL-12153, Pacific Northwest National Laboratory, Richland, Washington.

Williams, M. D., V. R. Vermeul, J. E. Szecsody, and J. S. Fruchter. 2000. *100-D Area In Situ Redox Treatability Test for Chromate-Contaminated Groundwater*. PNNL-13349, Pacific Northwest National Laboratory, Richland, Washington.

Williams, M. D., V. R. Vermeul, M. Oostrom, J. C. Evans, J. S. Fruchter, J. D. Istok, M. D. Humphrey, D. C. Lanigan, J. E. Szecsody, M. D. White, T. W. Wietsma, and C. R. Cole. May 1999. *Anoxic Plume Attenuation in a Fluctuating Water Table System: Impact of 100-D Area In Situ Redox Manipulation on Downgradient Dissolved Oxygen Concentrations*. PNNL-12192, Pacific Northwest National Laboratory, Richland, Washington.

Wilson, C. R., C. M. Einberger, R. L. Jackson, and R. B. Mercer. 1993. "Design of Ground-Water Monitoring Networks Using the Monitoring Efficiency Model (MEMO)." *Ground Water* 30(6):965-970.

Womack, J. C. and D. J. Larkin. 1971. *Investigation and Evaluation of 102-BX Tank Leak.* ARH-2035, Atlantic Richfield Hanford Company, Richland, Washington.

Wood, M. I., T. E. Jones, R. Schalla, B. N. Bjornstad, and S. M. Narbutovskih. 2000. *Subsurface Conditions Description of the B-BX-BY Waste Management Area*. HNF-5507, Rev. 0, CH2M HILL Hanford Group, Inc., Richland, Washington.

Yonge, D., A. Hossain, R. Cameron, H. Ford, and C. Storey. 1996. *Hanford Soil Partitioning and Vapor Extraction Study*. BHI-00861, Bechtel Hanford, Inc., Richland, Washington.

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