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Pacific Northwest National Laboratory
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Evaluation of Potential Sources for Tritium Detected in Groundwater at Well 199-K-111A, 100-K Area

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Prepared for the U.S. Department of Energy
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Summary

Tritium concentrations in groundwater at well 199-K-111A near the northwest corner of the 100-K Burial Ground have been rising rapidly since fall 2000. The source for the tritium observed at the well is uncertain; the well does not lie in the direct downgradient flow path from known sources, such as the KE Fuel Storage Basin and the KE Condensate Crib. No other contaminants show a similar increasing trend at that well. Circumstances similar to those discovered at the 618-11 solid waste burial ground, where tritium from buried materials has apparently created a high concentration, localized groundwater plume, may also exist at the 100-K Burial Ground.

Several investigations were undertaken during fall 2001 provide more information on a possible source for tritium observed in groundwater at well 199-K-111A. These included:

- Analyzing groundwater flow direction and gradient, including the variability in those parameters: the new information would clarify whether groundwater flow pathways linked known tritium sources to groundwater at the well.
- Modeling the buildup of a groundwater mound beneath the interim remedial action injection site, located east of the well: radial flow patterns around the mound could potentially displace contaminated groundwater beneath the 100-K Burial Ground to the west, where it would be monitored at the well.
- Analyzing soil gas collected from previously installed sample tubes: tubes near the well had previously revealed evidence of a nearby tritium source in the vadose zone (e.g., materials in the burial ground) and/or a plume in the underlying groundwater.

Historical water table elevation data for the period 1994 to present were evaluated using trend-surface analysis to determine the orientation of the hydraulic gradient and its steepness. New elevation data were collected hourly during the period August 31 to September 17, 2001 and evaluated also. For the area between the KE reactor complex and the river, the trend-surface analysis results confirmed that well 199-K-111A does not lie in the direct downgradient flow path, as defined by hydraulic gradients, from known tritium sources.

A groundwater mound of uncertain size has been created beneath injection wells located ~700 meters to the east of well 199-K-111A. The potential exists for this mound to influence groundwater movement beneath the nearby burial ground. An analytical method (WTAQ3 program) was used to determine the potential mound characteristics given the treated effluent injection rate and assumed hydraulic properties. The analysis suggests that a hydraulic head increase of ~0.5 meters is possible at a distance of ~500 meters from the center of the injection network. The results do not show conclusively that mounding is displacing groundwater beneath the burial ground a significant distance to the west to well 199-K-111A, although the analysis does not rule out this possibility.

Soil gas samples were collected in September 2001 from sampling tubes previously installed near the northwest corner of the burial ground. The soil gas was analyzed for helium isotopes; the helium-3/helium-4 ratio will be higher in the presence of a nearby tritium source, which could be in the vadose zone or an underlying groundwater plume. The new ratios were consistently higher than those determined in September 1999 and the distribution pattern was the same for both sampling events. The highest ratios were observed at locations closest to the northwest corner of the burial ground.

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1.0 Introduction

Analytical results from a groundwater monitoring well located near the 100-K Burial Ground have shown rapidly increasing concentrations of tritium since fall 2000. Although several potential sources for tritium are located within the general area, the monitoring well in question is not situated along the direct downgradient pathway from any of the documented sources. Therefore, special investigations were undertaken during the summer and fall of 2001 to identify the source of the tritium. The key findings from these investigations were initially communicated to DOE via internal memos (see the Appendix). A comprehensive description of the results is presented in this report. Where appropriate, groundwater monitoring information has been updated to include analytical results through April 2002.

1.1 Background

Tritium concentrations in groundwater collected from well 199-K-111A, which is located at the northwest corner of the 100-K Burial Ground (Figure 1.1), began rising rapidly in fall 2000 (Figure 1.2). The source for tritium observed in groundwater at the well is uncertain, as is the cause for the recent change in concentration trend. Multiple potential sources are known to exist in the general area. There is also evidence to indicate the possibility of a previously unidentified source within the burial ground. It has not been possible to establish a clear groundwater flow path connection to a particular tritium source, as the direction of groundwater movement in the vicinity of well 199-K-111A has not been defined in detail previously. Also, groundwater movement in this area may be changing as a consequence of injecting treated effluent from the interim remedial action at a location to the east.

Tritium is a common and widespread contaminant in the groundwater that underlies the reactor areas. The origin for this contamination is primarily past-practice disposal of liquid effluents from the KE and KW Reactors during the operating years, which spanned 1955 to 1971. Tritium has also been introduced to 100-K Area groundwater more recently by leakage from the KE Fuel Storage Basin (1976 to 1979, and again in 1993). Tritium, along with carbon-14, is believed to be currently introduced to groundwater via slow downward migration through the vadose zone at two past-practices disposal sites that are located to the east side of each reactor building (see Figure 1.2). Each site received condensate from the reactor atmosphere gas recirculation system. An aerial photograph of the 100-K Areas as it appears, is shown in Figure 1.3.

The tritium distribution in groundwater beneath the 100-K Area is shown in the annual groundwater monitoring reports (e.g., Hartman et al. 2002, p. 2.55). The distribution shown reflects the primary, documented sources. Uncertainty in this interpretation is introduced by the number and distribution of available monitoring wells. Although the existing well coverage reveals the general groundwater flow pattern and areas of contamination, coverage is not sufficiently comprehensive to provide a highly detailed characterization of (1) the direction, rate, and variability of groundwater movement, and (2) the boundaries of contaminant plumes.

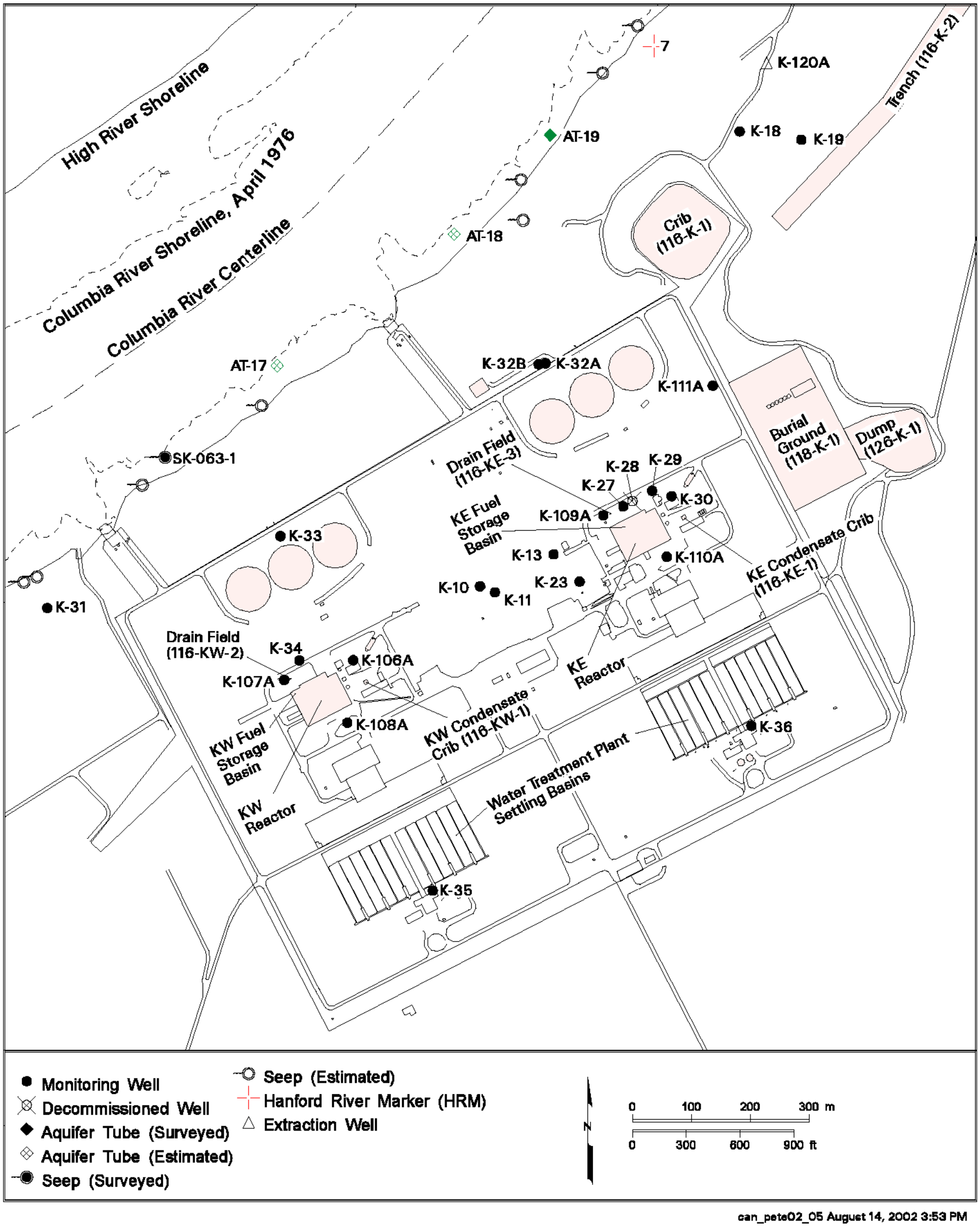

Figure 1.1. Location Map, Showing Principal Facilities and Monitoring Wells

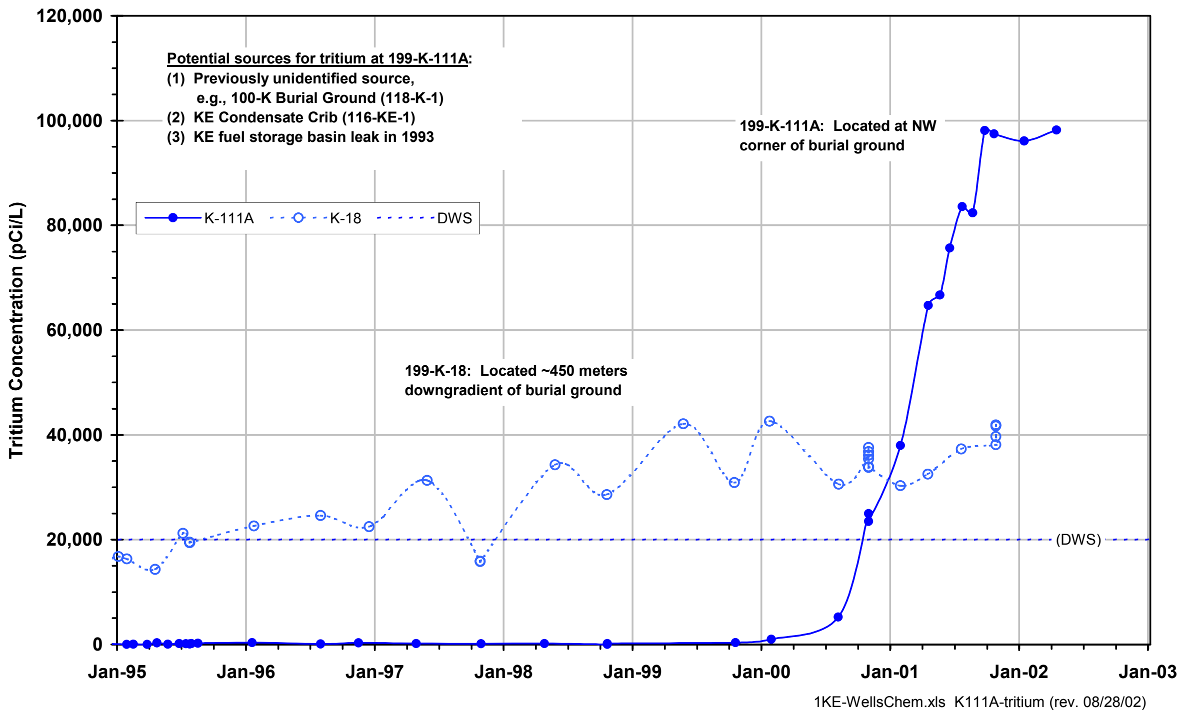

Figure 1.2. Tritium Trends in Well 199-K-111A

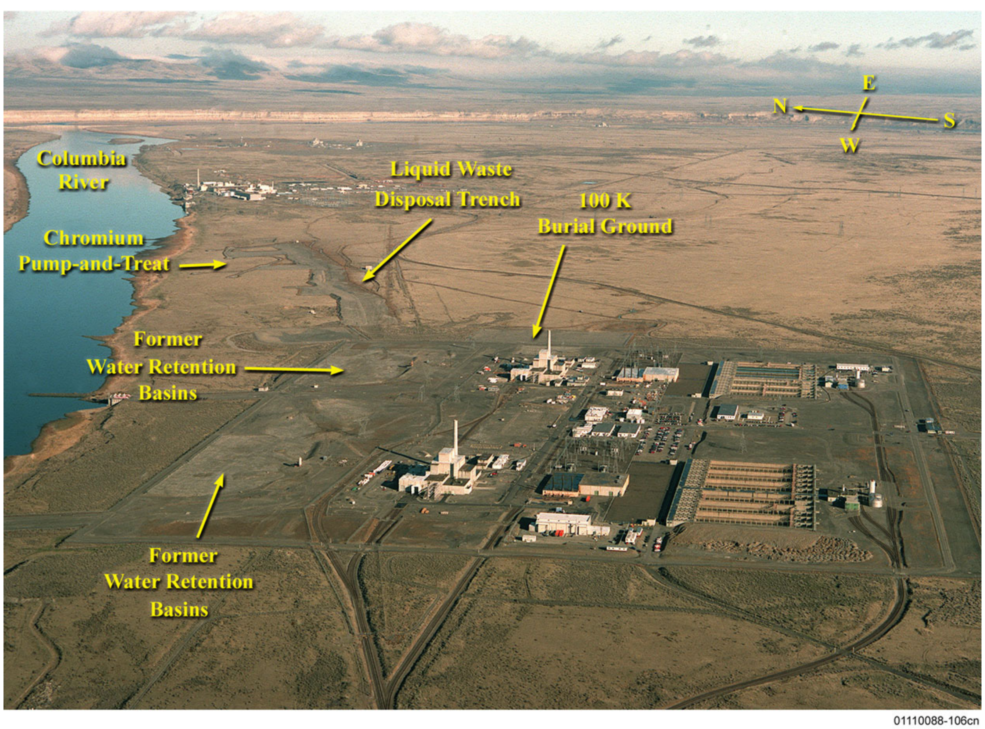

Figure 1.3. Aerial Photograph of 100-K Area

1.2 Scope of Work

The task of determining the source of tritium detected at well 199-K-111A has involved several independent but complementary lines of investigation. At the request of the U.S. Department of Energy (DOE), responsibility for performing this work was divided between Pacific Northwest National Laboratory (PNNL) and the Environmental Restoration Contractor (ERC). Individual tasks and responsibilities are described in the following sections.

1.2.1 Groundwater Flow Direction and Gradient

The direction and rate of groundwater movement, and the variability of these parameters with seasonal changes in hydrologic conditions, provide a technical basis for inferring where contaminant plumes are likely to travel. To help differentiate the various potential sources for tritium observed in groundwater at well 199-K-111A, historical data on water-table elevation were used to determine the direction and steepness of the hydraulic gradient in the general area of the KE Reactor complex and the 100-K Burial Ground. The time period represented by these elevation measurements spans 1994 to present, with measurement intervals typically monthly or longer. New data were collected hourly using a pressure transducer installed temporarily in well 199-K-111A during the period August 31 to September 17, 2001. These data were combined with hourly data from nearby wells to also determine direction and steepness of the hydraulic gradient. The results of these analyses are presented in Chapter 4. The analysis was performed by PNNL.

1.2.2 Potential Mound Buildup Beneath Interim Action Injection Wells

The groundwater flow pattern in the area directly east of the 100-K Burial Ground is being influenced by the buildup of a mound on the water table as a result of the interim remedial action to address chromium in groundwater. Effluent from the treatment system is being injected back into the aquifer at a location approximately 700 meters to the east of well 199-K-111A, which is located at the northwest corner of the 100-K Burial Ground. The possibility exists that the radial flow pattern at the injection site could displace a groundwater plume located beneath the burial ground to the west, where it would be detected at well 199-K-111A. Using the rate of effluent injection, assumed hydraulic properties, and the time since injection started in October 1997, a model of the potential mound buildup was developed. The model and its results are described in Chapter 5. The modeling was performed by PNNL.

1.2.3 Helium-3 in Soil Gas at Sites Near the 100-K Burial Ground

The presence of a tritium source in the vadose zone (i.e., a burial waste source) or an underlying groundwater plume can be revealed by analysis of soil gas samples. Tritium decays to helium-3, which can be detected in soil gas. An earlier analysis of soil gas samples from the area near the KE Reactor and the 100-K Burial Ground revealed an enrichment of helium-3 (relative to background levels) near the northwest corner of the burial ground and well 199-K-111A (Olsen et al. 2000). Also, helium-3 concentrations in soil gas near the 618-11 Burial Ground, where irradiated solid wastes containing tritium were buried, were found to be elevated (Olsen et al. 2001). Because of similarities in the construction and use of the 618-11 and 100-K waste sites, further investigation of a possible buried tritium source was undertaken. The sampling tubes near the 100-K Burial Ground that had been installed earlier were re-sampled and helium isotope levels in soil gas measured to ascertain whether the same pattern was present, and whether the levels of helium-3 had increased or decreased over time. The results of this investigation are presented in Chapter 6. The investigation was a joint effort involving the ERC (Bechtel Hanford, Inc.) and PNNL.

2.0 Facility/Waste Site Sources for Tritium

Known facility/waste site sources for tritium in the region near well 199-K-111A include the KE Fuel Storage Basin and its adjacent drain field, and the KE Condensate Crib. Previously undocumented potential sources include vertical cylindrical storage units (“silos”) within the 100-K Burial Ground that received irradiated fuel assembly components, some of which may have the capacity to release tritium. Descriptions of facilities and waste sites in the 100-K Area were prepared in 1994 as part of remedial investigation activities for the 100-KR-4 Operable Unit (Carpenter and Cote 1994). The following summary information is taken from that report, unless cited otherwise.

2.1 KE Fuel Storage Basin

The KE and KW Fuel Storage Basins (K Basins) are integral parts of each of the reactor buildings. They are currently in use to store irradiated fuel elements from past reactor operations. The basins are concrete structures that were originally designed for temporary storage of irradiated fuel from the KE and KW Reactors prior to transport to the 200 Areas for chemical processing to recover plutonium. Irradiated fuel from the N Reactor was added to the basins starting in 1975 and has been stored there ever since. Removal of spent fuel from the basins began in December 2000 as part of Hanford Site cleanup actions (DOE/RL 1999a; EPA 1999).

Comprehensive descriptions of the facilities and stored fuel are provided in Bergsman et al. (1995) and Praga (1998). When fuel removal work started, the KE Basin contained approximately 1,150 metric tons (1,268 tons) of irradiated reactor fuel. Much of that fuel has deteriorated because of damage to the cladding and from being stored in open canisters. The deterioration has resulted in high concentrations of radionuclides in the shielding water and accumulation of radioactive sludge on the basin floors. The basin is an unlined concrete structure that has a shielding water capacity of approximately 4.9 million liters (1.3 million gallons). A shielding water re-circulation system provides temperature control and removal of some radionuclides. Tritium is present at relatively high concentrations in KE Basin shielding water, with a recent average concentration of approximately 2,500,000 pCi/L. Strontium-90 and cesium-137 also are present in each basin, at average concentrations of 1,186,000 and 3,016,000 pCi/L, respectively. These radionuclides are less mobile in the environment than tritium because of adsorption onto sediment. The concentrations of these three radionuclides are shown in Figure 2.1. Technetium-99, a mobile radionuclide in the environment, also is presumed to be present in the shielding water, but concentrations have not been monitored routinely.

There have been two periods of extensive leakage from the KE Basin. The first occurred during the early phase of converting the basin from its original purpose during reactor operations to that of storage of fuel from the N Reactor. An estimated 56.8 million liters (15 million gallons) of shielding water is presumed to have been lost to the underlying soil column during the period 1976 to 1979 (DOE/RL 1999b, p. 2-2). Four new monitoring wells were installed along the downgradient side of the KE Basin in 1981 in response to this leakage. However, the monitoring data for these wells do not reveal the passage of a plume created by the leakage. Apparently the plume created by the 1976 to 1979 leakage had already passed downgradient of these well locations by the time monitoring started in 1981.

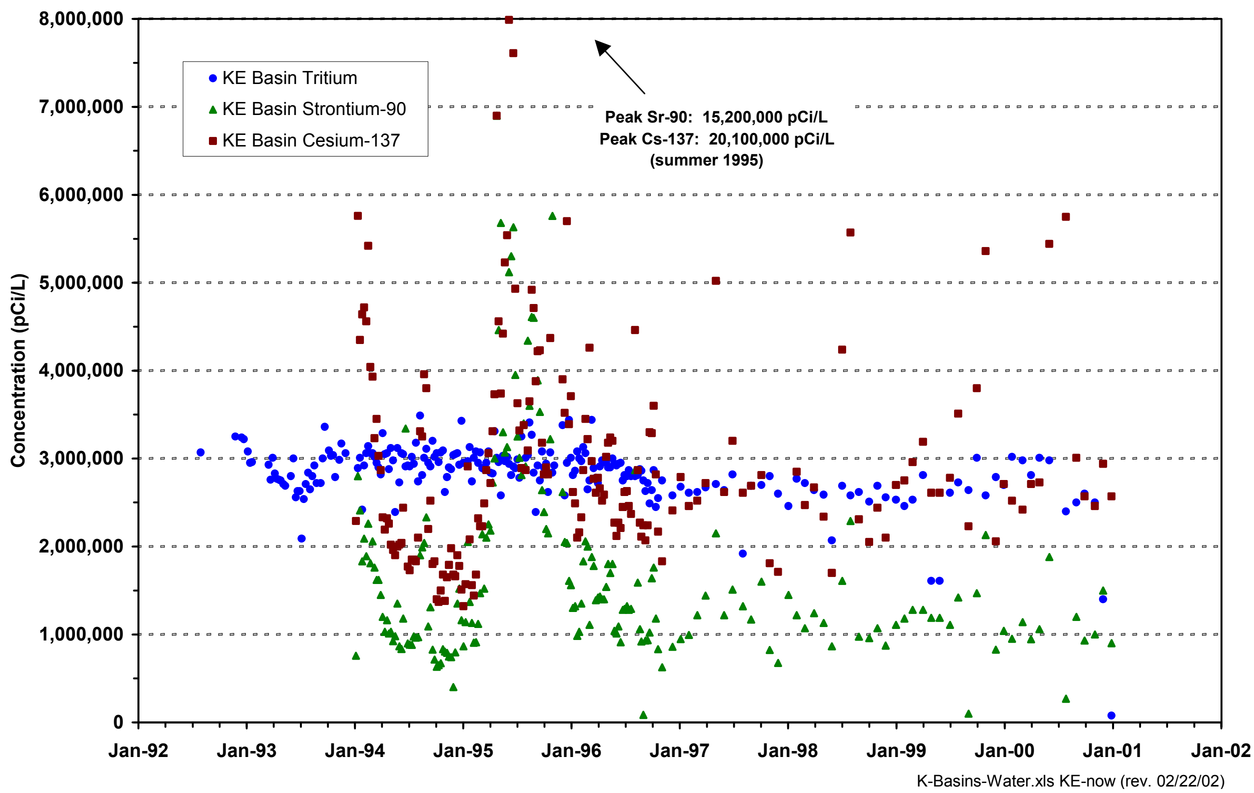

Figure 2.1. Concentrations of Various Radionuclides in KE Basin Shielding Water

Radionuclide concentrations in the KE Basin shielding water were relatively low during the late 1970s when leaks occurred. However, approximately 2,500 curies of radionuclides, exclusive of tritium, were estimated to have been released; the highest rate of water loss occurred during 1977. This inventory, except for tritium, was largely retained within the vadose zone because of adsorption onto soil particles. Following tritium and technetium-99, strontium-90 is the next radionuclide most likely to appear in groundwater downgradient of the basin. One estimate suggests a vadose zone travel time of 1.4 years for strontium-90 to reach the water table and an additional 26 years via groundwater flow to reach the nearest downgradient well (Johnson et al. 1995, pg. 3-7). If accurate, strontium-90 from the late 1970s leakage would reach well 199-K-27, the nearest monitoring well, by the early 2000s.

A second period of leakage was first noticed in February 1993 when water balance calculations showed an increased loss rate that could not be explained by evaporation alone. Approximately 341,000 liters (90,000 gallons) are presumed to have been lost during this time (Bergsman et al. 1995, pp. 2-4 to 2-5). The construction joint between the KE Reactor building and the fuel storage basin is the suspected leakage location, and additional measures to seal it were undertaken. By March 1995, the loading chute basin (the construction joint lies beneath this basin) was physically isolated from the main storage basin and contamination removed.

A groundwater plume was created by the 1993 leakage and recorded as it passed downgradient monitoring well 199-K-27 (Figure 2.2). Technetium-99 also was present in the plume created by the leakage.

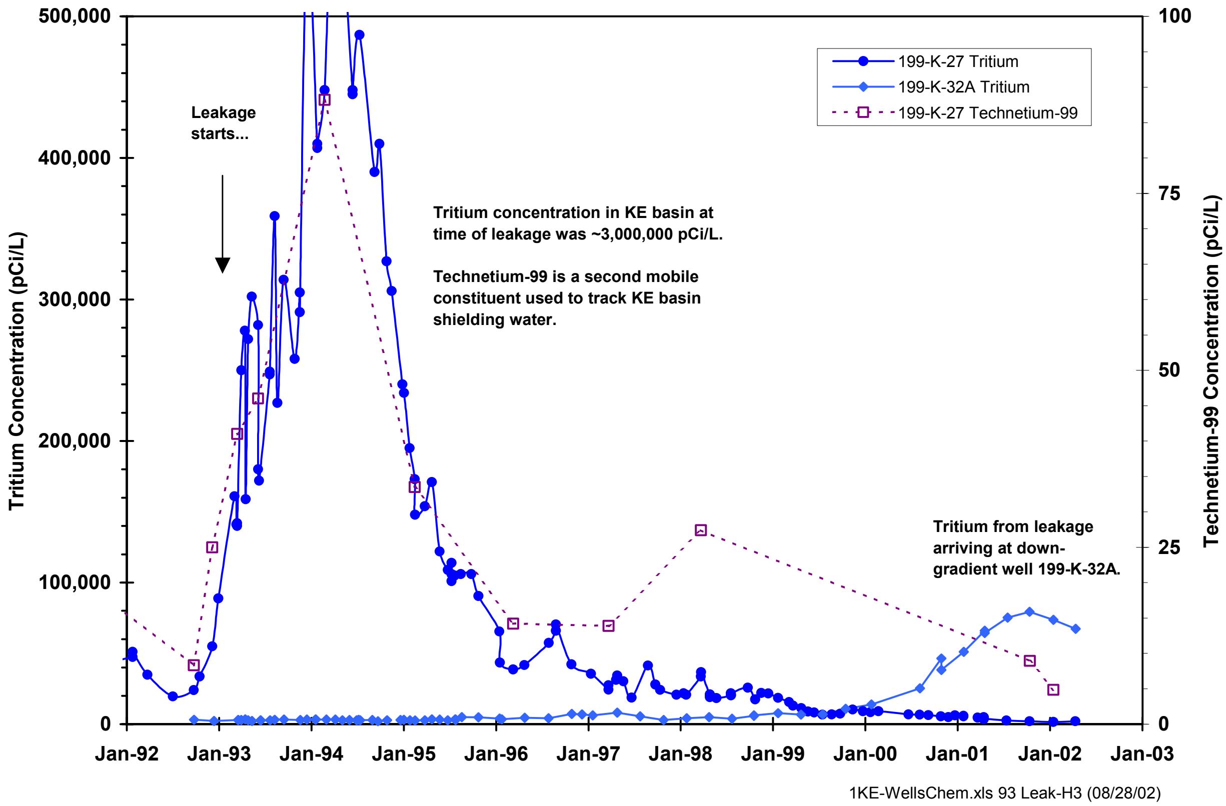

Figure 2.2. Evidence for Groundwater Plume Created by 1993 KE Basin Leak

Since that time, a primary monitoring objective has been to track the plume, which has remained elusive because of available well coverage. However, it now appears that the plume front arrived at down-gradient well 199-K-32A in fall 2000 (see Section 3.4 for further discussion of rate). A more complete discussion of the impacts these leakage episodes had on groundwater is presented in Johnson et al. 1998, pp. 1.2 to 1.7, and 2.14).

2.2 KE Condensate Crib (Waste Site 116-KE-1)

The 115-KE and 115-KW Condensate Cribs received moisture from the reactor atmosphere gas purification system. The condensate contained significant quantities of tritium and carbon-14. The cribs were soil column disposal facilities located at the east side of each reactor building. They operated during 1955 to 1971, during which time approximately 800,000 liters (211,200 gallons) of condensate was discharged to the KE crib. As of 1986, it was estimated that the crib contained approximately 56 curies of tritium and 110 curies of carbon-14. It is believed that vadose zone moisture containing tritium and carbon-14 continues to feed a groundwater plume that originates beneath this crib (Johnson et al. 1998, pp. 2.1 to 2.15).

Well 199-K-30 is located approximately 30 meters (98.4 feet) downgradient along the flow path beneath the KE crib. The tritium and carbon-14 concentrations in groundwater at this well are shown in Figure 2.3.

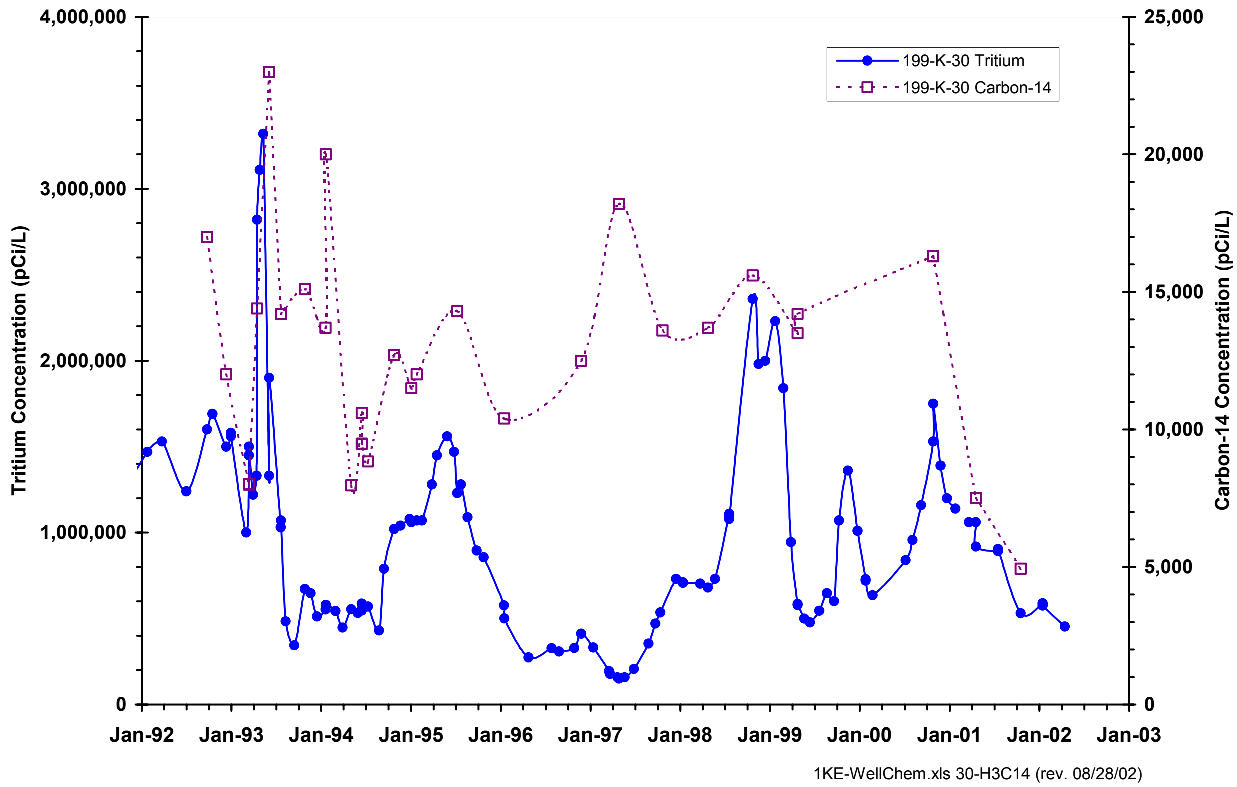

Figure 2.3. Tritium and Carbon-14 in Groundwater Downgradient of KE Condensate Crib

2.3 100-K Burial Ground (Waste Site 118-K-1)

This site was the primary burial ground for solid waste generated in the 100-K Area. It is located outside of the eastern perimeter fence. It included various pits, trenches, incinerators, and vertical "silos" that were used to store irradiated metallic waste from the K and N reactors. There is reference to zirconium cladding from lithium target elements being placed in one silo (Miller and Wahlen 1987). It is also known that lithium targets were irradiated at each of the reactors between 1950 and 1964 (DeNeal 1970, p. 45), creating the possibility that some targets may have been placed in the burial ground as well. Additional reference to lithium-aluminum alloy "special materials" being stored in the K Basins is available (Clough 1971, p. 39), further suggesting that this type of fuel element was present in the 100-K Area.

An aerial photo taken in 1954 (Figure 2.4) shows the vertical silos that are suspected of containing irradiated lithium targets, which are believed to be capable of producing tritium that ultimately gets into the underlying groundwater. There are several features of the 100-K Burial Ground that are similar to those at the 618-11 Burial Ground, which is located near the Energy Northwest Columbia Generating Station. At the 618-11 site, a reasonably clear connection has been established between lithium targets in the burial ground and relatively high concentrations of tritium in the underlying groundwater (Olsen et al.

Figure 2.4. Aerial Photograph Showing 100-K Burial Ground Under Construction (view toward southeast)

2001). The possible mechanism by which tritium from lithium targets disposed to burial grounds gets to groundwater is described highly as follows: Tritium gas escapes from the target material, interacts with vadose zone moisture, and migrates downward to groundwater.

3.0 Hydrologic Setting

This section provides background information on the geology, hydrology, and contaminant distribution beneath the 100-K Area. The information presented is limited to that which is relevant to investigations involving the recent increase in tritium concentrations in groundwater at well 199-K-111A.

3.1 Previous Work

The first comprehensive description of the hydrology and geology of the 100-K Area was prepared in 1993 to support Environmental Restoration Program objectives (Lindberg 1993). This report was updated two years later to include information that became available from the installation of six new monitoring wells (Lindberg 1995).

In 1996, descriptions of conceptual site models for each groundwater operable unit in the 100 Area (excluding 100-NR-2) were prepared to support environmental restoration decisions (Peterson et al. 1996). That report draws heavily from the earlier reports but provides additional information on hydrologic units, groundwater movement, and the distribution of contaminants. Tables also are presented that show the ranges in water level and specific (i.e., electrical) conductance observed in wells, as a function of the wells' distance inland from the Columbia River. A summary of the best available values for aquifer hydraulic properties is provided in the Peterson et al. (1996) report.

Comprehensive descriptions of the groundwater conditions beneath the 100-K Area are presented in a variety of reports from the Hanford Groundwater Monitoring Project. The groundwater monitoring and assessment plan for the 100-K Fuel Storage Basins (Johnson et al. 1995) describes the facilities, hydrologic setting, and strategy for monitoring. The most recent periodic update of the conceptual model for contamination associated with the fuel storage basins is presented in Johnson et al. (1998). Annual updates on groundwater contamination conditions are provided in the annual Hanford Groundwater Monitoring Project report (e.g., Peterson and McMahon 2002, pp. 2.31 to 2.65).

3.2 Stratigraphy and Hydrologic Units

The uppermost hydrologic unit beneath the 100-K Area is Ringold Formation Unit E, which consists of heterogeneous sandy gravel deposits of low-to-moderate transmissivity. The contact with the overlying informally-defined Hanford formation, which is more transmissive, lies above the water table. A new cross section has been prepared to support information needs associated with the fuel storage basins (Figure 3.1). This section extends from the KE Basin to the Columbia River. Well 199-K-111A, if projected onto this section, would appear approximately midway between wells 199-K-32A and 199-K-27 (see Figure 1.1 for well location map). Most of the groundwater monitoring wells in the 100-K Area do not penetrate the entire thickness of the uppermost hydrologic unit, so estimates for aquifer thickness are uncertain in many areas.

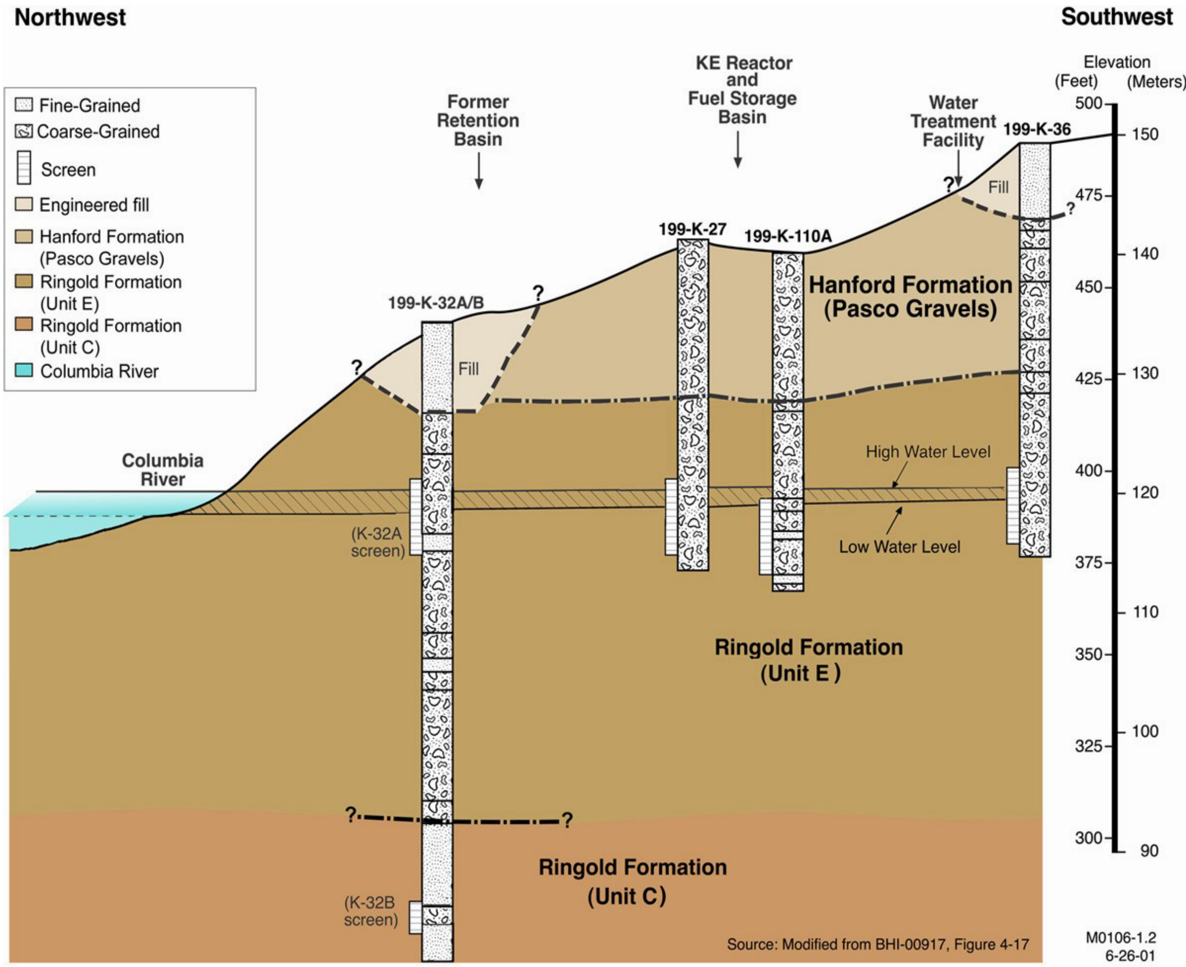

Figure 3.1. Hydrostratigraphic Cross Section Between KE Basin and Columbia River

3.3 Aquifer Hydraulic Properties

Tests to measure hydraulic conductivity for the uppermost aquifer in the 100-K Area are limited. A slug test conducted in well 199-K-32A indicated a hydraulic conductivity of 24.2 meters (80 feet) per day (0.028 centimeter [0.01 inch] per second) (DOE/RL 1994). Slug injection and withdrawal tests were conducted in well 199-K-111A as part of well completion activities. Hydraulic conductivity based on the injection test was 7.8 meters (25.53 feet) per day (0.0090 centimeter [0.0035 inch] per second) and on the withdrawal test 8.4 meters (27.38 feet) per day (0.0097 centimeter [0.0038 inch] per second) (Williams 1994, p. 16). A review of single well test results for 100 Area wells indicated that hydraulic conductivity may have been underestimated, so the above results may be biased toward low values.[(a)]

(a) Letter report from F. A. Spane to M. P. Bergeron (Pacific Northwest National Laboratory, Richland, Washington) *Possible Inclusion of Hydraulic Property Values Available for 100 Area Operable Units Within Site-Wide Groundwater Flow Model*, dated November 5, 1996.

The most recent value for hydraulic conductivity assumed for the area near the 100-KR-4 pump-and-treat system injection wells is approximately 10 meters (32.8 feet) per day.[a] This value was adopted for performance evaluation modeling associated with the remedial action for chromium. As reported in the Technical Memorandum, hydraulic conductivity is believed to fall in the range 2.8 to 26.5 meters (7.9 to 74.4 feet) per day in the vicinity of the 100-K liquid waste disposal trench.

Reasonable assumptions for the hydraulic properties of the uppermost hydrologic unit beneath the 100-K Area, based on recent descriptions of hydraulic properties in published reports and various datasets, include (a) horizontal hydraulic conductivity in the range 2 to 30 meters (6.6 to 98.4 feet) per day; (b) effective porosity in the range 10 to 20%; and (c) hydraulic gradients in the range 0.003 to 0.006. An additional assumption commonly used in hydrologic investigations at the Hanford Site is that the vertical hydraulic conductivity is 0.1 that of the horizontal hydraulic conductivity.

3.4 Direction and Rate of Groundwater Movement

The direction and rate of groundwater flow are key hydrologic parameters for describing the distribution of contaminants as well as for interpreting changes in concentration trends. To provide a general overview of groundwater movement beneath the 100-K Area, a map showing the average water-table elevation beneath the 100-K Area during FY 2001 is shown in Figure 3.2. Uncertainty in the shape of the water-table elevation contours is a consequence of the uneven distribution of monitoring wells and their relatively limited number.

The direction of groundwater flow is inferred from lines drawn perpendicular to the contours, i.e., flow is generally northwesterly toward the river. The rate of flow is controlled by the hydraulic conductivity, effective porosity, and hydraulic gradient. For the range of hydraulic properties listed in Section 3.3, the resulting average linear flow velocities are shown in Table 3.1.

Previous determinations of groundwater flow direction and rate in 100-K Area wells include a test in February 1993 of the KV Associates ™ (KV Associates, Inc., Falmouth, MA) borehole flowmeter.[b] This instrument measures in-well horizontal flow direction and velocity using a heat-pulse probe/thermistor arrangement (Kerfoot 1988). The results for well 199-K-30 indicated a flow direction of 325 degrees (azimuth clockwise from true north) and a velocity of 1.13 meters (3.7 feet) per day. The direction is consistent with other recent evidence, but the velocity appears to be anomalously high.

Near the KW Reactor complex, the February 1993 results from well 199-K-34 indicate a direction of 300 degrees and a velocity of 0.24 meter (0.8 foot) per day. Measurements were also made in well 199-K-35, which is located farther inland near the former KW water treatment plant settling basins. Flow

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(a) Technical Memorandum IOM 044735 from M. H. Sturges to A. J. Knepp (Bechtel Hanford, Inc.), author M. J. McMahon, *Updated Predictive Model to the 100-KR-4 Operable Unit Interim Action Pump and Treat*, dated May 2, 1997.

(b) Letter report, D. B. Barnett to J. W. Roberts, "Brief Summary of K-Area Flowmeter Application," May 4, 1993, Westinghouse Hanford Company.

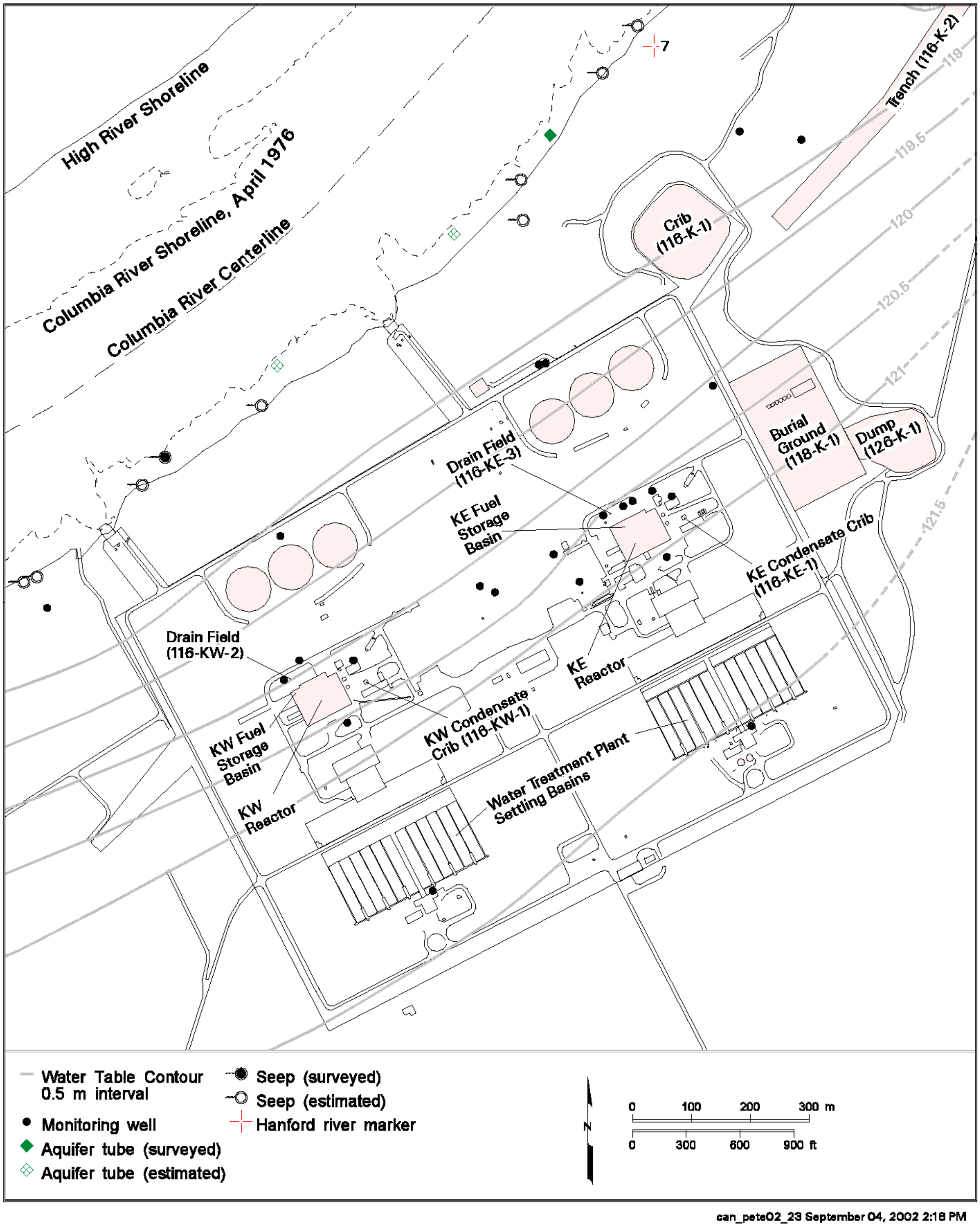

Figure 3.2. Water-Table Elevation During FY 2001 (from Peterson and McMahon 2002)

Table 3.1. Average Linear Flow Velocities (m/d)—Darcy Equation

Hydraulic Conductivity (m/d)	Gradient			
	0.003	0.004	0.005	0.006
Effective Porosity = 10%				
2	0.06	0.08	0.10	0.12
5	0.15	0.20	0.25	0.30
10	0.30	0.40	0.50	0.60
20	0.60	0.80	1.00	1.20
25	0.75	1.00	1.25	1.50
30	0.90	1.20	1.50	1.80
Effective Porosity = 15%				
2	0.04	0.05	0.07	0.08
5	0.10	0.13	0.17	0.20
10	0.20	0.27	0.33	0.40
20	0.40	0.53	0.67	0.80
25	0.50	0.67	0.83	1.00
30	0.600	0.80	1.00	1.20
Effective Porosity = 20%				
2	0.03	0.04	0.05	0.06
5	0.08	0.10	0.13	0.15
10	0.15	0.20	0.25	0.30
20	0.30	0.40	0.50	0.60
25	0.38	0.50	0.63	0.75
30	0.45	0.60	0.75	0.90

direction at that well was 335 degrees and velocity was 0.15 meter (0.5 foot) per day. Both of these measurements appear to be consistent with current assumptions based on measured gradients and assumed values for hydraulic conductivity and effective porosity.

The KV Associates™ flowmeter was again used in well 199-K-106A in March 1994 (Williams 1994, pp. 6 and D.4). This well is located near the northeast corner of the KW Reactor complex; its location is analogous to well 199-K-30 at the KE Reactor complex. The direction of flow was determined to be 342 degrees, with a velocity of 0.63 meter (2.07 feet) per day, assuming an effective porosity of 20 percent. This velocity estimate is very consistent with an estimate derived from the migration rate for a tritium plume from 199-K-106A downgradient to well 199-K-33 (Figure 3.3).

Estimates for contaminant transport flow velocities and travel times to the river were prepared in 1995 as background information for the 100-K Area Fuel Storage Basins groundwater monitoring plan (Johnson et al. 1995, p. 2-12 to 2-16). That analysis suggested groundwater flow velocities in the range 0.01 to 0.4 meter (0.03 to 1.3 feet) per day, assuming hydraulic conductivities in the range 0.95 to 16 meters (3.1 to 52.5 feet) per day, an effective porosity of 20%, and gradients between 0.003 and 0.005. For movement between the KE Basin and the Columbia River when the gradient toward the river was steepest, the computed average linear flow velocity ranged between 0.014 and 0.24 meter (0.05 to 0.79 foot) per day, depending on the hydraulic conductivity value that was assumed for the computation.

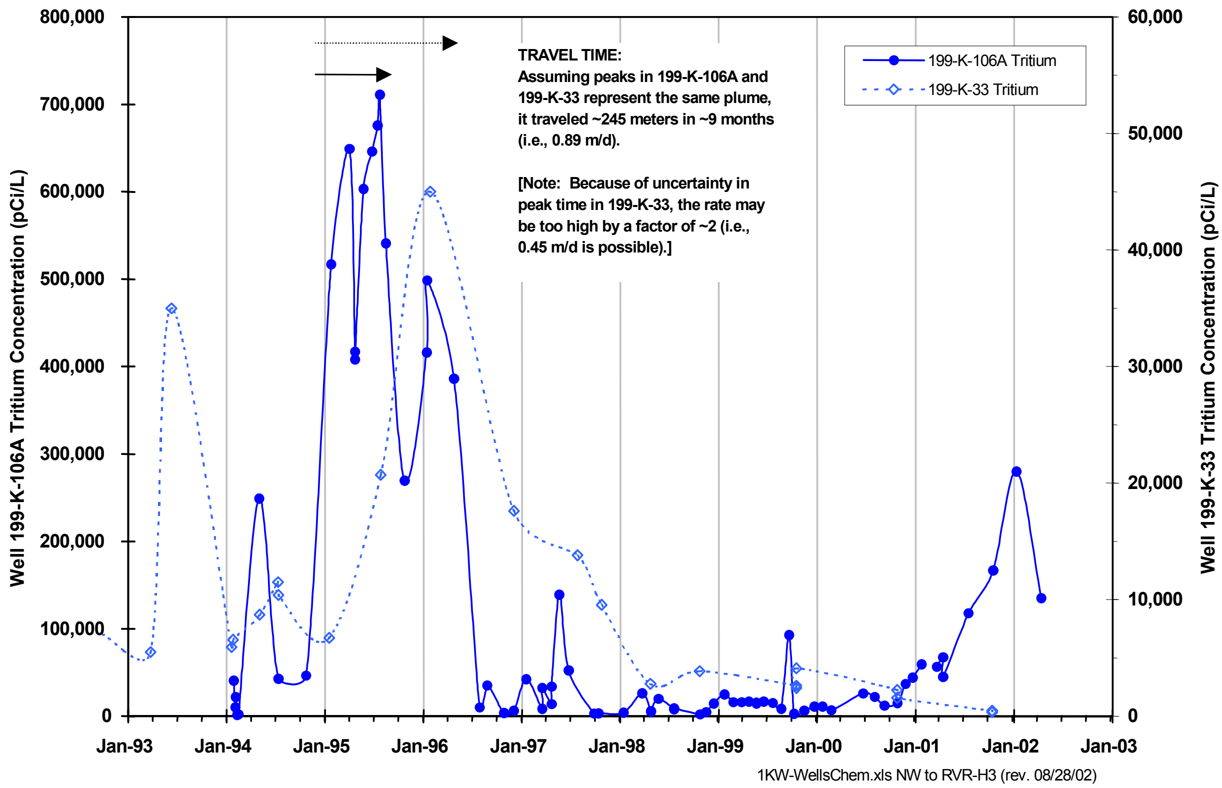

Figure 3.3. Tritium Plume Migration from KW Condensate Crib Toward Columbia River

The most recent direct evidence for the flow rate between the KE Reactor complex and the Columbia River suggests a rate of approximately 0.12 meter (0.4 foot) per day (Peterson and McMahon 2001, p. 2.32). This estimate is based on the migration of a tritium plume associated with leakage from the KE Basin in 1993. Figure 3.4 shows tritium concentrations in well 199-K-27, located adjacent to the KE Basin on the downgradient side, and well 199-K-32A, located along the downgradient flowpath from the KE Basin to the Columbia River (see Figure 1.1 for location map). The assumption is made that the pulse in tritium concentrations in each well represents the early 1993 release of shielding water from the KE Basin. Its arrival at well 199-K-32A approximately six years later is used to infer travel time and flow velocity.

3.5 Seasonal Effects on Groundwater Flow Direction

Changes in contaminant concentrations in the 100-K Area have been previously interpreted to be caused by a shift in the position of plumes, because of an inferred change in flow direction during high and low seasonal river discharge periods (Johnson et al. 1995, p. 3-9 and 3-10; Johnson et al. 1998, pp. 2.1 and 2.15). An illustration was included in those reports to show the range in flow direction from various potential source sites for tritium near the KE Reactor building. The illustration is included in this report as Figure 3.5. The shaded corridors do not indicate the extent of contaminant plumes, but do

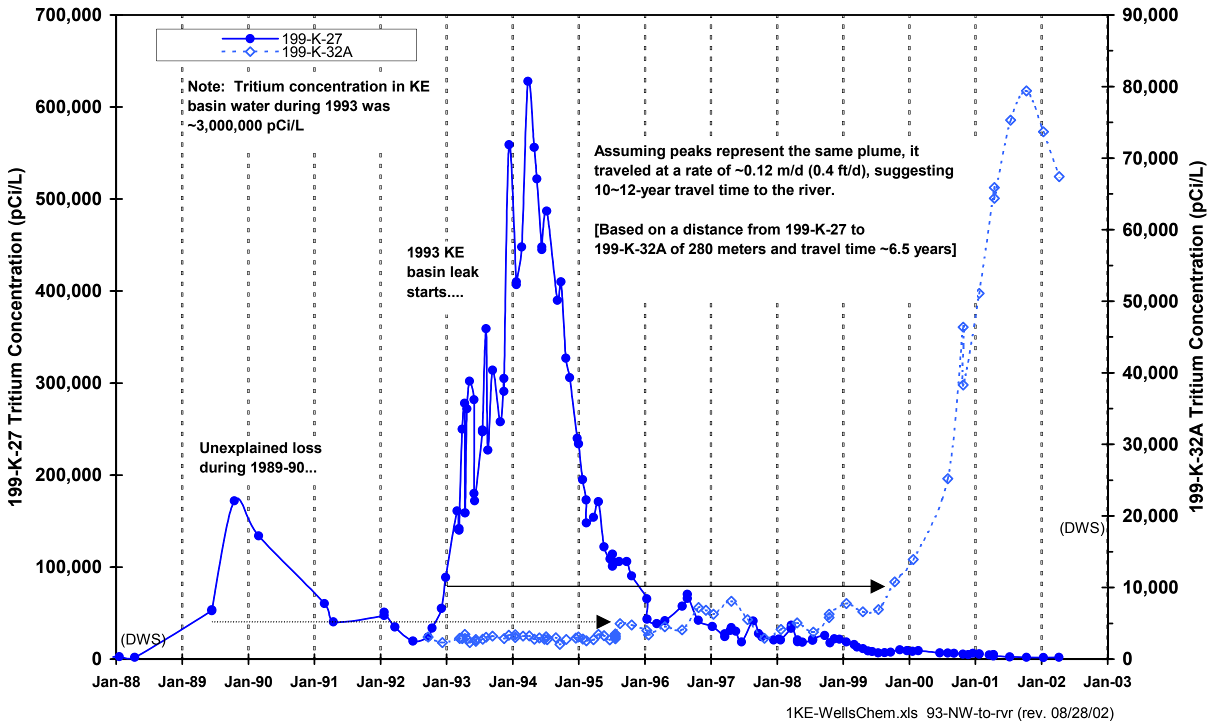

Figure 3.4. Tritium Plume Migration from KE Basin Toward Columbia River

indicate the possible range in direction of flow pathlines from various sources. Plume boundaries along these corridors are expected to be somewhat wider because of lateral diffusion.

To further investigate the potential displacement of plumes brought on by seasonal water-table variations, an analysis of historical water-table data was made during 1999 as part of routine 100-K Area groundwater surveillance activities. Water-level data obtained since 1992 were subdivided into several categories that represented various river discharge conditions. The categories were:

- Long-term average elevation — January 1, 1992 through March 1, 1999
- Long-term drought conditions — January 1, 1993 through December 31, 1995
- Long-term wet conditions — January 1, 1996 through December 31, 1998
- Very low conditions — November 1, 1994 through March 1, 1995
- Very high conditions — May 1, 1997 through September 6, 1997

The basis for selecting a time interval to represent the very low and very high conditions requires that several months' continuous duration of the condition would be necessary to displace a groundwater

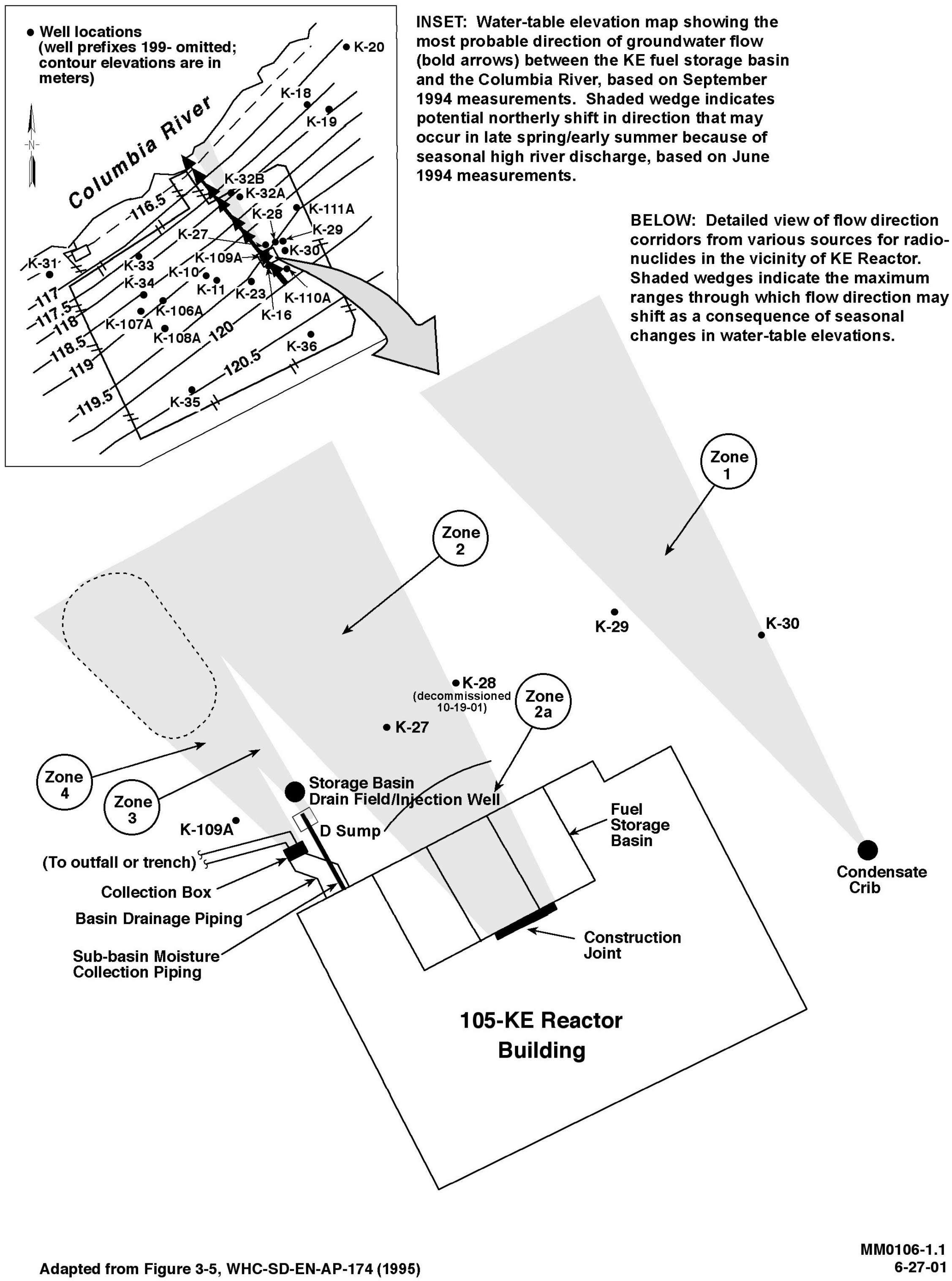

Figure 3.5. Groundwater Flow Corridors Downgradient of KE Basin

contaminant plume to be recognized in monthly monitoring results. During a four-month period of changed direction, groundwater would be expected to move between 18 and 36 meters (60 and 120 feet), assuming a flow rate of 0.15 and 0.30 meter (0.5 to 1.0 foot) per day. More recent evidence suggests that this flow rate may be too high for the area between the KE Basin and the Columbia River (see Section 3.4).

Depth-to-water measurements were assembled from various sources and the groundwater elevation calculated using the most recent survey data for the top-of-casing of each well. The principal data sources are the Hanford Environmental Information System (HEIS) and unpublished data from the ERC. The latter included monthly measurements made to calibrate transducers in wells that are used to evaluate the performance of the pump-and-treat remedial actions and measurements from several miscellaneous surveys. Averages were then calculated for the five time periods listed in the preceding paragraph. A more readily-accessible database containing water-level data for the Hanford Site became available after this work was conducted; this new database is maintained by the Hanford Groundwater Monitoring Project at PNNL.

The average values were then plotted on maps and contoured. On the basis of the contours, no evidence for major shifts in groundwater flow direction is indicated. However, the distribution of monitoring wells is not ideal for accurately mapping the water-table configuration, so uncertainty exists in conclusions based on groundwater contours alone.

3.6 Contaminant Distribution Patterns

Maps showing the distribution patterns for tritium, carbon-14, and strontium-90 during the period October 2000 to October 2001 (FY 2001) were prepared for the annual groundwater report using the most recent information on water movement patterns, groundwater concentrations, and potential source sites (Peterson and McMahon 2002).

The shape of tritium contamination (Figure 3.6) reflects known sources near the KW and KE Reactor buildings, and isolated occurrences between the 100-K Trench and the Columbia River. Contours for the region upgradient of the 100-K Burial Ground have been dashed to indicate uncertainty, in light of the absence of monitoring wells in that region. The most recent tritium result (April 2002) at well 199-K-111A, located at the northwest corner of the 100-K Burial Ground, is 98,200 pCi/L and indicates a possible leveling off of the rise in concentrations (see Figure 1.2).

Tritium is being re-introduced to the aquifer at the pump-and-treat injection wells located to the east of the 100-K Burial Ground. Effluent concentrations during 2000 averaged 12,600 pCi/L (DOE/RL 2001, p. 3-33), with most of the tritium having come from extraction well 199-K-120A. Tritium was not detected, or detected at very low concentrations, at the pump-and-treat injection well sites prior to the startup of the interim remedial action (i.e., conditions in November 1996). The tritium being re-introduced was expected to appear at the nearest downgradient wells (i.e., monitoring well 199-K-19 and extraction well 199-K-119A) within several years following the startup of operations in October 1997. The most recent analytical results suggest that tritium re-introduced to the aquifer at the injection wells has now reached extraction well 199-K-119A (Figure 3.7). Travel time between these two sites is accelerated by

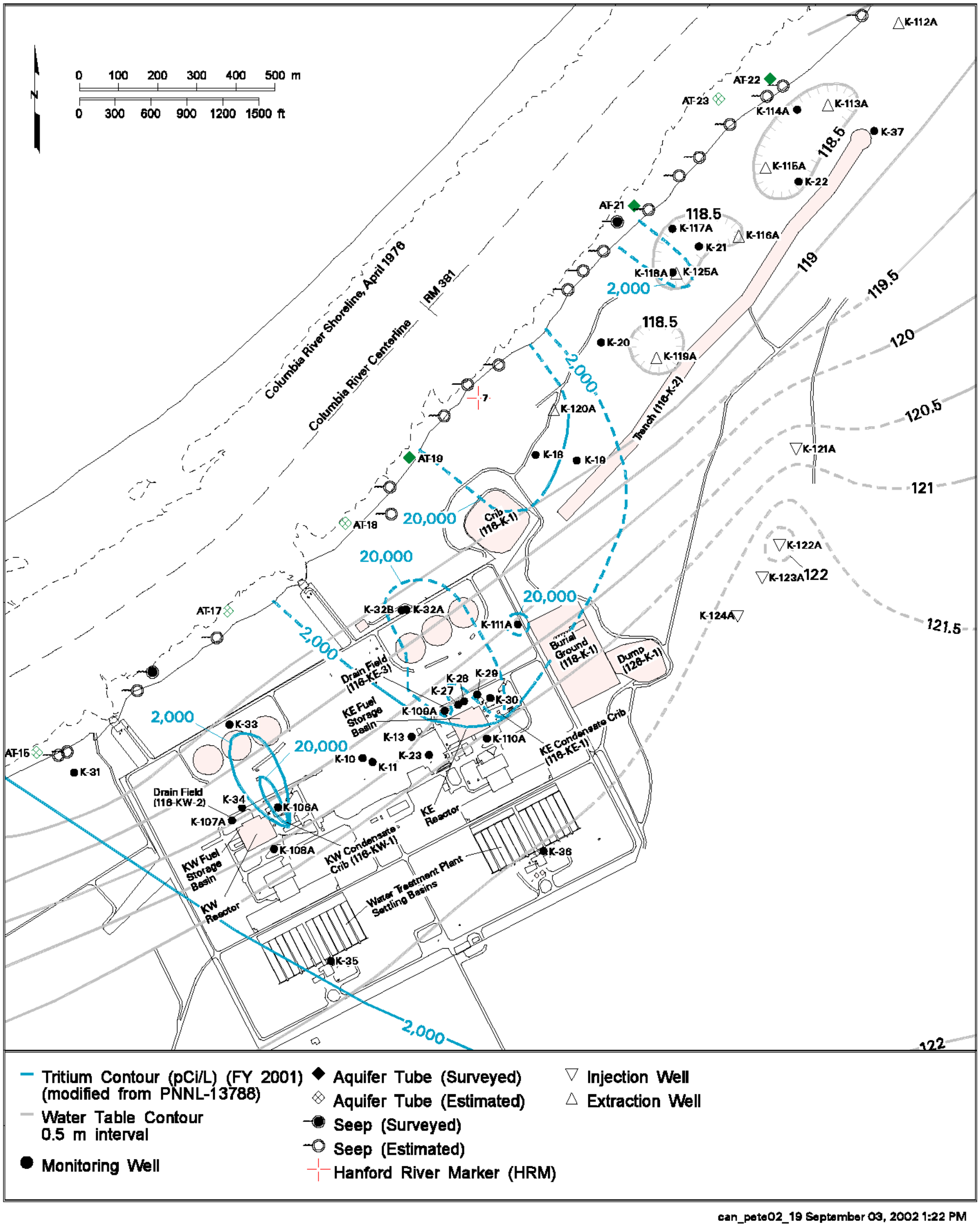

Figure 3.6. Tritium Distribution in 100-K Area Groundwater, FY 2001

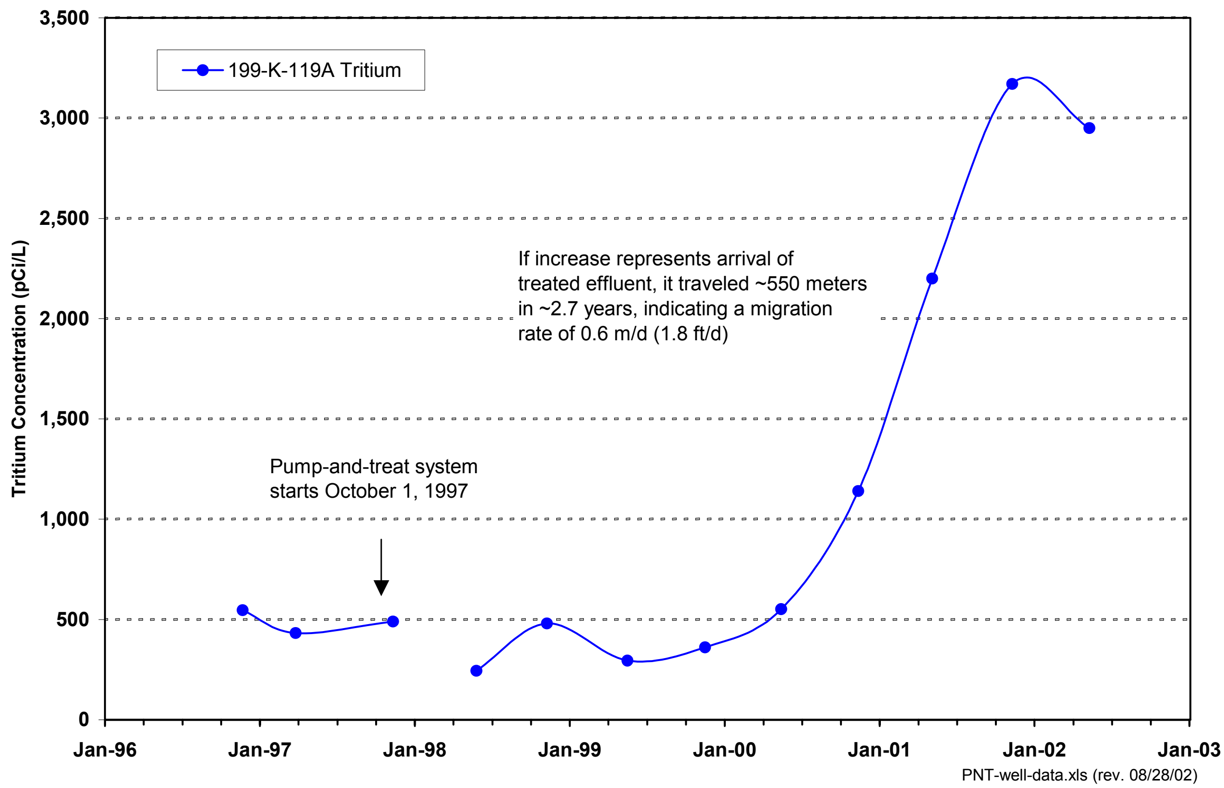

Figure 3.7. Arrival of Tritium at Well Downgradient of Injection Well Field

mounding at the injection site and a cone of depression at the extraction well site, and is, therefore, faster than travel time under natural gradient conditions.

The distribution of carbon-14 (Figure 3.8) is relatively limited and reflects two known sources: the KW and KE Condensate Cribs, which received reactor atmosphere gas condensate that contained tritium and carbon-14 during the operating years (1955 to 1971). The cribs are located on the east side of each reactor building. Although each crib was used in essentially the same way during operations, the resulting groundwater plumes are different in their concentration levels and their distribution pattern. The higher concentrations at the KW Basin may reflect a stronger driving mechanism for moving vadose zone moisture downward to groundwater than at the KE Basin. The larger pattern at the KW Basin may reflect a more transmissive unconfined aquifer and faster groundwater flow rates than at the KE Basin. This is consistent with borehole flow measurements indicating faster flow beneath the KW Reactor than below the KE Reactor (see Section 3.4).

Strontium-90 (Figure 3.9) illustrates the distribution of a radionuclide that is moderately retarded by adsorption onto sediment. Strontium-90 was introduced to the soil column at the drain fields associated with each reactor, and also to the 100-K Trench. The relatively high concentrations shown near the

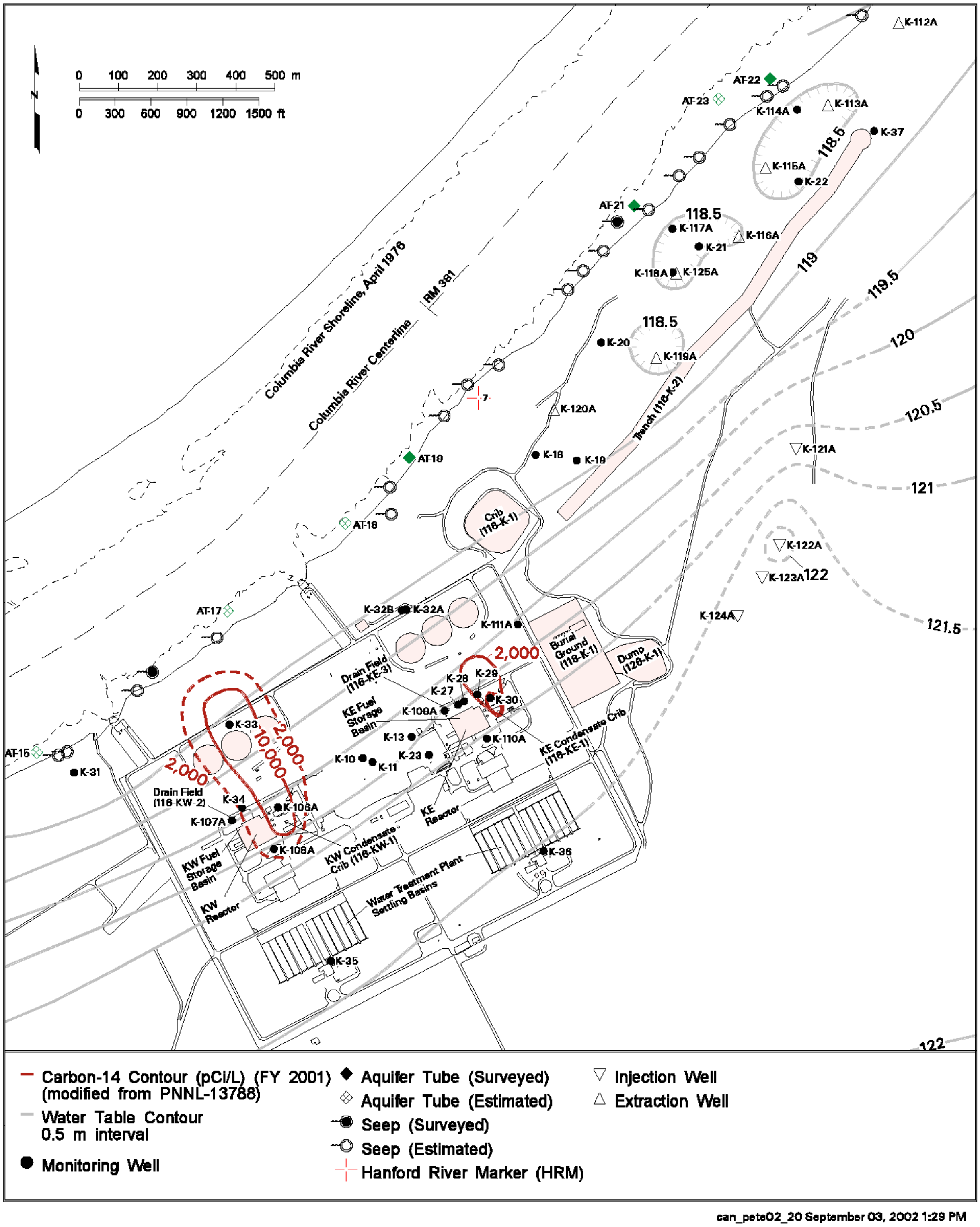

Figure 3.8. Carbon-14 Distribution in 100-K Area Groundwater, FY 2001

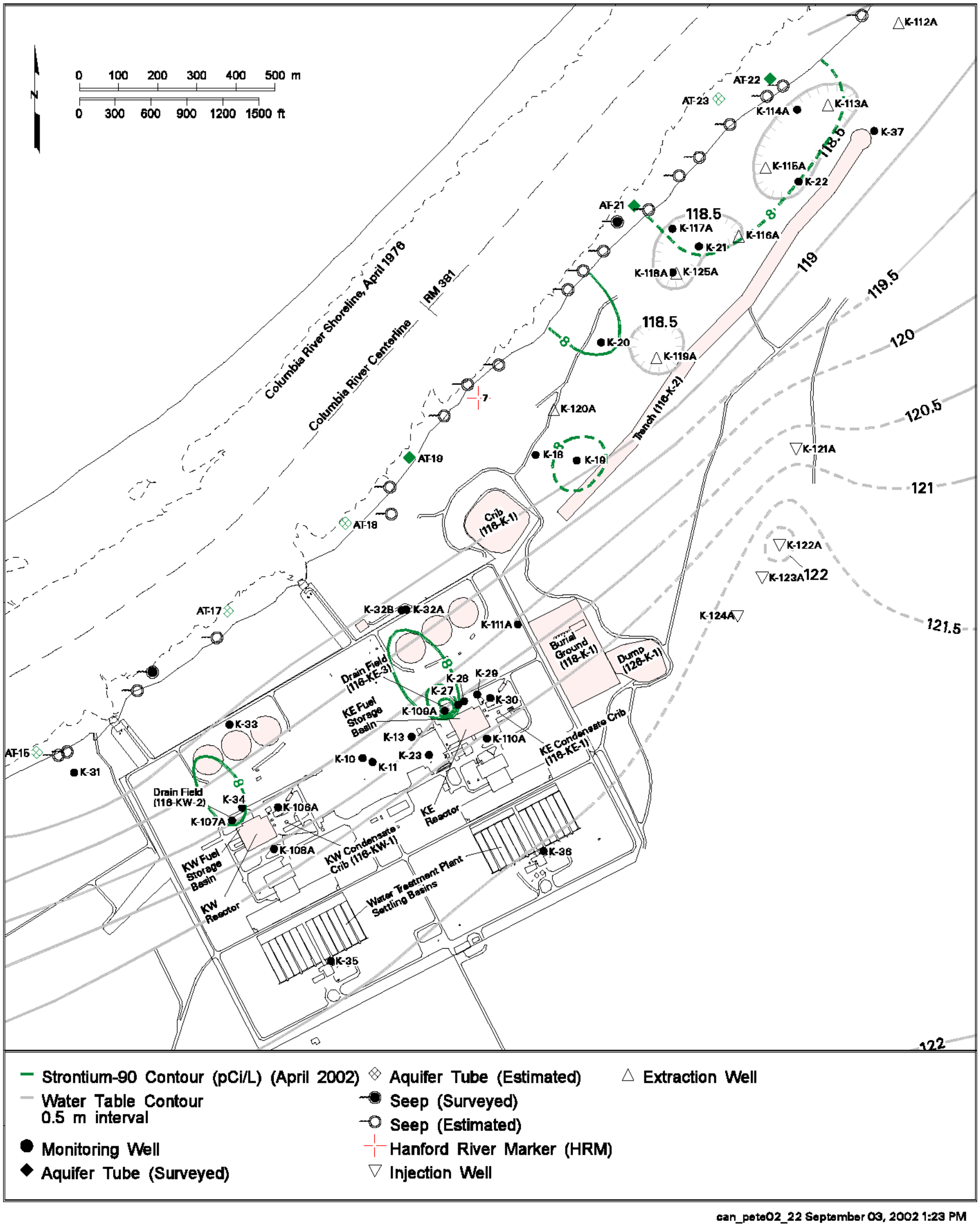

Figure 3.9. Strontium-90 Distribution in 100-K Area Groundwater, FY 2001

northwest corner of the KE Reactor building have appeared fairly recently. This is likely the result of remobilizing vadose zone strontium-90 by infiltration of water from overlying fire suppression water utility lines and hydrants.

3.7 Water-Quality Indicators Unique to Potential Sources

Historical and newly collected groundwater quality data were reviewed in an attempt to define unique signatures for the well-documented sources for tritium contamination, i.e., the KE Basin and KE Condensate Crib. For past leakage from the KE Basin, tritium and technetium-99 are mobile in groundwater and have been demonstrated to be useful indicators for the presence of shielding water in groundwater. Significant quantities of other radionuclides in shielding water, such as strontium-90 and cesium-137, are less mobile and have not yet been distributed widely in groundwater as a result of past leakage.

Effluent disposed to the KE Condensate Crib contained tritium and carbon-14. Carbon-14 does not migrate as freely in groundwater as does tritium because of geochemical interaction with carbonate minerals. However, carbon-14 is believed to be a unique indicator for the condensate crib source.

Technetium-99 has not been detected in groundwater samples from well 199-K-111A, and carbon-14, while detectable, is at relatively low concentrations and its historical trend does not match the increasing tritium trend (Figure 3.10). To date (July 2002), no other constituents in groundwater have revealed a rapidly increasing concentration trend that correlates with the changing tritium trend in this well.

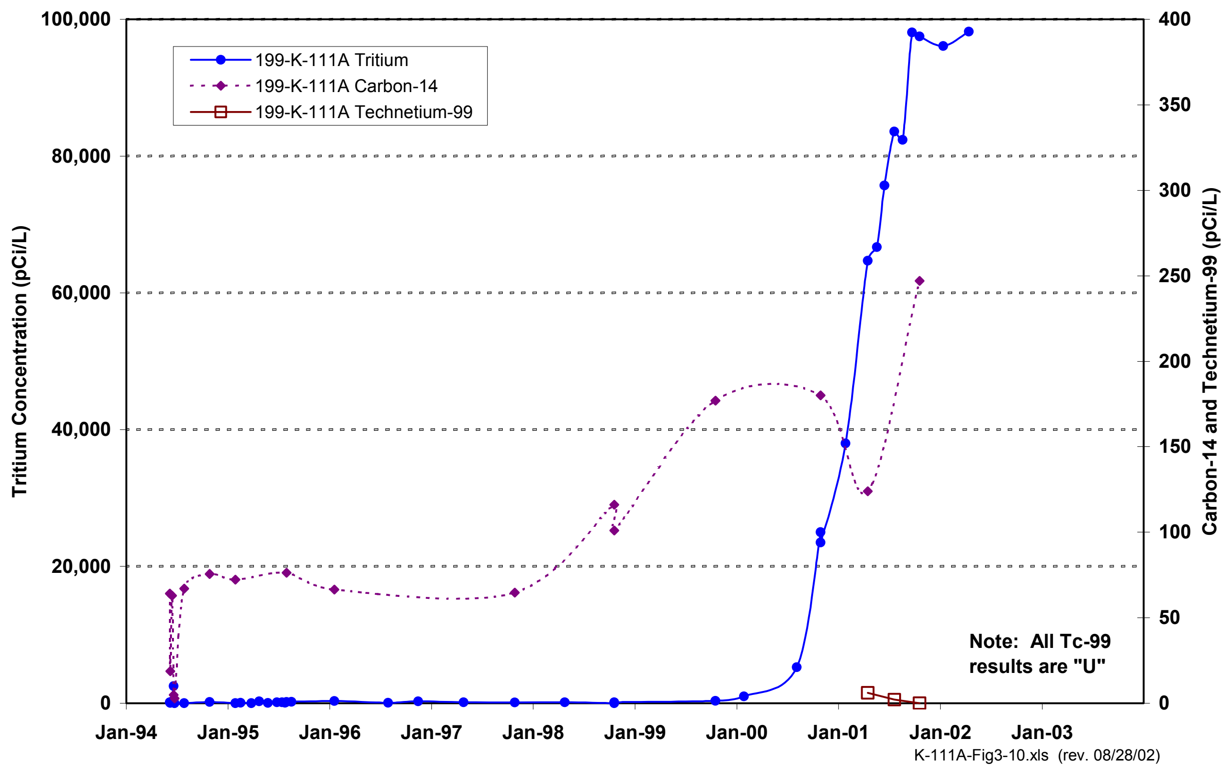

Figure 3.10. Tritium, Carbon-14, and Technetium-99 in Well 199-K-111A

4.0 Groundwater Flow Direction and Gradient

The investigation of groundwater movement near the KE Reactor complex and nearby 100-K Burial Ground included a trend-surface analysis of water-level data from several wells located in the area. Direction and gradient for groundwater flow can be determined by analysis of the hydraulic head at three or more locations, using trigonometric relationships to calculate the groundwater-flow vector. Trend-surface analysis has been used on two different data sets: (1) a collection of historical steel tape measurements and (2) newly collected hourly data obtained from pressure transducers.

4.1 Historical Water-Table Elevation Data

Water-table elevation data for wells 199-K-30, 199-K-111A, and 199-K-32A were used to calculate hydraulic gradient direction and steepness. The time period of the data set is June 1994 to January 2001. Hydrographs for these three wells are shown as gray lines in Figure 4.1 (see Figure 1.1 for well locations). Not all of the historical data for these three wells were used to compute flow direction and azimuth; only measurement sets taken within a three-day time window were included in the calculations (symbols along hydrographs in Figure 4.1). The data used, the calculated gradient direction (azimuth in degrees relative to true north), and the gradient steepness are listed in Table 4.1. The flow vectors for direction and relative gradient steepness are shown in Figure 4.2.

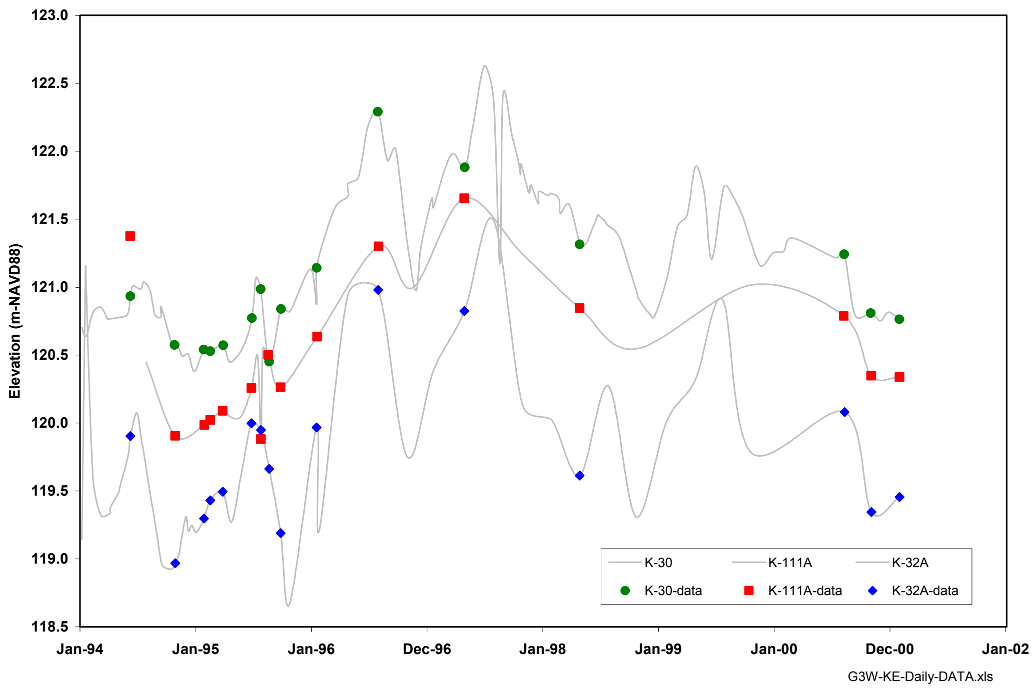

Figure 4.1. Hydrographs for Three Wells Used to Determine Flow Direction from Historical Depth-to-Water Data

Table 4.1. Results of Trend-Surface Analysis for Water Level Data

Well 199-K-30		Well 199-K-111A		Well 199-K-32A		Azimuth (Deg. True)	Gradient
Elev. (m)	Date	Elev. (m)	Date	Elev. (m)	Date		
120.933	9-June-94	121.375	8-Jun-94	119.903	9-Jun-94	*266*	*0.0053*
120.574	26-Oct-94	119.906	28-Oct-94	118.968	28-Oct-94	329	0.0053
120.540	26-Jan-95	119.986	28-Jan-95	119.297	27-Jan-95	332	0.0042
120.528	16-Feb-95	120.022	16-Feb-95	119.431	16-Feb-95	334	0.0037
120.571	29-Mar-95	120.089	27-Mar-95	119.495	27-Mar-95	332	0.0036
120.772	27-Jun-95	120.257	26-Jun-95	119.998	26-Jun-85	*350*	*0.0030*
120.985	25-Jul-95	119.882	26-Jul-95	119.949	26-Jul-95	*10*	*0.0056*
120.452	21-Aug-95	120.501	18-Aug-95	119.662	21-Aug-95	*286*	*0.0030*
120.839	27-Sep-95	120.263	26-Sep-95	119.190	26-Sep-95	323	0.0053
121.141	18-Jan-96	120.635	18-Jan-96	119.967	17-Jan-96	331	0.0039
122.290	29-Jul-96	121.299	31-Jul-96	120.979	30-Jul-96	*356*	*0.0054*
121.881	29-Apr-97	121.653	28-Apr-97	120.824	28-Apr-97	310	0.0034
121.314	27-Apr-98	120.845	27-Apr-98	119.614	27-Apr-98	316	0.0055
121.241	9-Aug-00	120.787	8-Aug-00	120.080	10-Aug-00	327	0.0038
120.808	1-Nov-00	120.348	2-Nov-00	119.345	3-Nov-00	320	0.0047
120.763	30-Jan-01	120.339	31-Jan-01	119.455	31-Jan-01	321	0.0042
Average: (most frequent)		*Average: (most frequent)*		*Average: (most frequent)*		*Average: (most frequent)*	*Average: (most frequent)*
120.927		120.443		119.606		325	0.0043
Average: (overall)		*Average: (overall)*		*Average: (overall)*		*Average: (overall)*	*Average: (overall)*
120.977		120.512		119.760		326	0.0040

Note: Outlier values for azimuth and gradient are shown in *small italics*. These values are not included in the "most frequent" average values.

The calculated direction of groundwater flow downgradient from the KE Reactor complex is most frequently northwesterly (average azimuth 325 degrees) toward the Columbia River, with gradients ranging between 0.0034 to 0.0055. Two groups of outlier vectors are present: one indicating a more westerly direction and a second indicating a more northerly direction. Because these water-level measurements were not made simultaneously in all three wells, it is suspected that these outliers represent measurements made during periods of rapidly changing water-table elevations.

Immediately following the seasonal high river discharge that typically occurs during late May and early June, there is some evidence to indicate a temporary shift to a more northerly groundwater flow direction (Figure 4.3). This shift appears to last for approximately one month, thus providing a limited period of time for a plume to be displaced a significant distance from its normal course. Assuming this shift is real and not the product of non-simultaneous water-level measurements, the amount of plume displacement that would occur is minimal. For example, assuming a flow velocity of 0.12 meter (0.4 foot) per day for the area, a plume edge might be displaced only 3.7 meters (12 feet) to the east of its normal northwesterly course during a one-month period (i.e., July).

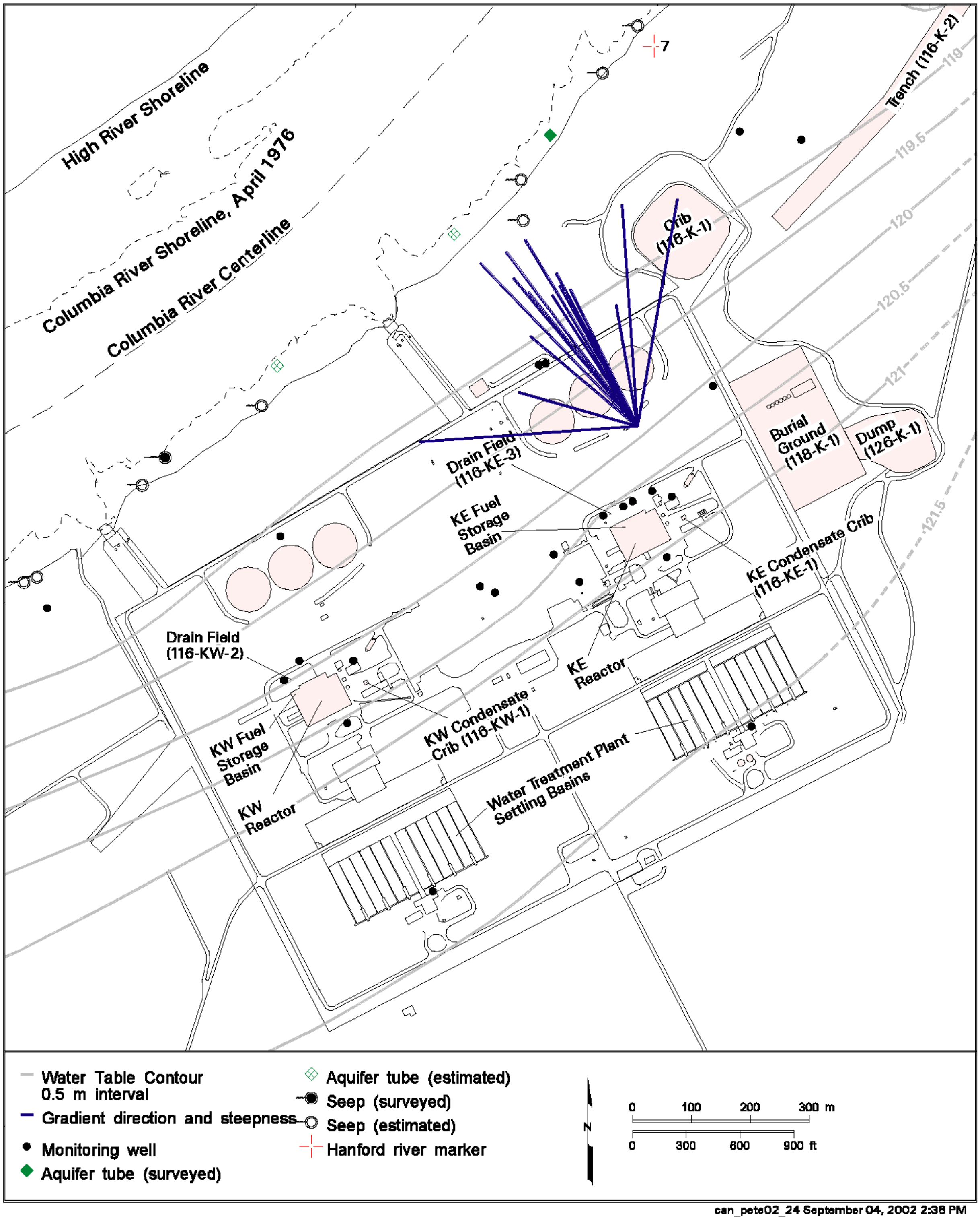

Figure 4.2. Flow Vectors Determined from Historical Depth-to-Water Data

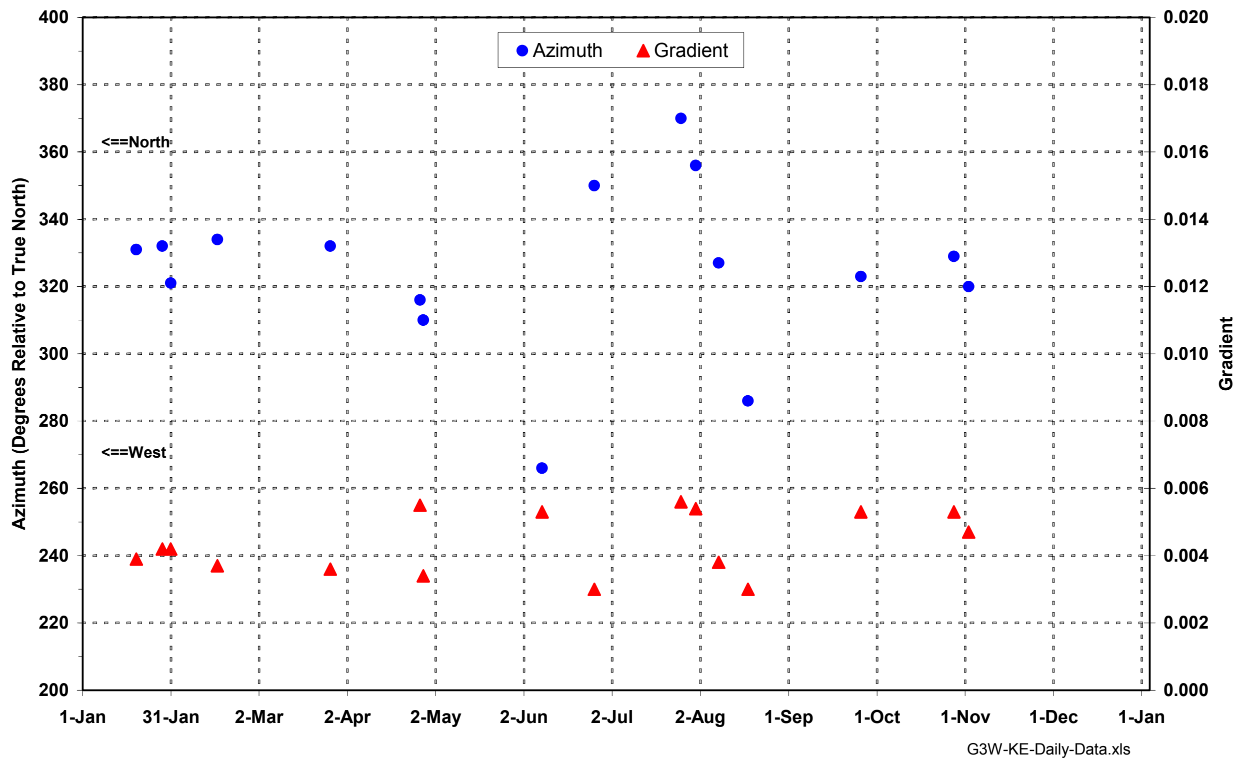

Figure 4.3. Monthly Variability of Flow Direction and Gradient

A similar analysis of flow direction between the KE Reactor building and the Columbia River was performed during the data quality objectives process that supported the original K Basins groundwater monitoring plan (Johnson et al. 1995, pp. 3-7 to 3-11). That analysis included data for high (June) and low (September) water-table conditions during 1994. Patterns were drawn on maps that indicated the ranges of flow direction from various sources for tritium, as inferred from the 1994 water-table elevation data (see Figure 3.5). It can be inferred from their analysis that tritium from the nearest upgradient source would not pass by well 199-K-111A, which lies to the east of the predicted pathline corridor. However, the predicted corridors do not consider (a) lateral diffusion and (b) preferential pathways created by heterogeneity in aquifer hydraulic properties, and possibly by underground engineered structures.

4.2 New Pressure Transducer Data

Hourly data from pressure transducers installed in the same wells from which historical water-table elevation data were used (i.e., wells 199-K-30, 199-K-111A, and 199-K-32A) and nearby well 199-K-18 were collected during the period August 31 to September 17, 2001, which is representative of low river stage conditions. Trend-surface analyses using these data were performed for two groupings: (1) wells 199-K-30, 199-K-111A, and 199-K-32A and (2) wells 199-K-32A, 199-K-111A, and 199-K-18. The flow vectors are shown in Figure 4.4.

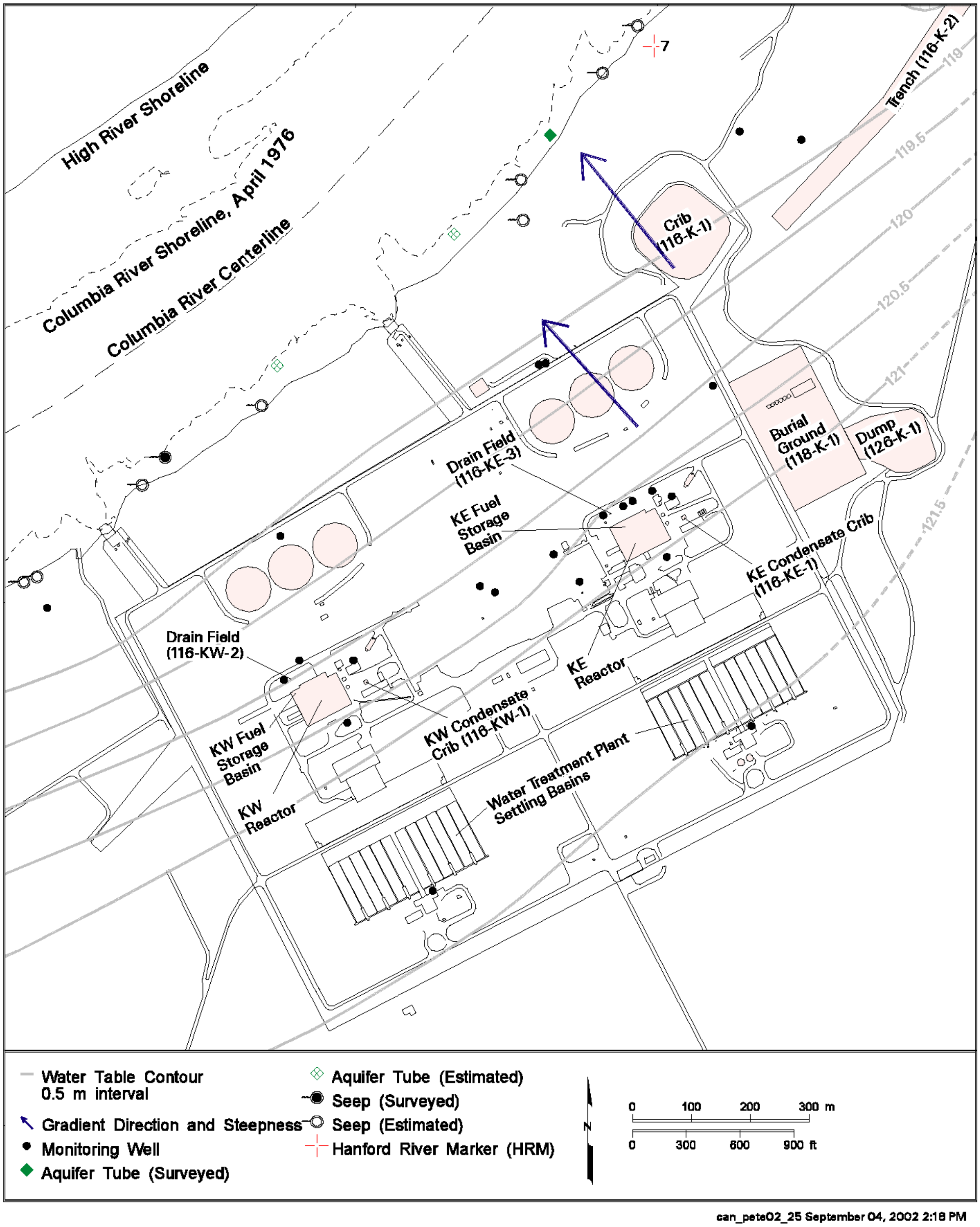

Figure 4.4. Flow Vectors Determined from Hourly Elevation Data

For the first group of three wells, the hourly data indicate an average flow direction of 318 degrees, which is consistent with the average direction determined from historical data. The variability in direction during the several week period is limited to plus-or-minus approximately 3 degrees from the average. The gradient ranged between 0.0045 and 0.0049, which is also within the range indicated by the historical data. The second group of three wells indicated very similar results: average flow direction of 321 degrees, plus-or-minus approximately 2 degrees, with the gradient between 0.0046 and 0.0052.

4.3 Discussion and Summary

An in-depth discussion of the trend-surface analysis method and its underlying assumptions is presented in Spane (1999, pp. 5.1 to 5.6). The key assumptions and influences on uncertainty include:

- Hydraulic head data used for groundwater-flow analysis must be from wells that (a) monitor the same hydrologic unit and (b) are situated along the same groundwater-flow path.

- Aquifer properties should be reasonably consistent within the area monitored.

- Wells monitor a planar potential surface and vertical hydraulic head gradients are minimal.

- The dynamic response characteristics for all monitoring wells are similar. Any change to hydraulic head within the hydrologic unit affects all wells equally. Well bore storage and skin effects are similar for all wells involved in the analysis.

- Hydraulic head measurements for wells used in the groundwater flow analysis should be made as closely in time to each other as possible. This is especially important where pressure fluctuates frequently in the aquifer (e.g., near the Columbia River) or where atmospheric pressure changes are a significant component of hydraulic head change (e.g., Hanford Site Central Plateau).

- When the objective is to describe the path and extent of a contaminant plume, the temporal effects of external stresses (e.g., river-stage fluctuations and barometric pressure variations) should be removed from the well measurements used to determine hydraulic head. Removal of temporal external stress effects permits determining the average groundwater flow characteristics over the period of measurement, which is representative of long-term contaminant plume direction and rate-of-movement.

The historical water-table elevation data used for the preceding analysis have not had the temporal effects of external stresses removed, and only the hourly data (Section 4.2) meet the criteria for using data collected simultaneously at each monitoring well. The remaining assumptions for trend-surface analysis, however, are reasonably well met. Even though these analyses contain uncertainty because of not meeting some of the required conditions, the results are nevertheless considered useful in providing insight on groundwater flow direction and variability.

The gradient vectors calculated from historical and recent hourly data provide a consistent representation of direction and gradient. The vectors are also consistent with flow direction inferred from previously published water table contour maps (e.g., Hartman et al. 2002, Plate 1). The general northwest direction supports the hypothesis that tritium plumes emanating from known sources near the KE Reactor are unlikely to move laterally such that they pass by well 199-K-111A.

Following the format used previously to describe “flow direction corridors” (Johnson et al. 1995, pp. 3-7 to 3-11; see Figure 3.5 in this report), an updated version of the flow direction corridors map is shown in Figure 4.5. In the updated version, the position of potential plumes created in the past from their respective sources is illustrated along each “corridor.” (Note: As in the original representation, lateral dispersion of plumes perpendicular to flow direction has not been considered, but is assumed to be small relative to dispersion in the direction of flow.)

Departures from the general northwest direction may occur for a brief period immediately following the seasonal high (i.e., during the period of lowest river discharge). The potential shift is to a more northerly direction, although there is considerable uncertainty associated with this interpretation because of the very limited existing data. In any event, the duration of this potential shift does not appear to be sufficient to displace a plume a significant distance.

Trend-surface analysis is an effective method to obtain information on hydraulic gradient slope and direction. By collecting hydraulic head data simultaneously at multiple locations over a full seasonal cycle of the river, an accurate characterization of the range in groundwater flow patterns can be developed. The results can be used to help determine the need for additional monitoring wells in local areas of interest.

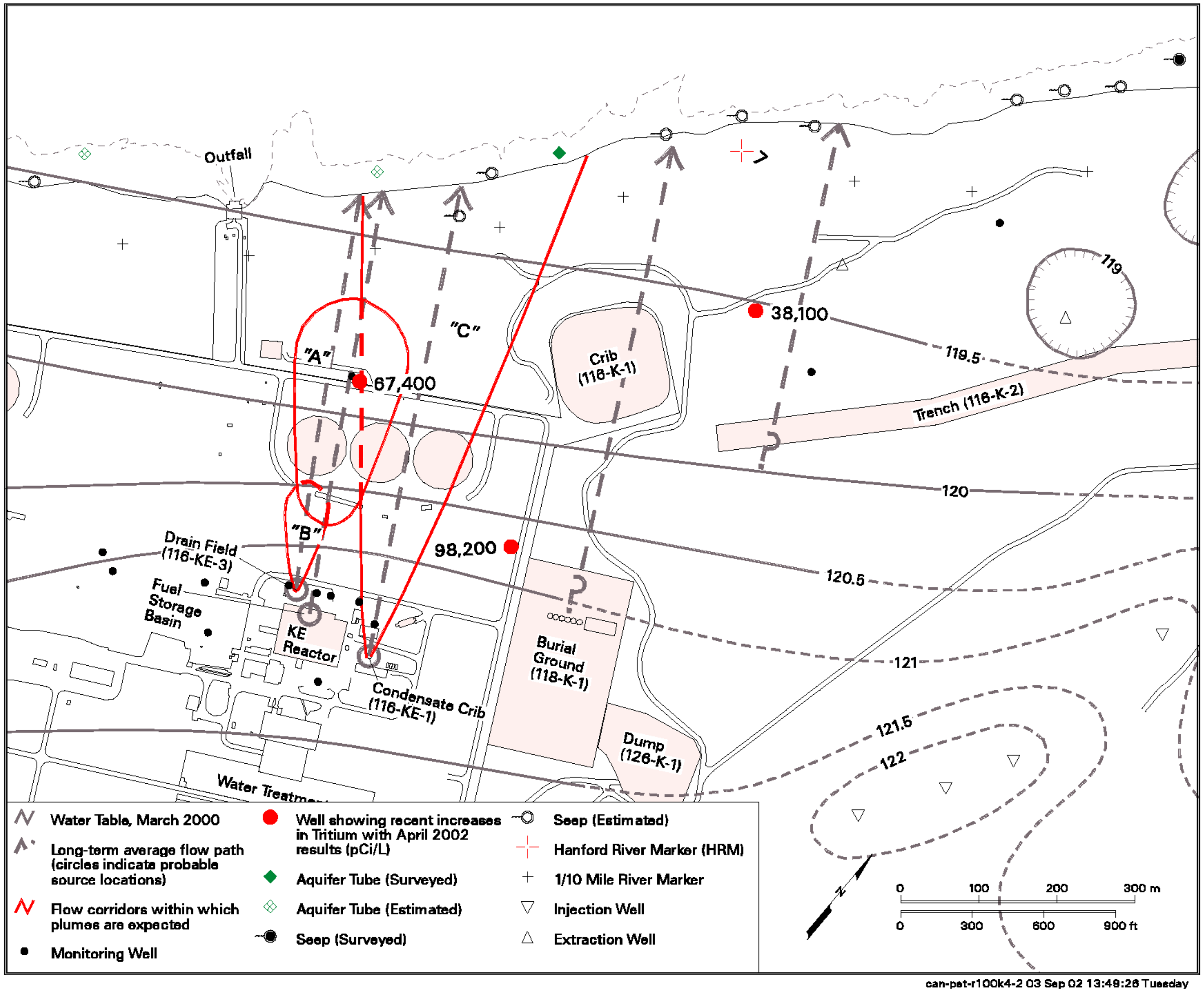

Figure 4.5. Updated Groundwater Flow Corridors Downgradient of KE Basin

5.0 Potential Mound Buildup Beneath Injection Wells

This section describes the water table mound created by injection of treated effluent from the interim remedial action addressing chromium contamination near the 100-K Trench. The groundwater mound is of hydrologic importance due to its potential influence on the direction and rate of flow for groundwater in the vicinity of well 199-K-111A and the 100-K Burial Ground.

5.1 Background

The 100-KR-4 pump-and-treat system is designed to withdraw contaminated groundwater from the unconfined aquifer within the 100-K Area using a series of extraction wells located between the Columbia River and the 100-K Trench (Figure 5.1). The contaminated water is piped to a surface treatment facility for chromium removal and the treated water is then re-injected at upgradient wells 199-K-121A, 199-K-122A, 199-K-123A, and 199-K-124A. The pump-and-treat system was put into operation in October 1997 and has run with varying degrees of online production performance to present. A description of yearly performance of the 100-KR-4 pump-and-treat system is contained in annual DOE reports (e.g., DOE/RL 1999c; DOE/RL 2000; DOE/RL 2001; DOE/RL 2002).

The extraction and injection of groundwater have the potential to modify the natural groundwater flow and contaminant transport characteristics in the area. This section presents a preliminary evaluation of the possible characteristics of a groundwater mound associated with injection wells within the 100-KR-4 pump-and-treat system. Specifically, the possible lateral extent and shape of the groundwater mound are examined, and the reliability of injection well elevations as indicators of actual mound height is discussed.

5.2 Analysis Assumptions

To evaluate characteristics of a recharge mound associated with injection practices at the 100-KR-4 pump-and-treat system, the following simplifying assumptions were used:

- An infinite, unconfined aquifer that initially is of uniform thickness
- A horizontal water table
- Three injection wells, equally spaced (100 meters [328 feet] distance) located along a linear azimuth direction of 330 degrees (note: North = 0°; East = 270°); an injection rate of 150 liters (39.6 gallons) per minute at each well
- Aquifer properties: transmissivity (T) = 100 and 225 square meters (1,076 and 2,421 square feet) per day; thickness (b) = 10 meters (32.8 feet); specific storage (S_s) = 1.5 x 10^{-5}, specific yield (S_y) = 0.15; vertical anisotropy (K_D) = 0.1; horizontal anisotropy (K_x/K_y) = 1.0

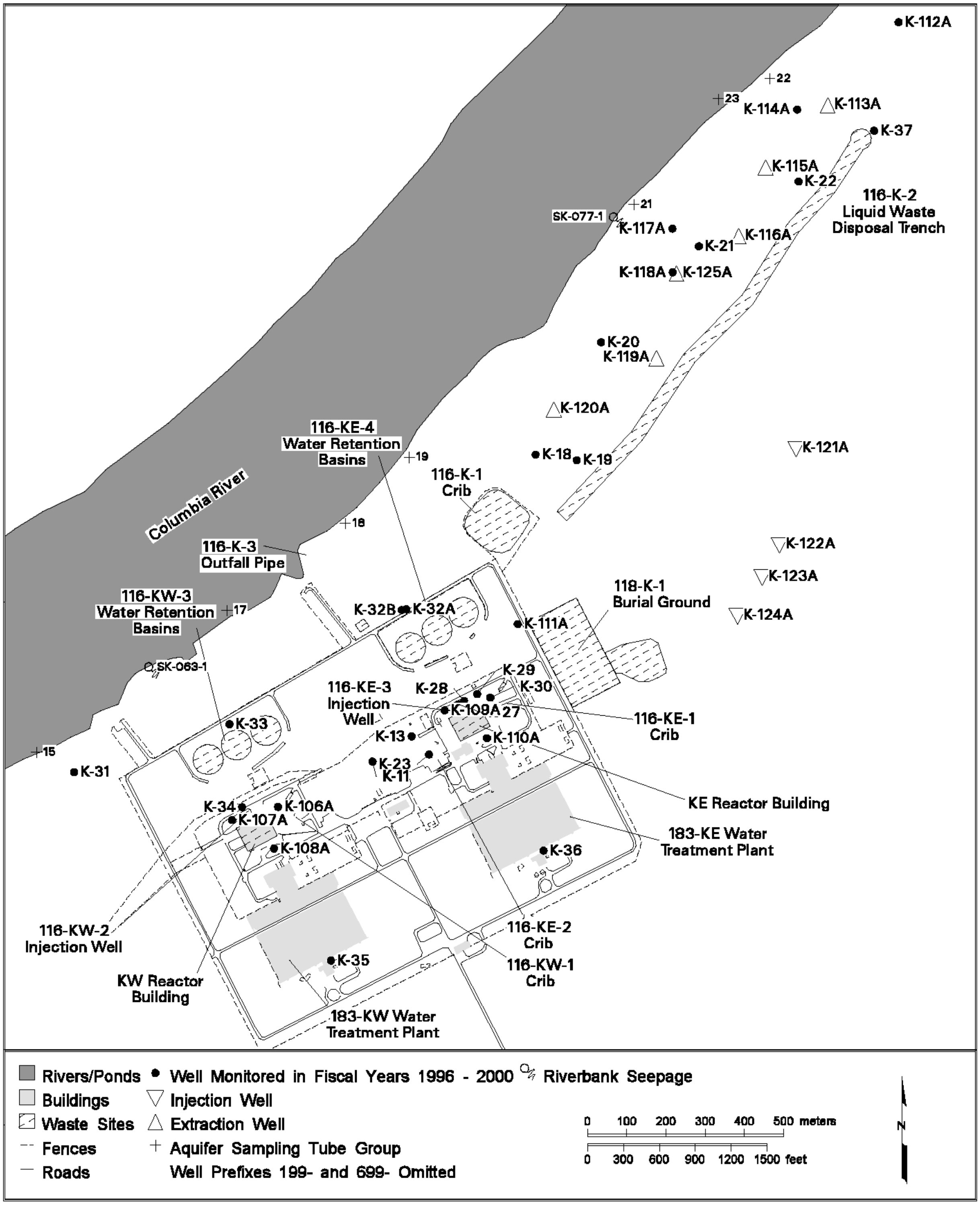

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Figure 5.1. Location Map Showing Wells Used in 100-KR-4 Pump-and-Treat Network

The simplifying assumptions were made to facilitate the analytical model approach discussed in the following paragraphs. The analytical method used is preferable (i.e., in comparison to numerical methods) for this evaluation, because of its ability to simulate both well and aquifer behavior. For this preliminary assessment, no complex boundary conditions (e.g., river boundary, irregular aquifer base) were considered. In addition, a horizontal water-table condition was used to determine the characteristics of the recharge mound solely attributable to injection well activities. The presence of a sloping water table and location of distant extraction wells would distort the imposed injection mound described in this chapter.

The characteristics of the three injection wells (e.g., spacing, azimuth direction) examined in this investigation were designed to simulate injection performance imposed by wells 199-K-122A, 199-K-123A, and 199-K-124A. Inclusion of a fourth injection well to simulate the impact imposed by the more distant well 199-K-121A well was not considered in this initial mound evaluation. Because of its distance and azimuth characteristics, the impact of a fourth injection well would likely extend and broaden the recharge mound in its direction; however, the maximum recharge height would remain centered in the vicinity of the three, more-closely spaced injection wells. Because of the secondary importance and the anticipated increase in effort to include the impact of the more distant well, a fourth injection well was not included in this initial study. The injection rate of 150 liters (39.6 gallons) used in the study was arbitrarily selected, but compares favorably with estimated average injection rate of 136 and 162 liters (35.9 and 42.8 gallons) per minute that occurred during 1998 and 1999, respectively, for the three injection well locations (DOE/RL 1999; DOE/RL 2000).

The aquifer properties used in this evaluation are consistent with values assigned for the unconfined aquifer in this region of the Hanford Site. Originally, numerical studies of the performance of the 100-KR-4 pump-and-treat system used transmissivity values for the injection well region that were based solely on developmental pumping drawdown results. Transmissivity estimates for unconfined aquifers based on specific capacity data, however, may be subject to considerable error as discussed in Razack and Huntley (1991) and Meier et al. (1999). These various sources of error generally produce an underestimate of transmissivity, particularly for unconfined aquifer conditions. The most recent estimated value of transmissivity (i.e., approximately 100 square meters [1,076 square feet] per day) for the injection well area that was used by McMahon[(a)] was obtained through numerical model calibration to observed injection well water levels. This value represents an increase for the original estimated values for transmissivity for the injection well site location. As will be shown, however, injection well water levels may not provide a true depiction of water-table conditions within the aquifer (i.e., the elevations within the well are higher); and, therefore, calibrated transmissivity values likely underestimate actual aquifer conditions. For these reasons in addition to a transmissivity value of 100 square meters (1,076 square feet) per day, a higher transmissivity value of 225 square meters (2,421 square feet) per day was also used for comparison purposes of possible mound buildup within the injection well area. For an initial aquifer thickness of 10 meters (32.8 feet) (based on geologic log information for this area), hydraulic conductivity values of 10.0 and 22.5 meters (32.8 and 73.8 feet) per day are, therefore, indicated for the injection well region.

(a) Technical Memorandum IOM 044735 from M. H. Sturges to A. J. Knepp (Bechtel Hanford, Inc.), author M. J. McMahon, *Updated Predictive Model to the 100-KR-4 Operable Unit Interim Action Pump and Treat*, dated May 2, 1997.

These hydraulic conductivity values fall within the middle to upper range of hydraulic conductivities (2.8 to 26.5 meters [9.2 to 86.9 feet] per day) based on specific capacity data for wells in the vicinity of the 100-K Trench, as reported in McMahon[(a)].

5.3 Approach

Because the accuracy and ease of implementation, an analytical method approach was adopted for assessing potential mound buildup in the 100-KR-4 injection well area. The induced mound buildup was determined for each injection well using the WTAQ3 computer program described by Moench (1997). WTAQ3 can be used to simulate drawdown during pumping tests over a wide range of test and aquifer conditions, including partially penetrating wells, confined or unconfined aquifer models, and wellbore storage at both the stress (pump) and observation (monitor) well locations. Predicted mound buildup was assumed to be equivalent to the drawdown predicted using the WTAQ3 program, minus the effects of increasing aquifer transmissivity (i.e., due to increasing aquifer thickness) attributed to the saturation of the overlying vadose zone due to mound buildup. The effects of increasing aquifer transmissivity were accounted for by modifying the relationship originally introduced by Jacob (1963) to describe drawdown within an unconfined aquifer (s_u), which is expressed as the sum of the drawdown associated with confined aquifer flow (s_c), plus the drawdown associated with aquifer dewatering (s_D), i.e., due to decreasing aquifer transmissivity:

$$s_u = s_c + s_D \tag{5.1}$$

where $s_D = s_c^2/2b$
b = initial aquifer thickness.

For simulation of injection well mound buildup, the predicted buildup (i.e., drawdown) was corrected for the effect of increasing aquifer transmissivity, using the correction (i.e., subtracted) as originally presented in Equation (5.1). The composite mound response imposed by the three wells was generated by superimposing the combined buildup effect along an axis line connecting the injection well centers (azimuth = 330 °; North = 0°; East = 270°), and along a line perpendicular to this well axis line constructed through the middle injection well location (azimuth = 60°). This superposition procedure is similar to the approach taken by Kasenow (2001) to predict the composite response of multiple wells within an unconfined aquifer setting.

5.4 Results

To evaluate the effect of hydraulic properties on predicted mound buildup, the effects of transmissivity and specific yield on areal response are shown in Figures 5.2 and 5.3, respectively. The responses show the response characteristics surrounding a single injection well, after 1 month and 1 year of injection. As shown in Figure 5.2, a much higher mound and a significantly larger area of higher

(a) Technical Memorandum IOM 044735 from M. H. Sturges to A. J. Knepp (Bechtel Hanford, Inc.), author M. J. McMahon, *Updated Predictive Model to the 100-KR-4 Operable Unit Interim Action Pump and Treat*, dated May 2, 1997.

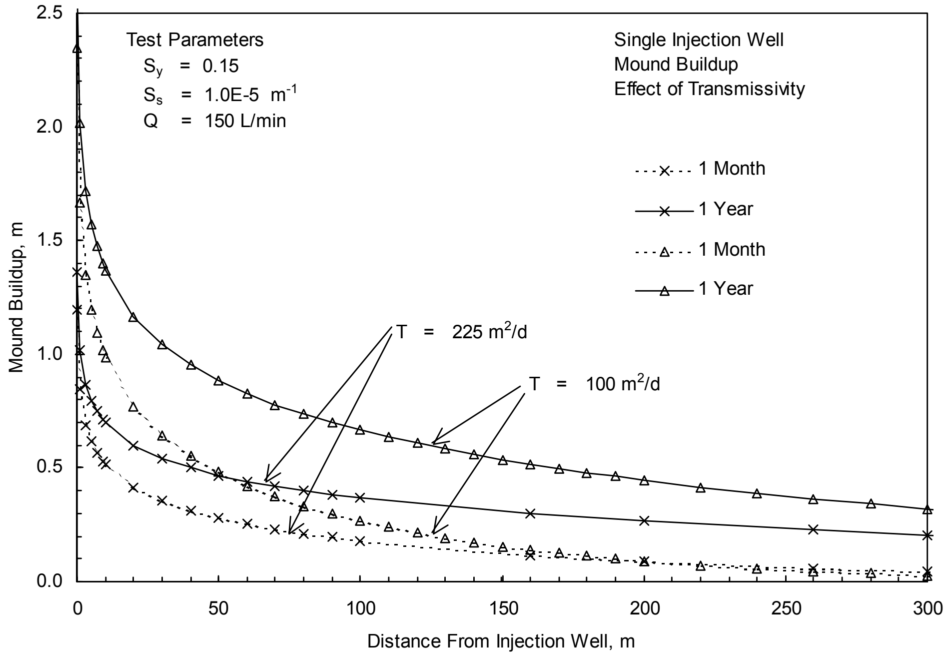

Figure 5.2. **Effect of Transmissivity on Predicted Mound Buildup Associated with a Single Injection Well for 1 Month and 1 Year Injection Times**

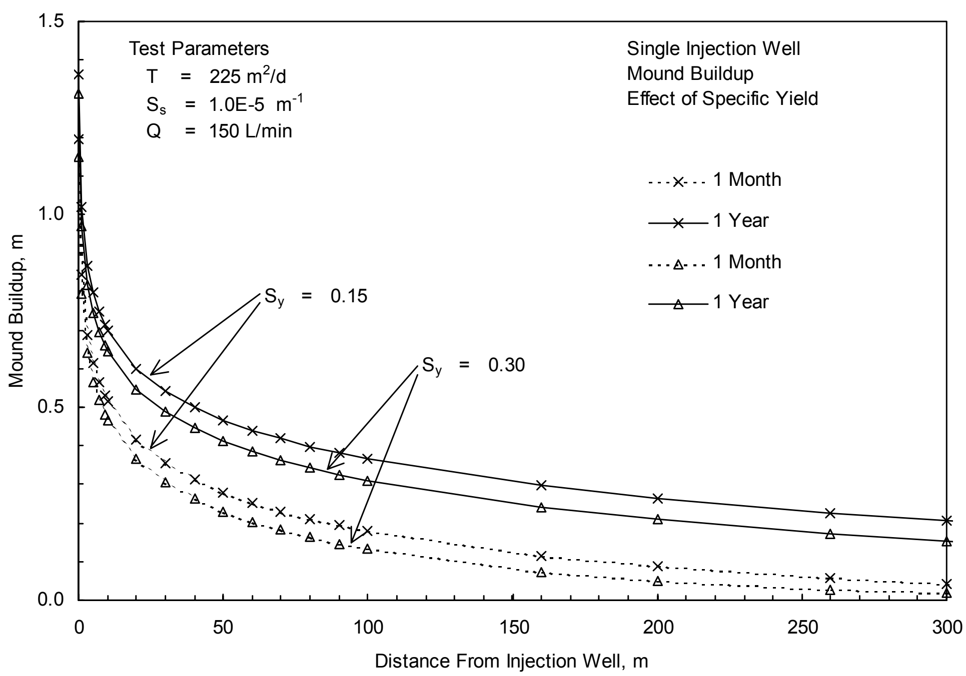

Figure 5.3. **Effect of Specific Yield on Predicted Mound Buildup Associated with a Single Injection Well for 1 Month and 1 Year Injection Times**

hydraulic gradients (i.e., water-table slope) surrounding the injection well are indicated for the lower transmissivity condition (100 m^2/d). With distance (not shown), mound buildup is less for an aquifer with a lower transmissivity, indicating a more broad mound effect within aquifers having higher transmissivities.

Figure 5.3 shows the influence of specific yield on mound build up characteristics. In contrast to transmissivity, the impact of varying specific yield is relatively uniform away from injection well centers, with higher specific yield values associated with lower mound buildup. A comparison with transmissivity effects in Figure 5.2, also indicate that specific yield exerts considerably less impact on mound shape characteristics (note: different y-axis scale magnitudes for Figures 5.2 and 5.3).

Figure 5.4 shows the effect of injection time on mound buildup. As shown, mound buildup continues to increase with time, but at a significantly decreasing rate. For example the predicted mound buildup at distances of ≤300 meters (984 feet) from the injection well, increases only between 10 to 50% between 1 year and 4 years of injection (note: larger percentage increases occurring with distance from injection well).

Figures 5.5 and 5.6 show the predicted composite mound buildup produced by the three injection wells along an axis line connecting the well centers (azimuth = 330°), and along a line perpendicular to this line (azimuth = 60°), intersecting the middle injection well (i.e., 199-K-123A). The composite mound characteristics shown in Figures 5.5 and 5.6 were generated based on transmissivity values of 100 and 225 square meters (328 and 738 square feet) per day, respectively, for an injection time of 1 year. For direct comparison purposes, the predicted composite mound buildup for the two transmissivity values examined is presented for each azimuth axis direction in Figures 5.7 and 5.8.

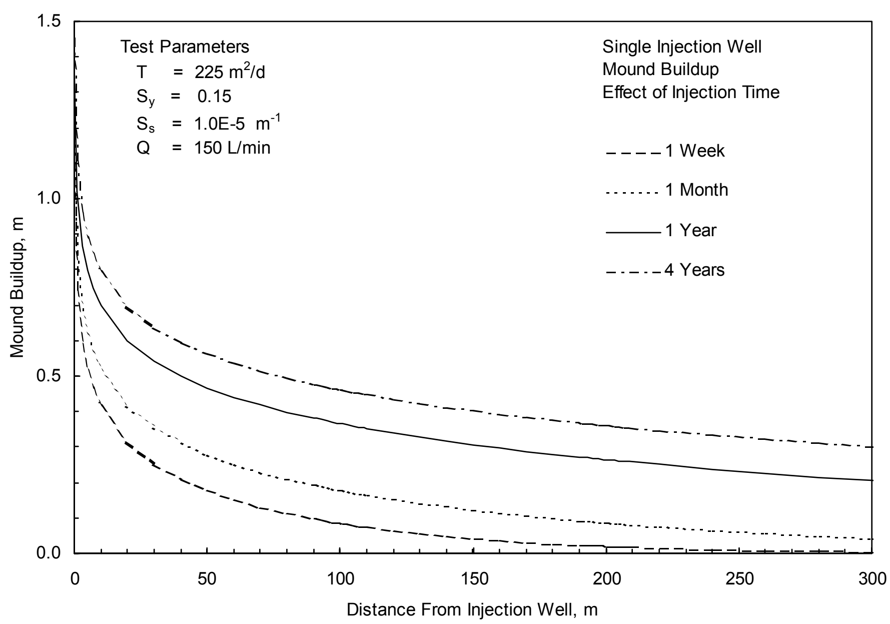

Figure 5.4. Effect of Injection Time on Predicted Mound Buildup Associated with a Single Injection Well

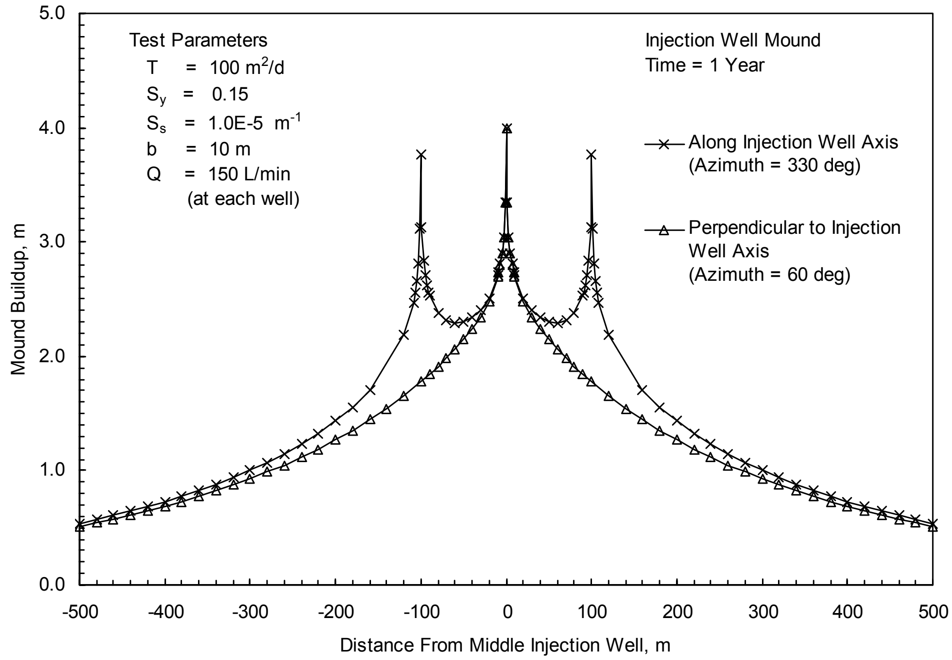

Figure 5.5. Predicted Composite Mound Buildup Associated with Three Injection Wells: Transmissivity = 100 m^2/d

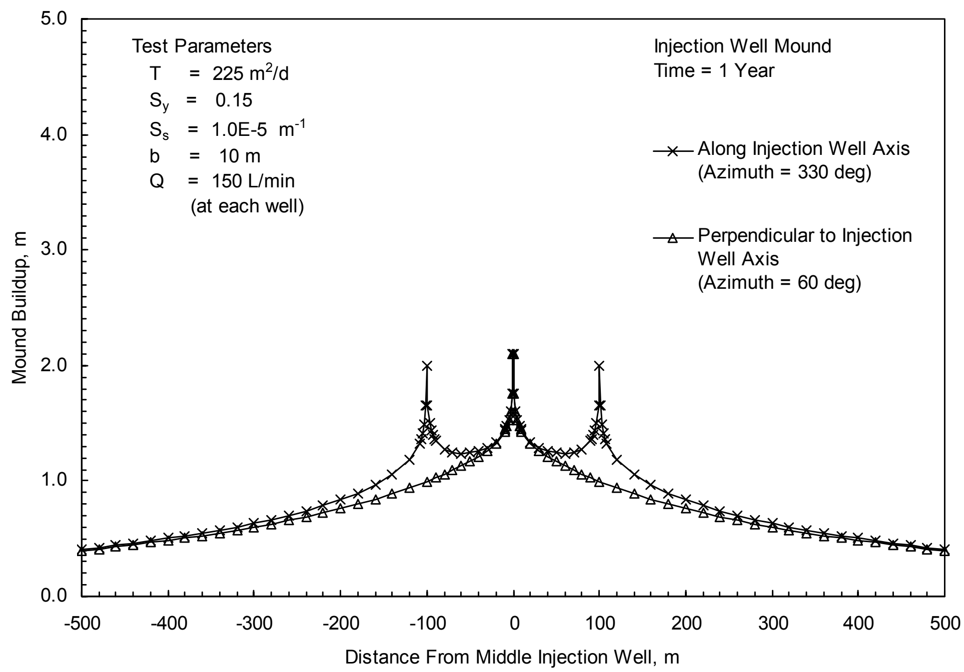

Figure 5.6. Predicted Composite Mound Buildup Associated with Three Injection Wells: Transmissivity = 225 m^2/d

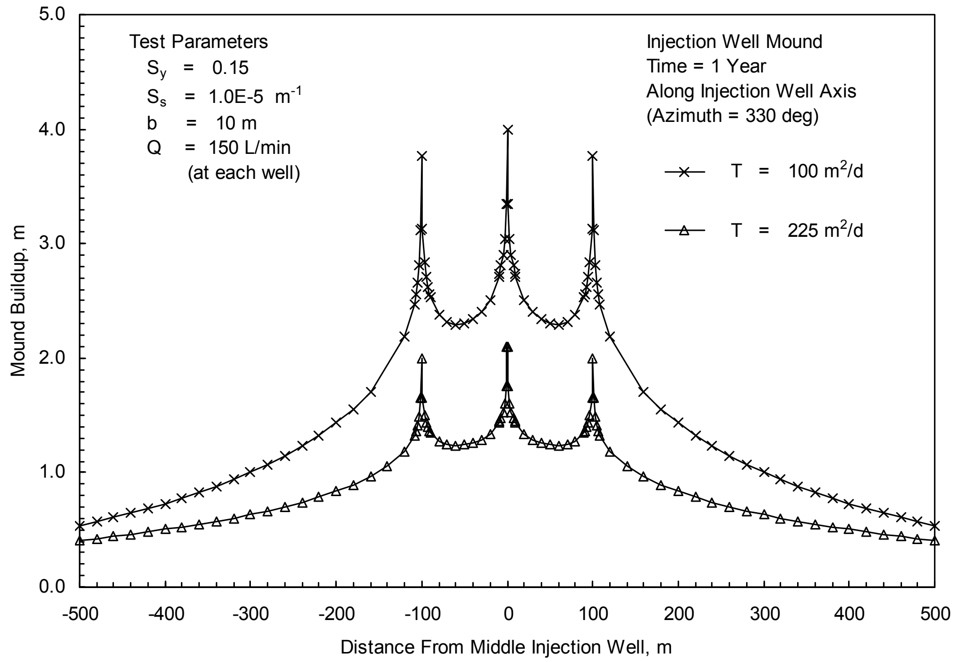

Figure 5.7. Predicted Composite Mound Buildup Associated with Three Injection Wells: Along Well Axis Azimuth (330 degrees)

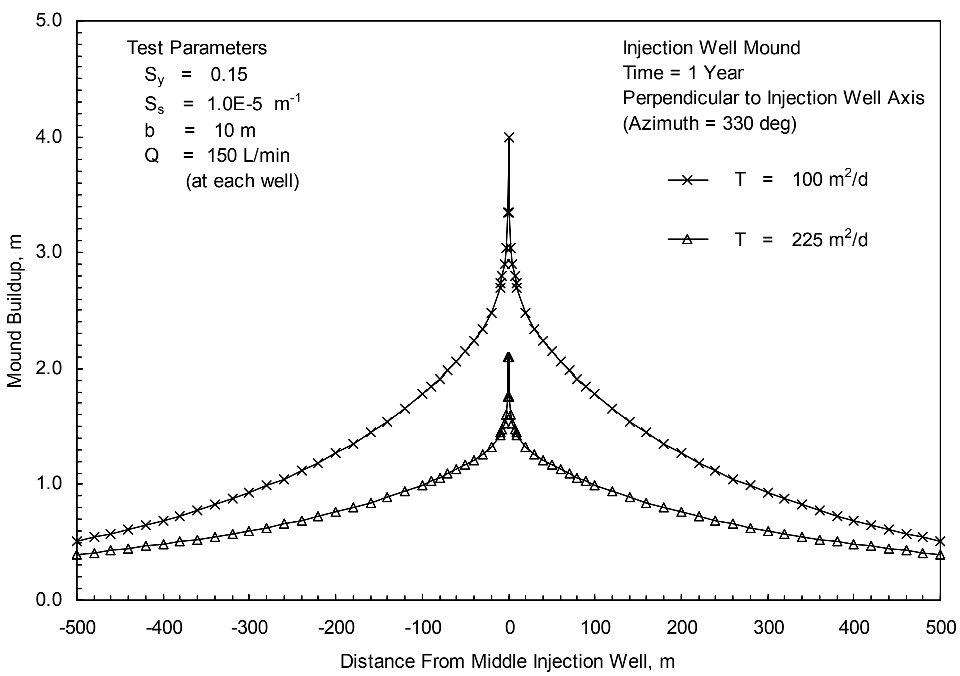

Figure 5.8. Predicted Composite Mound Buildup Associated with Three Injection Wells: Perpendicular to Well Axis Azimuth (60 degrees)

The mound plots in Figures 5.5 through 5.8 exhibit several salient features. First, mound height is more pronounced along the axis line connecting the injection well centers (see Figures 5.5 and 5.6). Second, because of the higher mound height, hydraulic gradient conditions (i.e., the water-table slope) are higher over a larger area for the lower aquifer transmissivity case (see Figures 5.7 and 5.8). Third, water-levels exhibited within the injection wells are elevated considerably over actual water-table mound conditions within the aquifer. This is even more pronounced for lower transmissivity aquifer conditions as shown in Figures 5.5 and 5.7. This elevated well height condition (i.e., in comparison to water-table height in the surrounding aquifer) is an artifact of introducing recharge to the aquifer through finite-diameter well sources (i.e., singularity effects). Water-level heights within injection wells, therefore, are not valid representations of average mound height conditions within the surrounding aquifer.

As a means of corroborating the mound heights predicted with the analytical well model (WTAQ3), average mound heights were also estimated using the MOUNDHT program described in Finnemore (1995). This program is based on the Hantush (1967) analytical solution for calculating maximum mound height of the water table from surface recharge sources. Although the recharge source mechanism are different, once the vadose zone becomes saturated, similar mounding heights would be expected. Utilizing the same parameters used in the analytical well model, the total injection rate of 450 liters (118.8 gallons) per minute was applied as an average recharge rate across the 200 meters (656 feet) injection well distance as input to the MOUNDHT program. Based on these inputs, a predicted maximum mound height after one year of recharge was estimated at 1.47 meters (4.82 feet) for a transmissivity of 225 square meters (738 square feet) per day and 2.78 meters (9.1 feet) for a transmissivity of 100 square meters (328 square feet) per day. The MOUNDHT-predicted maximum mound heights compare favorably with the weighted, average mound values calculated with the analytical model of 1.33 meters (4.4 feet) for a transmissivity of 225 square meters (738 square feet) per day and 2.5 meters (8.2 feet) for a transmissivity of 100 square meters (328 feet) per day), which were calculated over the 200 meters (656 feet) inter-well distance.

5.5 Findings and Discussion

The findings listed below are based on the limiting assumptions utilized in this preliminary evaluation. These assumptions were used to simplify the mound assessment process. This preliminary assessment can provide guidance in the design of a more comprehensive, numerical model evaluation of mound development that can incorporate more aspects of the hydrogeologic complexities of the area.

Theoretically after one year, a groundwater mound would be produced from the 100-KR-4 injection well system that could cause hydraulic head increases of ≥0.4 meter (1.3 feet) at radial distances of 500 meters (1,640 feet) from the injection well system center (i.e., well 199-K-123A), with an average (weighted) predicted mound height between the injection wells of between 1.33 to 2.5 meters (4.4 to 8.2 feet) (depending on aquifer transmissivity). The mound would have an elliptical pattern and be elongated parallel to the line of injection wells. This idealized depiction of an injection well mound would be and distorted by a) a sloping water table, b) operating extraction wells, and c) variations in subsurface hydrogeologic properties.

Mound height and areal extent are directly associated with the hydraulic properties of the unconfined aquifer. Transmissivity (the product of hydraulic conductivity and aquifer thickness) has the most profound influence on injection mound shape characteristics. Specific yield (drainage pore volume) exerts a uniform influence on areal mound characteristics, but at a level significantly less than the effect of aquifer transmissivity. Vertical anisotropy (ratio of vertical to horizontal hydraulic conductivity) has essentially no discernable impact on mound buildup (except during transient time periods of less than a month), due primarily to the fully penetrating nature of the injection wells.

Because of their point-source/singularity attributes, water levels measured within injection wells are not quantitative representations of mound characteristics in the surrounding aquifer (e.g., Charbeneau and Street 1979). Efforts to match numerical model head results (which do not include fully-coupled well modules, e.g., MODFLOW), with injection well water-level elevations for calibration of input parameters (e.g., transmissivity) or mound delineation are not recommended. A fully-coupled well module has recently been incorporated in the original STOMP code (White and Oostrom 2000a, 2000b) maintained by PNNL, however, that can be used to simulate well water-level response behavior in complex, unconfined aquifer conditions.

Hydraulic property information for the injection well area is poorly known. No formal hydraulic testing has been performed on any of the 100-KR-4 injection wells. Preliminary hydraulic properties assigned for these wells in earlier numerical modeling of pump-and-treat system performance studies were based on developmental pumping specific-capacity data. Because of the qualitative nature of the developmental pumping data and the questionable reliability of specific capacity (as an indication of hydraulic conductivity) within unconfined aquifers, hydraulic properties within the injection well area should be considered uncertain at this time. Hydraulic property information within the injection well area, however, may be assessed by analyzing buildup/recovery responses at injection well locations immediately following and during extended cessation periods of pump-and-treat system operation. This was shown to be successful in Spane and Thorne (2000) in analyzing well response associated with the 200-ZP-1 pump-and-treat system.

6.0 Helium-3 in Soil Gas Near the 100-K Burial Ground

Previous Hanford Site experience with using helium isotopes in soil gas samples to characterize tritium contamination was applied to the problem of identifying a source for tritium observed in groundwater at well 199-K-111A. Existing soil gas sampling tubes near the well were sampled in July 2001 and the soil gas analyzed for helium isotopes. Re-analyzing samples from this location provided an opportunity to a) determine whether previous distribution patterns still existed, and b) whether helium-3 enrichment had changed in magnitude since the initial analyses in September 1999.

6.1 Background

In 1999, sixteen soil gas sampling points (Figure 6.1) were installed to the north and east of the KE Reactor complex (Olsen et al. 2000). Soil gas samples were collected in September 1999 and analyzed for helium isotopes (helium-3 and helium-4) to calculate helium-3/helium-4 ratios normalized to ambient air concentrations (defined at 1.0). Helium-3/helium-4 ratios ranged from 0.972 to 1.131. The highest helium-3/helium-4 ratios were found in the southeast corner of the survey area, which is adjacent to the 100-K Area Burial Ground. This burial ground received solid waste that included irradiated metallic reactor components during the operating years 1955 to 1971.

There are similarities in construction and use of this burial ground with the 618-11 Burial Ground, where relatively high enrichment of helium-3 was found in soil gas (Olsen et al. 2001). A high concentration tritium plume in the underlying groundwater was also discovered (Dresel et al. 2000). The suspected source for the helium-3 observed in soil gas and for tritium in groundwater is lithium-aluminate target material contained in vertical pipe units and caissons in the 618-11 Burial Ground. The 100-K Burial Ground has similar vertical, cylindrical storage units ("silos") and irradiated lithium-aluminate targets were used in nearby reactors.

One conclusion drawn from the results of the September 1999 study was that no major tritium plume in groundwater, beyond the tritium already mapped by monitoring, was present beneath the survey area. However, the data suggested the possibility of a tritium groundwater plume or a vadose zone source of helium-3 (indicating the presence of tritium) to the southeast of the 1999 survey area, i.e., in the vicinity of the 100-K Burial Ground.

6.2 Current Investigation

In September 2001, soil gas samples were collected from existing tubes located in the vicinity of well 199-K-111A (i.e., southeast corner of previous survey area). The tubes re-sampled include SG-11, SG-12, SG-13, SG-14, and SG-17 (see Figure 6.1). The re-sampling plan included tube SG-16, which had the highest helium-3/helium-4 ratio during September 1999, but that tube was destroyed during construction activities that took place between the two sampling events.

Table 6.1 contains the most recent and previous helium-3/helium-4 ratio results measured at selected locations. Note the duplicate samples results at SG-12 and SK-13 sampling points. Both values were

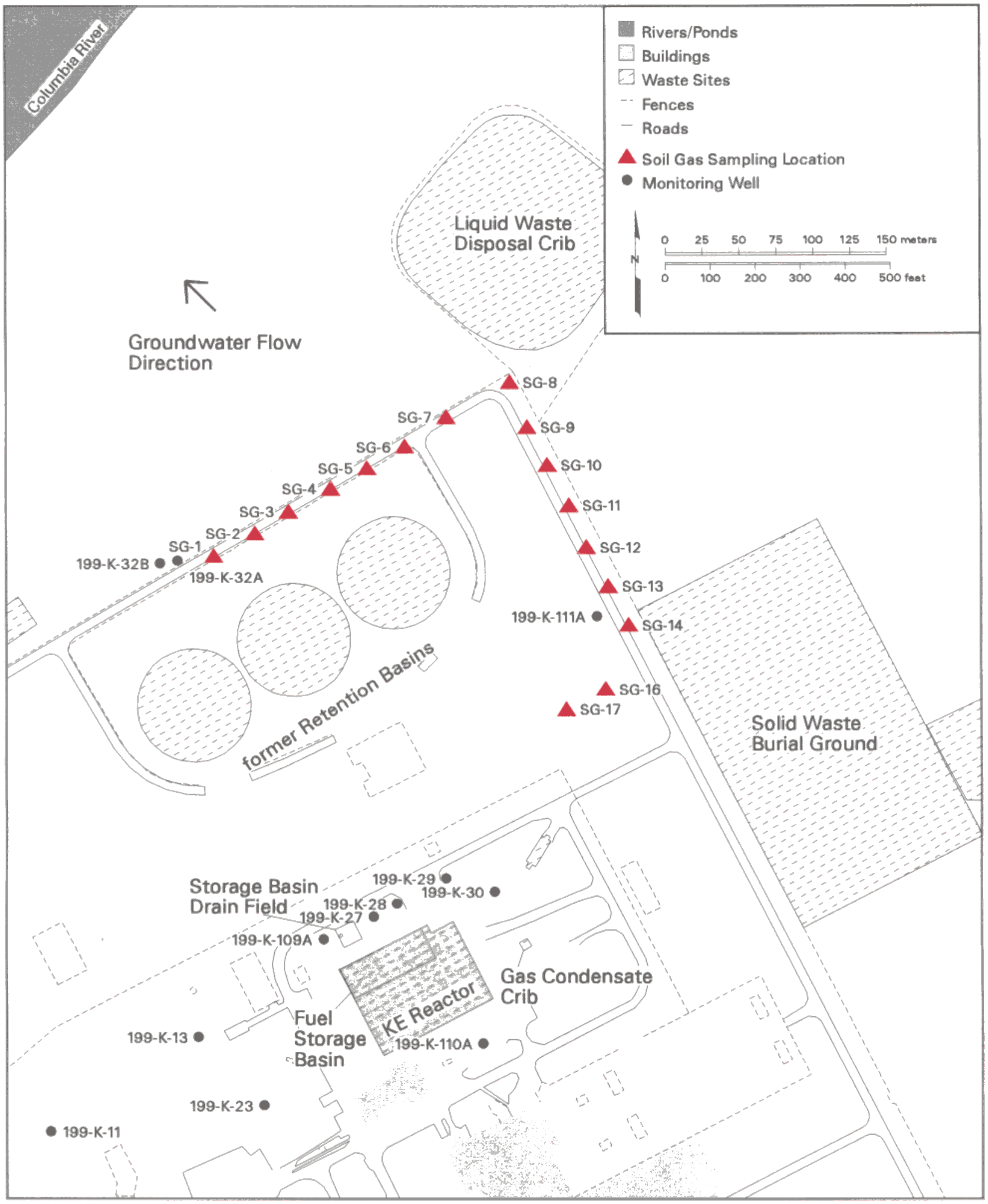

Figure 6.1. Location Map Showing Soil Gas Sampling Sites Near KE Reactor Complex

Table 6.1. Helium-3/Helium-4 Ratio for Soil Gas Samples Collected in September 1999 and September 2001

Location	2001: Date Sampled	2001: $^{3}He/^{4}He$ Ratio	2001: $^{3}He/^{4}He$ Ratio	1999: $^{3}He/^{4}He$ Ratio	Relative % Increase
100-K SG-11	9/6/01	1.039	1.039	0.988	5.03
100-K SG-12	9/6/01	1.066	1.035[(a)]	1.011	2.32
100-K SG-12	9/6/01	1.005			
100-K SG-13	9/6/01	1.025	1.046[(a)]	1.025	2.05
100-K SG-13	9/6/01	1.066			
100-K SG-14	9/6/01	1.109	1.109	1.035	6.92
100-K SG-16	N/A	(b)	(b)	1.131	N/A
100-K SG-17	9/6/01	1.015	1.015	1.014	0.09

(a) Average between two measurements.
(b) Unable to sample because soil gas tube was destroyed during recent construction activity.

averaged to give a single value for comparison to the 1999 results. The highest ratio observed in the 2001 sampling is 1.109 at SG-14, which is somewhat lower than the highest ratio measured in 1999 (1.131 at SG-16).

Based on the most recent sampling results, the concentrations of helium-3 in soil gas (daughter product of tritium decay) have increased within the study area during the time between these two sampling events. The modest increases in helium-3/helium-4 ratios are not viewed as evidence of a high concentration tritium plume (i.e., millions of pCi/L tritium concentration) beneath the soil gas survey area. However, the increase is coincident with the increase in groundwater tritium concentrations at well 199-K-111A during this time period and the latter increase is indicative of recent plume movement in the area.

6.3 Summary and Discussion

The new helium-3/helium-4 results for soil gas samples collected from sites near well 199-K-111A are consistent in distribution and concentrations with results for samples collected in September 1999, though the more recent concentrations are slightly higher than the earlier results. All results suggest the presence of tritium nearby. However, it is premature to conclude the exact location and source for the tritium based on existing soil gas sampling results alone. Several different source scenarios could explain the increase in helium-3/helium-4 ratios observed in the vicinity of well 199-K-111A. The helium-3 could be coming from a tritium source(s) in the vadose zone, a groundwater plume, or both potential sources in the area.

The nearest potential vadose zone sources are (1) vertical caissons (“silos”) in the 100-K Burial Ground, located approximately 120 meters (393.6 feet) to the east of the SG-14 soil gas sampling site and are known to have received irradiated metallic wastes associated with fuel elements, and (2) the KE Condensate Crib, located approximately 225 meters (738 feet) to the south-southwest of the SG-14 sampling site. Lateral diffusion of helium-3 from a source is presumed to be restricted to the immediate vicinity of the source, so potential source locations that are closer to the sampling site are the more likely candidates.

The best potential groundwater source is the tritium plume intercepted by well 199-K-111A. Tritium plumes are present in the general area because of several possible sources, including the KE Condensate Crib, the plume created by the 1993 KE Basin leak, and/or a previously undetected tritium plume beneath the 100-K Burial Ground. It should be noted that the existing soil gas sampling sites are not optimally located to detect groundwater plumes from the KE Reactor source sites or a plume potentially present beneath the 100-K Burial Ground. Additional evidence is needed to clearly identify the source for the tritium in groundwater at well 199-K-111A.

7.0 Conclusions and Path Forward

The following paragraphs provide a summary of the new information gained from investigations into the source for tritium detected in groundwater at well 199-K-111A.

7.1 Water Quality Signatures for Various Tritium Sources

- For the tritium plume created by the 1993 leak from the KE Basin, technetium-99 is a co-contaminant. Technetium-99 is a mobile constituent in groundwater, but has not been detected in samples from well 199-K-111A, thus suggesting that KE Basin leakage is not the source for tritium at the well.

- Tritium introduced to groundwater at the KE Condensate Crib is accompanied by carbon-14—the two principal waste indicators in reactor atmosphere gas condensate. Although carbon-14 is detected at well 199-K-111A at relatively low concentrations, its historical trend does not correlate with the recent rapid increase in tritium at the well, so the KE Condensate Crib is also an unlikely source.

- Tritium is the only groundwater constituent that shows a recent, rapidly increasing trend in concentration at well 199-K-111A, suggesting that the responsible waste site source is producing only tritium. For typical reactor area waste sites that include tritium contamination, other waste indicators are usually present. Production of tritium in solid waste that includes lithium-aluminate targets has not yet been shown to include other indicators that might be diagnostic of the source.

- Path Forward: Continued quarterly sampling at well 199-K-111A, to include analyses for tritium, screening for other radiological constituents, and basic water quality constituents; carbon-14 and technetium-99 are being monitored annually.

7.2 Groundwater Movement in the Vicinity of Well 199-K-111A

- Trend-surface analysis of historical water table elevation data from the region between the KE Reactor and the Columbia River indicates a consistent northwesterly flow direction that would place well 199-K-111A outside of the expected pathway for plumes from the KE Basin and KE Condensate Crib. Analysis of recently collected hourly data from wells in this region confirms the historical trend.

- While seasonal changes in water table elevation affect the hydraulic gradient (and, therefore, flow rate), changes do not endure long enough to cause significant displacement of groundwater plumes in a direction other than that suggested by long-term average gradient directions.

- Buildup of a groundwater mound beneath the interim remedial action injection wells, which are located to the east of well 199-K-111A, may be sufficient to influence flow direction and gradient beneath the 100-K Burial Ground and at well 199-K-111A. However, it is premature to conclude that the mounding is sufficient to move an existing plume a significant distance without acquiring additional water table elevation data from monitoring wells in the area. Any potential shift in flow direction beneath the 100-K Burial Ground because of the interim action mound would be westerly—toward well 199-K-111A.

- Path Forward: Continued evaluation of depth-to-water data with respect to determining hydraulic gradient direction and magnitude in the vicinity of the KE Reactor complex and 100-K Burial Ground. Depending on resources availability, additional hourly water level data will be obtained to better characterize the seasonal variability in flow direction caused by river stage fluctuations.

7.3 Helium-3 in Soil Gas Near the 100-K Burial Ground

- Helium-3, a decay product of tritium, is elevated above background in soil gas samples collected near well 199-K-111A. Samples collected in September 2001 show an increased amount of helium-3 compared to sample results from September 1999.

- The elevated levels of helium-3 may indicate decay of tritium contained in an underlying groundwater plume, the presence of which is suggested by the increasing groundwater concentrations observed in well 199-K-111A, and/or by lateral migration of helium-3 from a vadose zone source located nearby.

- Release of tritium from irradiated lithium-aluminate targets possibly located within the 100-K Burial Ground, analogous to the situation at the 618-11 Burial Ground, remains an explanation to be tested by further investigation of the burial ground contents (underway in September 2002).

- Path Forward: Additional soil gas sampling tubes are planned for installation along the northern perimeter of the 100-K Burial Ground during fiscal year 2003. The objectives for these additional installations are to a) determine if elevated helium-3 concentrations exist along the groundwater flow path downgradient from the burial ground, and b) if so, define the boundaries of tritium contamination in groundwater, which is a potential source for helium-3 in soil gas. The outcome of this investigation will include recommendations regarding the need for additional groundwater monitoring wells.

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Appendix

Correspondence to DOE Reporting Initial Findings of Investigation

Appendix

Correspondence to DOE Reporting Initial Findings of Investigation

Peterson, Robert E

From: Peterson, Robert E
Sent: Wednesday, May 09, 2001 11:57 AM
To: Thompson, K M (Mike)
Cc: Luttrell, Stuart P; Tortoso, Arlene C
Subject: Tritium increases at 100-K Area

Mike,

To follow up on our conversation after the Inspector General audit meeting this morning, I've attached several figures that illustrate an emerging issue at the 100-K Area.

H3-trendchg-may01.PDF KE-traveltime-may01.PDF

The first chart shows the tritium concentration trends in wells 199-K-32A and 199-K-111A, which have shown increasing concentrations in recent months. When these increases first became apparent, we interpreted them as the arrival of a plume created by leakage from the KE basin in 1993. K-32A is in the direct downgradient path from the KE basin and K-111A is off to the north of the most direct path. The travel time between KE basin and K-32A or K-111A would be approximately 6 years, which is reasonable for movement through Ringold Unit E formation.

There are several potential tritium sources that might have contributed to groundwater contamination that is now appearing in wells downgradient of the KE basin: (1) basin leakage in 1993, (2) the 115-KE gas condensate crib, and (3) loss from the sub-basin drainage collection system. (With a flow velocity in the range of 0.5 to 1.0 ft/day, earlier water losses from the KE basin should be long gone from the area).

The continuing steep rise in concentrations, especially in K-111A which is not in the direct downgradient path from the sources listed above, has caused us to look closely at possible alternative sources. Well K-111A is located adjacent to the northwest corner of the 100-K burial ground (118-K-1 waste site). We have documentation to show that the burial ground included "silos" consisting of vertical corrugated conduit, 10-ft in diameter, extending 25-ft downward into the vadose zone. Metallic wastes from reactor operations were placed in these silos, and likely included irradiated reactor components, such as dummy fuel elements, aluminum spacers, process tubing, etc. Given the recent experience at 618-11 burial ground, we believe that the 100-K burial ground deserves close attention as a potential tritium source until additional evidence is discovered to prove otherwise.

If a tritium plume exists beneath the 100-K burial ground, its movement may be deflected toward the west (and well K-111A) by the change in groundwater flow direction that is occurring as a consequence of re-injecting treated effluent in the area east of the burial ground. Also, the burial ground could be the source for tritium that has long been observed in wells located some distance downgradient, i.e., K-18, K-19, and K-120A.

Bob

Robert E. Peterson **Phone:** (509) 373-9020 **Fax:** (509) 372-1704 **Email:** robert.peterson@pnl.gov
Mail: Pacific Northwest National Laboratory
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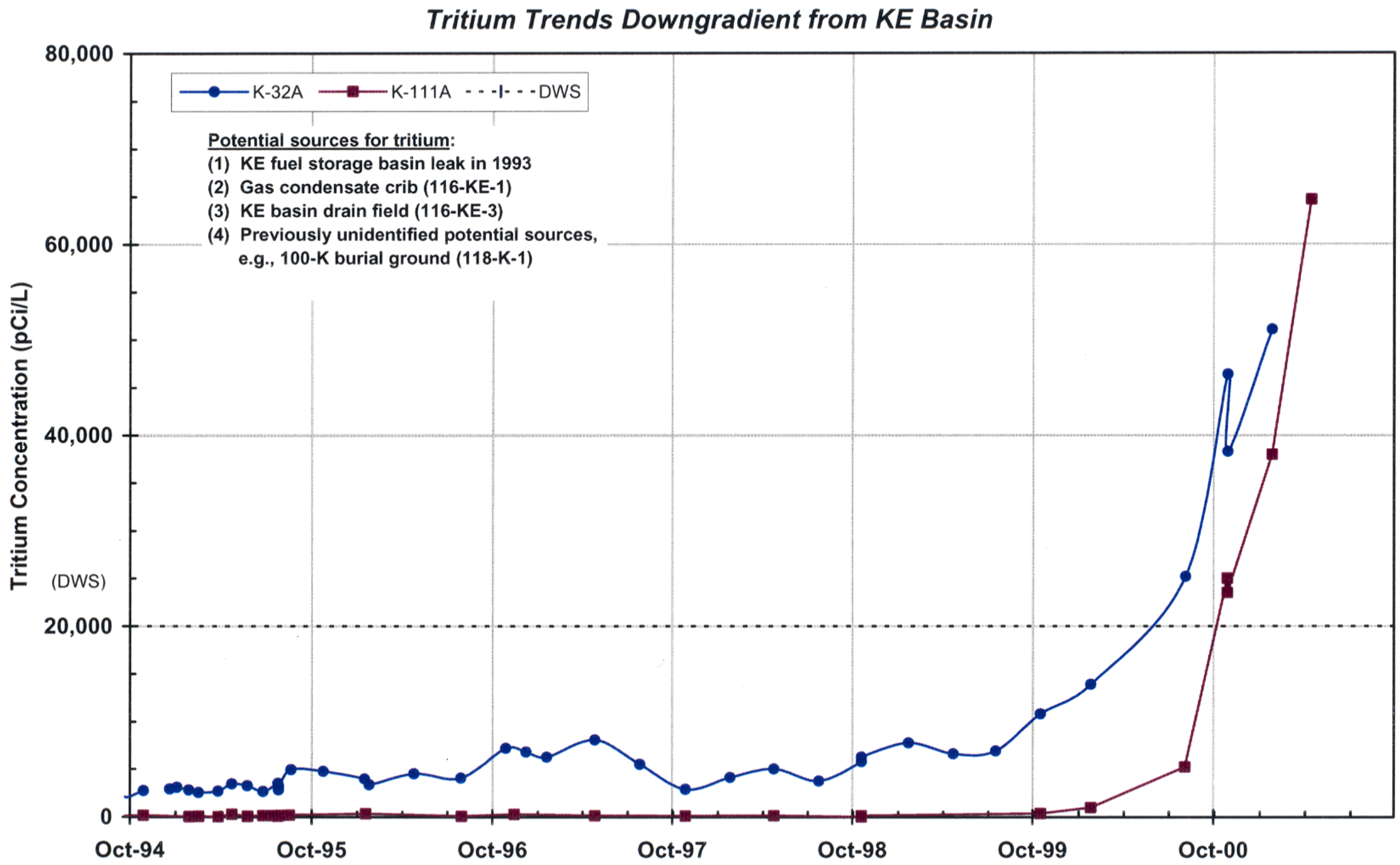
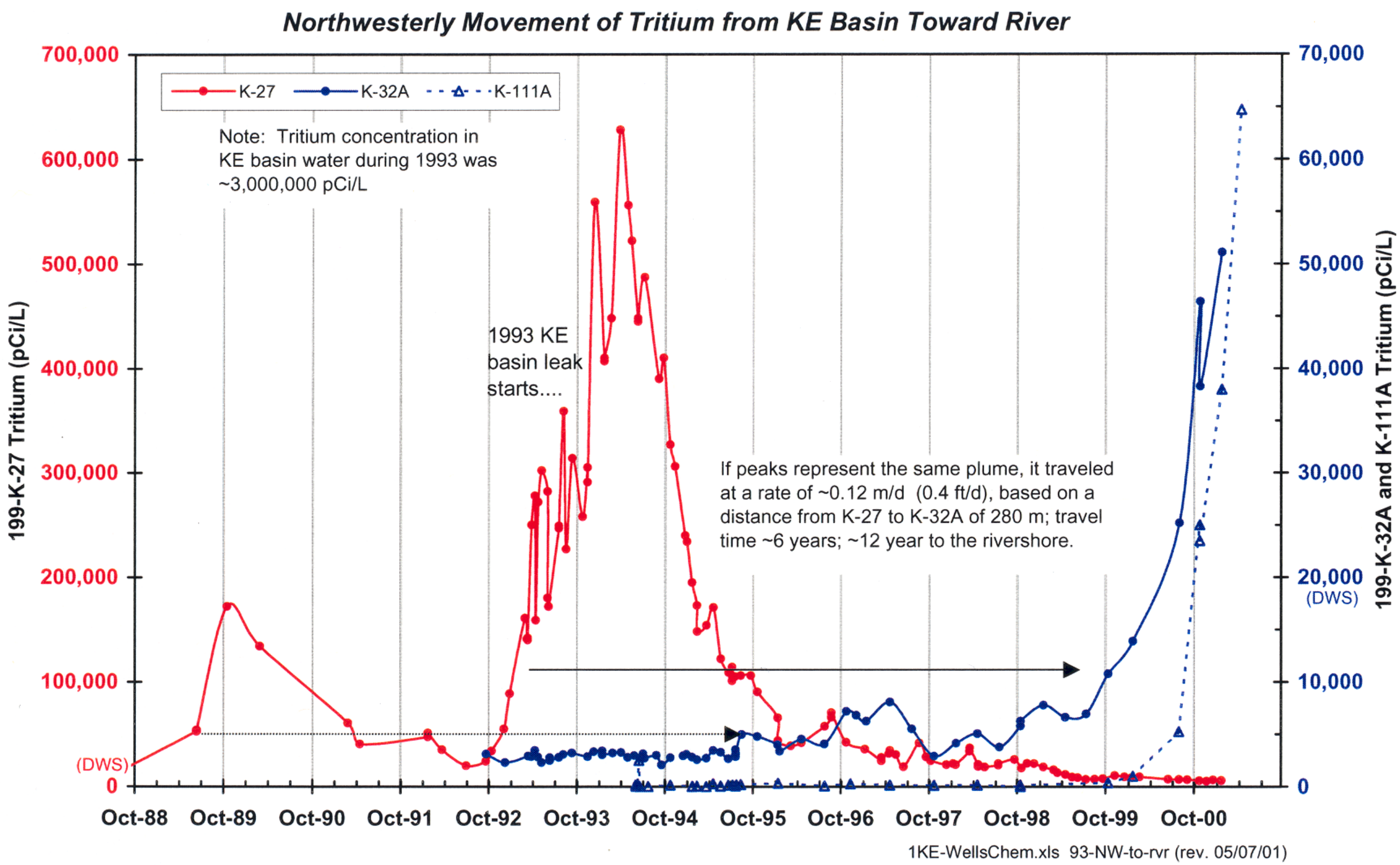

Tritium Trends Downgradient from KE Basin
K-32A
K-111A
DWS
Potential sources for tritium:
(1) KE fuel storage basin leak in 1993
(2) Gas condensate crib (116-KE-1)
(3) KE basin drain field (116-KE-3)
(4) Previously unidentified potential sources, e.g., 100-K burial ground (118-K-1)
Tritium Concentration (pCi/L)
(DWS)
80,000
60,000
40,000
20,000
0
Oct-94
Oct-95
Oct-96
Oct-97
Oct-98
Oct-99
Oct-00


Northwesterly Movement of Tritium from KE Basin Toward River
K-27
K-32A
K-111A
Note: Tritium concentration in KE basin water during 1993 was ~3,000,000 pCi/L
1993 KE basin leak starts....
If peaks represent the same plume, it traveled at a rate of ~0.12 m/d (0.4 ft/d), based on a distance from K-27 to K-32A of 280 m; travel time ~6 years; ~12 year to the rivershore.
199-K-27 Tritium (pCi/L)
199-K-32A and K-111A Tritium (pCi/L)
700,000
600,000
500,000
400,000
300,000
200,000
100,000
(DWS)
0
70,000
60,000
50,000
40,000
30,000
20,000
(DWS)
10,000
0
Oct-88
Oct-89
Oct-90
Oct-91
Oct-92
Oct-93
Oct-94
Oct-95
Oct-96
Oct-97
Oct-98
Oct-99
Oct-00
1KE-WellsChem.xls 93-NW-to-rvr (rev. 05/07/01)

Peterson, Robert E

From:	Peterson, Robert E
Sent:	Friday, August 10, 2001 3:20 PM
To:	Thompson, K M (Mike)
Cc:	Morse, John G; Tortoso, Arlene C; Fruchter, Jonathan S; Graham, Michael J; Borghese, Jane V
Subject:	July01 Status: 100K Tritium Investigation

Status Report on Investigation of Increasing Tritium Concentrations in Groundwater Near the 100-K Burial Ground

August 9, 2001

Tritium Concentrations in Well 199-K-111A

The most recent sample was collected on July 25, 2001. Tritium concentrations in groundwater at this well continue to increase. Concentration for the July sample is 83,600 pCi/L (see attached trend chart). The well is scheduled to be resampled in late August and late September, with 15-day turnaround for tritium analyses on the samples.

K-111A-H3-chg-Jul01.PDF

Recap of current information on the source for tritium observed in groundwater at well 199-K-111A: Of the known potential sources for tritium that are closest to this well, none are directly upgradient of the well. Also, co-contaminants for the known potential sources (i.e., technetium-99 for KE basin shielding water and carbon-14 for KE gas condensate crib effluent) have not been detected at the well. If a tritium plume is present east of the well (i.e., the area beneath the 100-K burial ground), a possibility exists that the plume is being displaced westward toward the well because of the mound created by the 100-KR-4 IRM injection wells.

Analysis of Water Movement Near 100-K Burial Ground

<u>Mounding Beneath the IRM Injection Wells</u>

An analysis is underway to estimate the extent of mound buildup beneath the IRM injection wells, using information on the injection rates and hydraulic properties for the sediments in the area. This analysis will provide insight on the possibility of a plume being displaced to the west, where it is now intercepted by well 199-K-111A.

<u>Three-Point Analysis of Water Level Data</u>

A pressure transducer will be installed in well 199-K-111A to record hourly water levels. These data will be combined with data from wells 199-K-32A and 199-K-30 and analyzed for flow direction and gradient using the 3-point method. We hope to have a transducer operating in K-111A later in August.

<u>Seasonal Influence on Flow Direction</u>

An analysis of historical water table elevations for various seasonal periods was completed earlier as part of a separate 100-K Area investigation. The objective was to determine whether seasonal changes in river discharge conditions caused appreciable changes to groundwater flow direction. The conclusion from the analysis was that it did not.

Soil Gas Investigation

Availability of Existing Soil Gas Sampling Tubes

Field surveillance of the soil gas sampling tubes that were used during the 1999 project at 100-K indicates that they are available for resampling.

Analysis of Soil Gas Samples

(See email from M.J. Graham to K. M. Thompson and J. G. Morse, August 10, 2001 regarding a BCP to conduct this work during FY 2001)

Bob

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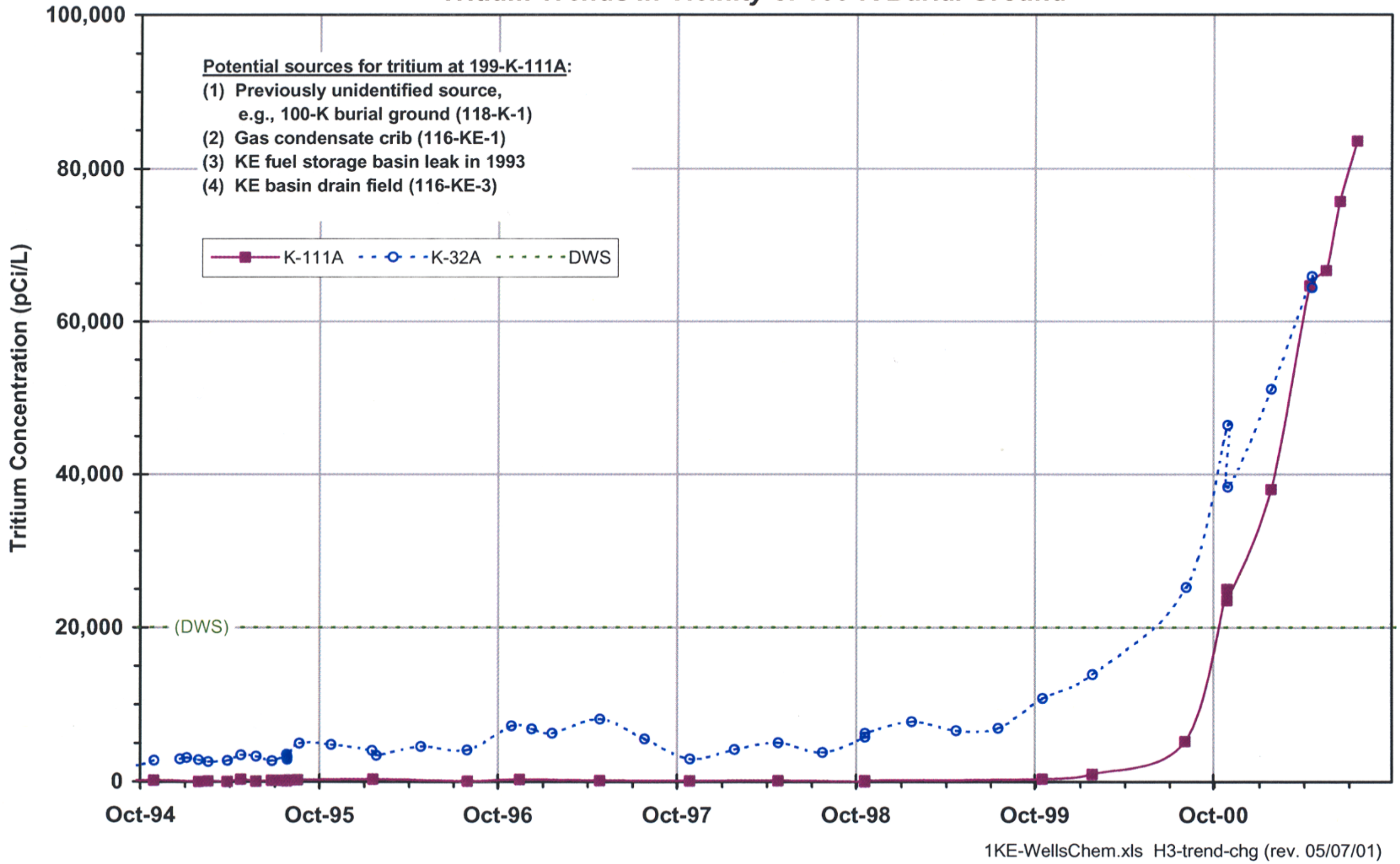
Tritium Trends in Vicinity of 100-K Burial Ground



From:	Peterson, Robert E
Sent:	Tuesday, November 13, 2001 4:24 PM
To:	Thompson, K M (Mike)
Cc:	Luttrell, Stuart P; Byrnes, Mark E; Borghese, Jane V; McMahon, William J; Watson, David J (Dave); Morse, John G; Tortoso, Arlene C
Subject:	Status Report #2 on 100-K Tritium Investigation

Status Report #2 on Investigation of Increasing Tritium Concentrations in Groundwater Near the 100-K Burial Ground

November 13, 2001

Background

- *Tritium concentrations in groundwater at well 199-K-111A started increasing sharply during late summer 2000. An explanation for the increase is not immediately obvious because the well is not located along the presumed downgradient flow path from known facility/waste site sources for tritium. No additional contamination indicators are observed to increase along with tritium. Certain information about the 100-K Burial Ground, located immediately to the east of the well, creates suspicion regarding a possible tritium source in that waste site.*

- *The groundwater flow pattern in the vicinity of the well may have changed in recent years because of a mound buildup beneath the interim remedial action injection wells, which are located approximately 650 meters to the east. Mound buildup could potentially shift a plume located east of well 199-K-111A in a westerly direction, causing the plume to be detected at the well.*

- *Three investigations are directed at the change-in-flow field hypothesis: (1) analyze historical water table elevation data to determine the hydraulic gradient direction and magnitude over a period of several years; (2) analyze newly collected hourly water table elevations to determine gradient direction and magnitude; and (3) calculate the height and extent of the mound buildup beneath the interim action injection wells.*

- *An additional investigation is directed at measuring the helium-3 and helium-4 in soil gas collected from existing soil gas tubes located near the well. Helium isotopes can be used to infer the presence of tritium in a nearby vadose zone and/or groundwater source.*

Highlights of New Information to Date

- Tritium concentrations continue to be elevated at well 199-K-111A, located near the 100-K Burial Ground. Concentration during August 2001 is 82,400 pCi/L, which is slightly less than the 83,600 pCi/L measured in July.

- Trend-surface analysis of water table elevation data supports the hypothesis that tritium plumes from sources near the KE reactor building would remain to the west of well 199-K-111A.

- Mound buildup from the interim action injection wells located east of the 100-K burial ground and well 199-K-111A could potentially displace groundwater (and any plumes) in a westerly direction, i.e., toward well 199-K-111A.

- New helium-3 and helium-4 results for soil gas samples collected from sites near well 199-K-111A are consistent in pattern and helium-3/helium-4 ratios for samples collected in September 1999, although the ratios are slightly higher than earlier results. All results suggest the presence of tritium nearby, either in an underlying groundwater plume and/or nearby vadose zone source.

Details of New Information and Status of Tasks in Progress

Tritium Concentrations in Well 199-K-111A

Samples were collected from the well on August 24, September 27, and October 24, 2001 for tritium analysis. The August sample result is 82,400 pCi/L, which is slightly lower than the previous sample collected on July 25 of 83,600 pCi/L (see attached trend chart). Results for the September sample should become available by late-November. A trend for well 199-K-18 is included in the figure because that is the next closest well along the downgradient pathway from the burial ground.

K111A-K18-H3.PDF

Groundwater Movement Near the 100-K Burial Ground

Depth-to-water data for wells 199-K-111A, 199-K-32A, and 199-K-30 for the period 1994 to present were used for a trend-surface analysis for gradient direction and magnitude. The results indicate that flow in the region between the KE reactor and the river is most frequently directed toward the north-northwest, which is consistent with previous descriptions of the water table configuration. Large variations in river stage immediately after the spring runoff may cause a short-term shift in direction to a more northerly direction. However, the duration of this shift is probably not long enough to displace a plume toward the northeast a significant distance.

Pressure transducer data were collected from well 199-K-111A from August 31 to September 17, 2001. These data were combined with similar hourly data collected from wells 199-K-30, 199-K-32A, and 199-K-18 for trend-surface analysis. The results indicate an average flow direction of 318 degrees (north-northwest) and gradient of 0.0047 in the area within the triangle formed by K-30, K-32A, and K-111A. In the triangle formed by K-111A, K-32A, and K-18, the direction is 321 degrees (north-northwest) with a gradient of 0.0049. These values are consistent with the values calculated previously using historical water table elevation data.

Assuming a hydraulic conductivity of 10 m/d and effective porosity of 20%, these gradients would produce an average linear flow velocity of ~0.24 m/d. The distance from the center of the burial ground to the river is ~675 meters, so the travel time from the burial ground would be ~7.7 years. The closest downgradient monitoring well is 199-K-18 (~450 meters downgradient) and groundwater at this well has shown a long-term gradual increase in tritium concentrations.

Mound Buildup Beneath the Interim Remedial Action Injection Wells

An estimate for the extent of mound buildup beneath the 100-KR-4 interim remedial action injection wells was completed on September 14, 2001. The estimate is based on the injection rates and hydraulic properties for the sediments in the area. It is currently inconclusive whether the potential mound buildup at the injection sites is extensive enough to shift a tritium plume potentially located beneath the 100-K Burial Ground. However, if the potential mound buildup is sufficient to cause a change in flow direction, the change in direction beneath the burial ground is to a more westerly direction and toward well 199-K-111A.

Soil Gas Investigation

Soil gas samples were collected on September 6, 2001 from existing tubes located near well 199-K-111A. The analytical results for the helium-3/helium-4 ratio are now available (see Letter Report #094248, M. J. Graham to K. M. Thompson, November 12, 2001). The ratios for the recent samples do indicate the presence of tritium in this area, and the ratios are consistently higher than those measured during in September 1999 (although they are not as high as ratios observed in the area downgradient of the 618-11 Burial Ground).

Several explanations for the differences are possible, including an increased amount of helium-3 (byproduct of tritium decay) moving into the vadose zone in the area, or possibly because of a tritium plume in groundwater moving closer to the soil gas sampling locations. The increase in tritium at well 199-K-111A provides evidence for the latter scenario. Additional coverage by soil gas sampling locations would likely provide a definitive answer, as that methodology did at the 618-11 site.

Letter Report Summarizing Water Movement and Helium-3/Helium-4 Investigations

A draft report describing the results, conclusions, and recommendations for all investigations undertaken to determine the source for tritium at well 199-K-111A has been prepared and is being reviewed internally. PNNL internal letter reports are currently available to provide additional details on the trend-surface analyses and the mound buildup investigations.

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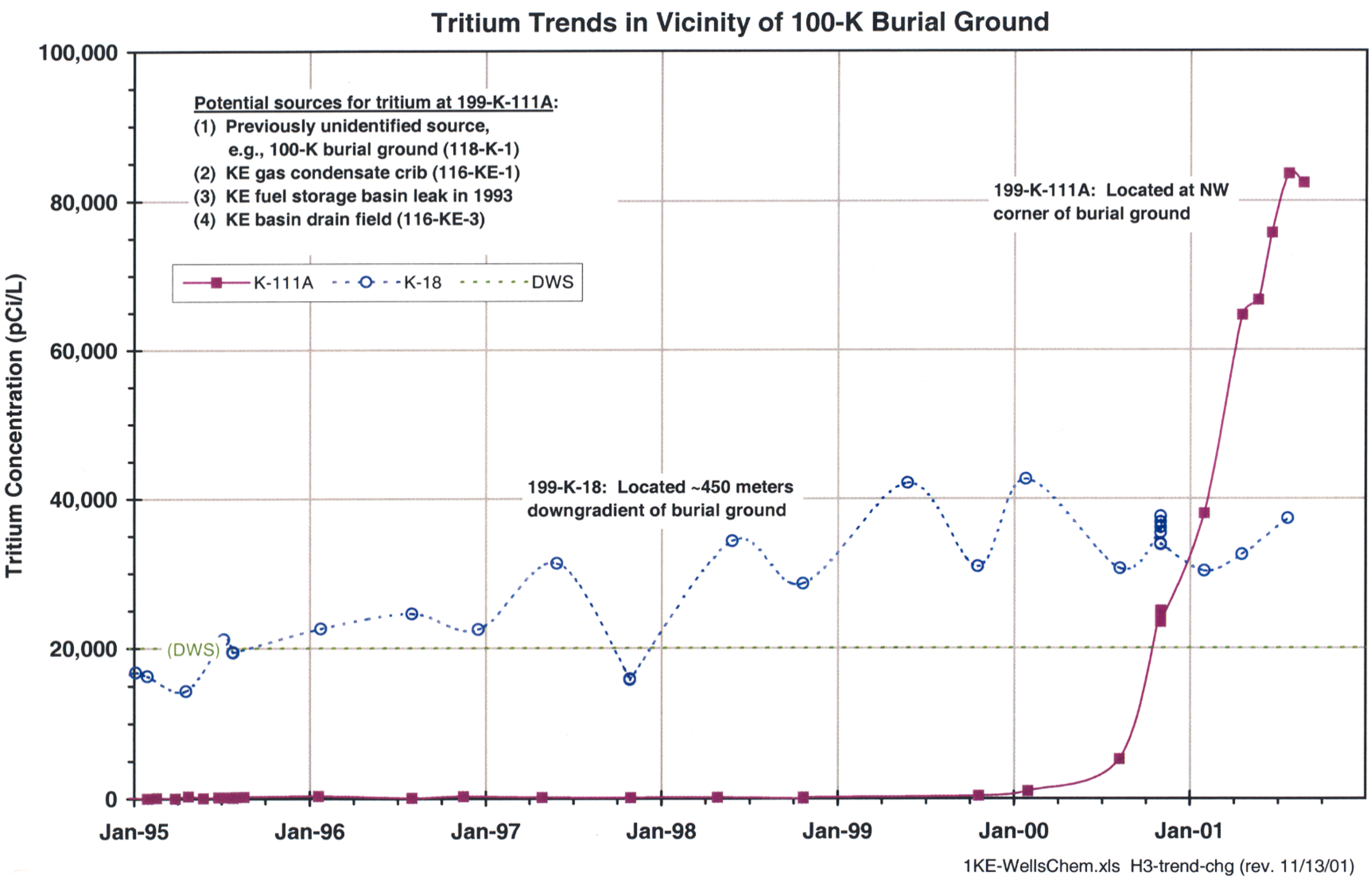
Tritium Trends in Vicinity of 100-K Burial Ground
Potential sources for tritium at 199-K-111A:
(1) Previously unidentified source, e.g., 100-K burial ground (118-K-1)
(2) KE gas condensate crib (116-KE-1)
(3) KE fuel storage basin leak in 1993
(4) KE basin drain field (116-KE-3)
K-111A
K-18
DWS
(DWS)
199-K-111A: Located at NW corner of burial ground
199-K-18: Located ~450 meters downgradient of burial ground
Tritium Concentration (pCi/L)
100,000
80,000
60,000
40,000
20,000
0
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Jan-00
Jan-01
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