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Pacific Northwest National Laboratory

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Selection of Sampling Pumps Used for Groundwater Monitoring at the Hanford Site

R. Schalla
W. D. Webber
R. M. Smith

November 2001

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RL901830

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Summary

The variable frequency drive centrifugal submersible pump, Redi-Flo2® made by Grundfos®, was selected for universal application for Hanford Site groundwater monitoring. Specifications for the selected pump and five other pumps were evaluated against current and future Hanford groundwater monitoring performance requirements, and the Redi-Flo2 was selected as the most versatile and applicable for the range of monitoring conditions.

The Redi-Flo2 pump distinguished itself from the other pumps considered because of its wide range in output flow rate and its comparatively moderate maintenance and low capital costs. The Redi-Flo2 pump is able to purge a well at a high flow rate and then supply water for sampling at a low flow rate. Groundwater sampling using a low-volume-purging technique (e.g., low flow, minimal purge, no purge, or micropurge®) is planned in the future, eliminating the need for the pump to supply a high-output flow rate. Under those conditions, the Well Wizard bladder pump, manufactured by QED Environmental Systems, Inc., may be the preferred pump because of the lower capital cost.

Acronyms

ABS	-	acrylonitrile-butadiene-styrene
CPVC	-	chlorinated polyvinyl chloride
DNAPL	-	dense nonaqueous-phase liquid(s)
EP	-	ethylene propylene
ETFE	-	ethyl-tetraethyl-ethylene
EVA	-	ethyl vinyl acetate
FEP	-	fluorinated ethylene propylene
FPP	-	flexible polypropylene
FPVC	-	flexible polyvinyl chloride
FRE	-	fiberglass reinforced epoxy
HDPE	-	high-density polyethylene
ID	-	inside diameter
LDPE	-	low-density polyethylene
NAPL	-	nonaqueous-phase liquid(s)
NTU	-	nepthelometric unit
PE	-	polyethylene
PFA	-	perfluoroalkoxy (resin)
PP	-	polypropylene
PTFE	-	polytetrafluoroethylene
PVC	-	polyvinyl chloride
PVDF	-	polyvinyldine fluoride
P(VDF-HEP)	-	polyvinyldine fluoride-hexaethylpropylene
RCRA	-	Resource Conservation and Recovery Act
SS	-	stainless steel
TPE	-	tetrapolyethylene
VFD	-	variable frequency drive
XLPE	-	extra low-density polyethylene

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Robert E. Peterson was the lead technical reviewer and provided valuable comments to improve the quality of the manuscript. Stuart Luttrell also performed technical review of the entire manuscript. Jim Bush provided additional comments. Bev Johnston provided the editorial review and assisted in the production of this document. Dave Lanigan and Chris Newbill provided the graphics. Lila Andor and Kathy Neiderhiser provided word processing support.

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1.0 Introduction

This report evaluates commercially available sampling pumps and recommends the types of pump that would accommodate the conditions and satisfy the requirements for groundwater monitoring at the Hanford Site (Figure 1.1). The importance of the type and design of the discharge riser that brings the water to the surface is also presented. However, the selection of a pump and discharge riser addresses only one issue that can effect collecting a groundwater sample that is representative of conditions in the aquifer. Issues, such as well design and construction, purging and sampling rates and volumes, sampling pump deployment (e.g., opposite preferential flow zones), groundwater velocity, and contaminants of concern, are only discussed briefly where needed in this report for selection of an appropriate sampling pump.

Groundwater sample collection from monitoring wells entails two basic activities, sometimes referred to as cycles: purging (not always necessary) and sampling. Purging is removal of stagnant water in the well casing and screen to obtain a representative sample from the water-bearing layers. Nearly all groundwater samples collected at Hanford are obtained using one sampling pump in each well, which has been the common practice since 1987. Previously, some wells would have two dedicated pumps, consisting of a high-discharge-volume submersible pump for purging and a bladder pump for sampling. Having a pump dedicated to each well eliminates the risk of cross contamination between wells; the labor and cost associated with the decontamination of sampling equipment between sampling events; and the cost of collection, containment, and disposal of wash and rinse water. Currently, at Hanford the most commonly used devices for purging and sampling monitoring wells are the fixed discharge rate Grundfos® submersible pump or the HydroStar™ piston pump.

The pumps currently in use at Hanford were selected over a decade ago when few of the newer pump designs were available. Since that time, pump designs changed and their performance improved significantly. The depth to water in most wells at Hanford is >70 m. The wells are constructed primarily of 10-, 15-, or 20-cm-dia. carbon steel or type 304 stainless steel casing and types 304 or 316L stainless steel wirewrap well screen, though several older wells are 25- or 30-cm-dia. carbon steel casing. As a consequence of the large diameters, the purge volumes may be large, though commonly 200 to 400 L per well before collection of samples can begin. It is desirable to have discharge rates of 8 to 20 L/min to reduce the amount of largely idle time during the purging cycle. However, such high discharge rates may not be necessary, particularly when filling sample bottles. At present, a bypass system, attached to the discharge riser, allows most of the water to continue flowing into a tanker truck while allowing water flow via a bleed valve at very low discharge rates suitable for filling sample bottles. Many of the existing wells may not require such large volumes or may require no purging at all.

To avoid the equipment, training, and maintenance cost of using multiple control systems and power sources, it is desirable to have only one type of pump in use for routine collection of groundwater samples. Therefore, certain performance requirements must be met, yet the final sampling device selected must also be a compromise that will meet current and future needs. To meet current purging and sampling needs, it is desirable to have a pump that has a variable discharge rate over a large range and can lift water to the surface from depths of up to 90 m. The variable discharge range can help reduce wastewater produced during the sampling cycle.

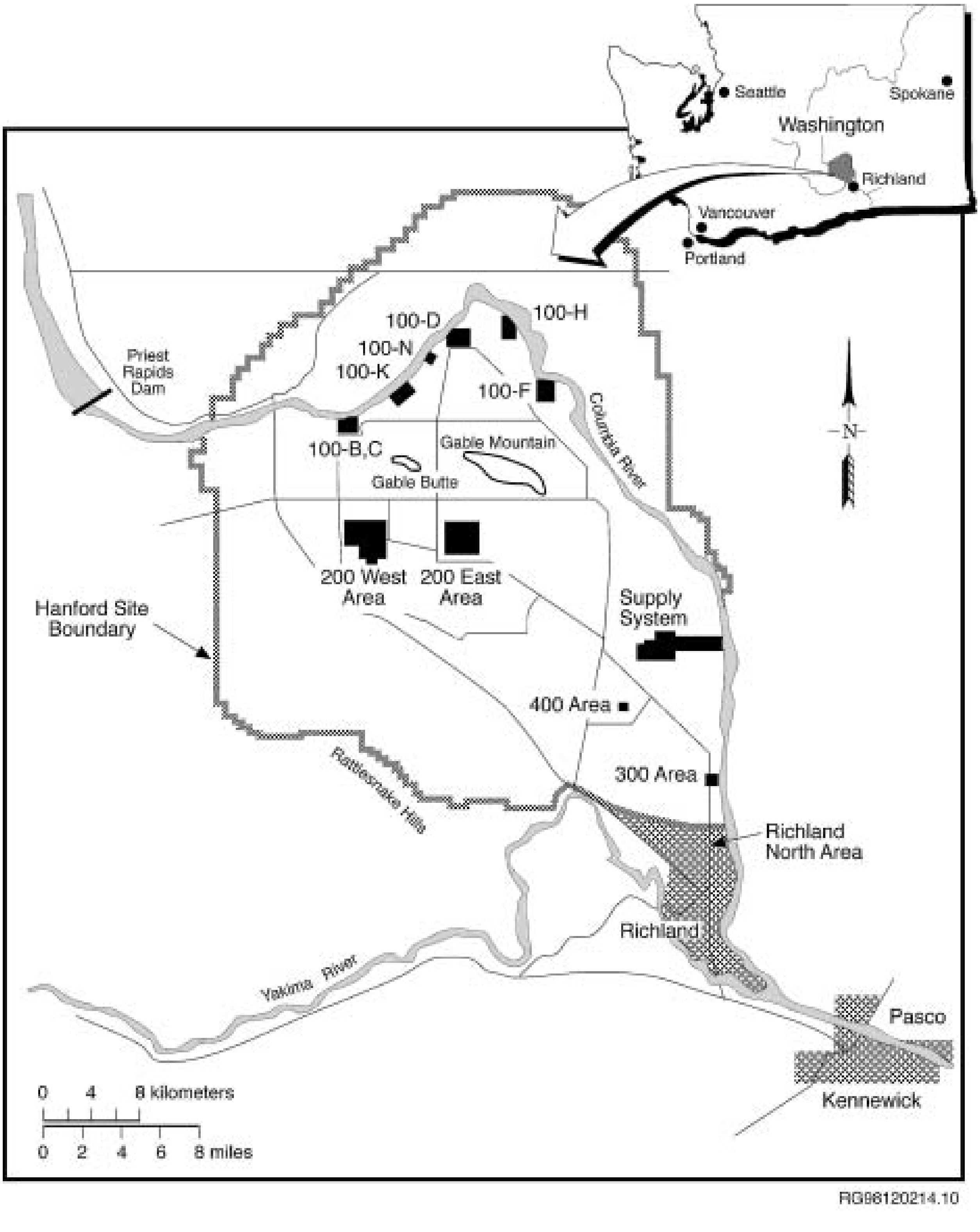

Figure 1.1. Location of Hanford Site

Outside of Hanford, the environmental industry uses a variety of dedicated sampling devices: the bladder pump and the variable speed submersible pump being the most common. Bladder pumps are generally considered the type of sampling pump that least perturbs groundwater samples, and studies tend to use it as a reference standard for other pumps. Numerous authors conclude that most types of pumps produce representative groundwater samples. Even errors detected in site-specific studies rarely produce significant changes that alter data interpretation. In an effort to reduce costs and wastewater, and in some instances improve the accuracy of groundwater samples, new techniques, using low flow rates and small volumes during both purging and sampling, are now done almost routinely. More recently, not purging the well at all, just the sampling device, appears viable at many sites where groundwater velocities are sufficiently high and the monitoring wells have been properly designed and developed. Also, most monitoring wells are 5- or 10-cm-dia. slotted polyvinyl chloride (PVC) casing, thereby reducing the amount of purge water and time required for any type of sampling method. Most monitoring wells at other hazardous waste sites are <35 m deep, which makes almost all types of devices suitable for groundwater sample collection. Also, these techniques and conditions eliminate the need for a pump with a large and variable discharge rate.

This report is organized so as to give the reader the conclusions and recommendations of the pumps chosen for groundwater sampling at the Hanford Site (Chapter 2.0). These conclusions and recommendations are followed by the narrative that describes the Hanford sampling conditions, including requirements, groundwater system characteristics, monitoring well construction, and sampling equipment parameters (Chapter 3.0). Chapter 4.0 describes the factors affecting the potential of a pump to influence sample characteristics, including well-bore mixing, turbidity, pressure changes, seal leakage, temperature changes, materials, and discusses current pumps and risers in use. Chapter 5.0 addresses the attributes and capabilities of the commercially available sampling pumps and devices, and compares pumps on the basis of their physical dimensions, lift capacity, flow-rate range, potential to influence water quality, power needs, maintenance, and procurement costs. Chapter 6.0 discusses the future for low-volume purging. Appendix A details the interactions of materials and how they may affect sample results. Appendix B contains the specifications and details that are necessary for procurement.

2.0 Conclusions and Recommendations

The authors have endeavored to present an unbiased view of commercially available groundwater sample pump equipment. Compromises in the recommendations were made to select the most versatile and applicable sampling pump to address the current and most of the future sampling needs for the Hanford Site groundwater-monitoring program. However, to address future groundwater-monitoring direction related to site stewardship and long-term monitoring, additional narrative is provided in Chapter 6.0.

Table 2.1 presents a summary of how well each pump meets the selected performance criteria for use at Hanford. Even though a pump may have been eliminated from consideration, it is included here for completeness. The variable frequency drive (VFD) submersible pump (Redi-Flo2® by Grundfos®) and the bladder pump (Well Wizard T1200 by QED Environmental Systems, Inc.) were the two pumps that were rated as the most appropriate for current and future Hanford use. The bladder pump has the single limitation that its maximum discharge rate is 2 L/min or less for most applications at Hanford; therefore, it would not be cost effective to use where the current purge volume is three or more well bore volumes. The Redi-Flo2 appears to be the most versatile of the pumps evaluated, meets all of the current sampling requirements, and, therefore, is the primary type of VFD submersible pump selected for use at the site.

Table 2.1. Comparison of Performance Criteria and Pumps

Performance Criteria	Redi-Flo2® (3™) [4™] Submersible Pump	QED Bladder Pump	Bennett Piston Pump 1800-8	HydroStar™ Single-Action Piston Pump	Keck Progressive Cavity Pump	Fultz SP201 [SP300] Gear-Driven Pump
Physical Dimensions – Fit in 10.1-cm well	Yes (Yes) [No]	Yes	Yes	Yes	Yes	Yes
Lift Capacity – 90 m	No (Yes) [Yes]	Yes	Yes	Yes	No	No
Effect on Sample Chemistry	None	None	None	None	None	None
Flow-Rate Range – 100 mL/min to 10 L/min	Yes (No) [Yes]	No	Yes	Yes	Yes	Yes
Power Requirement – Standard, Detachable Power Source	Yes to All	Yes	Yes	Yes	Yes	Yes
Maintenance	Moderate	Low	High	High	High	Moderate
Cost	Low	Low	High	Moderate	High	Moderate

Pump diameter is the first criterion that the pump must meet. All of the pumps evaluated, with the exception of the Redi-Flo4, meet this requirement. The Redi-Flo4 can only be used in a 12-cm-dia. or larger well. The Redi-Flo3 would be limited to 10-cm-dia. wells using high-discharge-rate purging techniques because the discharge rate cannot be reduced to 100 to 500 mL/min used for low-flow sampling.

The second criterion is lift, with depth to water (i.e., pump intake) of up to 90 m below ground surface. While pumps that are not capable of meeting this criterion could be used at many locations where the water table is closer to ground surface, they could not be used as an exclusive standard across the entire monitoring network.

The third is effect on sample chemistry. Some fixed-rate discharge submersible pumps at Hanford use nonfood-grade acrylonitrile-butadiene-styrene (ABS), others use a poorer choice, galvanized pipe. To acquire reliable data representative of aquifer conditions, many of the existing well and pump installations should be reconfigured with newer pump types and risers that use the more corrosion resistance stainless steels or more nonsorptive, inert polymeric materials.

The fourth criterion is that the pump can be used to purge the well at a flow rate up to10L/min prior to sampling and at a low rate during sample collection. The currently accepted sampling technique of purging the well of a specified large volume makes the upper flow rate at which a pump can discharge water from a well essential. But, equally important is the ability to reduce the flow rate to between 100 and 500 mL/min during sampling. For wells completed deeper than ~80 m, either the Redi-Flo4 pump (for 12 cm dia. or larger) or a bladder pump could be used under no- or low-flow purging.
The six pumps considered perform purging and sampling functions without significant loss of volatile constituents from the water samples. This statement is supported by numerous reports of relevant research in the scientific literature (Miller 1982; Ho 1983; Unwin 1984; Barcelona et al. 1984, 1985b; Stolzenburg and Nichols 1985; Garske and Schock 1986; Muska et al. 1986; Pearsall and Eckhardt 1987; Barcelona et al. 1988; Imbrigiotta et al. 1988; Liikala et al. 1988; Panko and Barth 1988; Pohlmann and Hess 1988; Schalla et al. 1988b; Unwin and Maltby 1988; Gibs and Imbrigiotta 1990; Gass et al. 1991; Gibs et al. 1993; Knobel and Mann 1993; Parker et al. 1993).

The method by which the pump is powered is important in determining if special devices are required. In all cases, the pumps can be powered with standard batteries, generators, or compressors as required by criterion 5. The pumps that are electrically powered also require a control box to adjust the flow rate. The control boxes for these pumps are portable and do not need to be dedicated to a specific well. The pneumatically controlled pumps require a portable actuator assembly.

The sixth criterion is maintenance. Maintenance and servicing are important and include the reliability, ease of installation and removal, and servicing onsite, but not necessarily at the well. The ability to easily service and reinstall the pumps, particularly in highly contaminated wells, is a consideration. For servicing of the pump or riser components, it is easiest for the bladder pump, more difficult for the VFD submersible, very difficult for the single-action piston pump, and extremely difficult for the double-action piston pump. During removal of the pump for servicing, the primary disadvantage of the bladder pump is dealing with the water left in the riser when the pump is pulled. Although the volume is usually less than a liter, highly contaminated water may pose a safety problem at ground surface. Larger volumes remain when servicing of the single-action piston pump. It is unknown before sampling or servicing how much water remains in the riser because of the pump seals leak eventually at various rates. As a result, the pump often drains stagnant water into the well over a long period of time. The submersible pump without a check valve is self-draining, and the double-action piston pump has a reverse switch for pumping water out of the line either before or as the pump is removed. The single-action piston pump not only leaks eventually at the Teflon® seal in the pump chamber but also at the surface where Teflon packing is used to prevent leaks around the rod assembly.

Ultimately, capital, maintenance, and operational costs are also major factors. For capital costs, the prices of the sampling pumps and accessories for the VFD submersible, bladder, and double-action piston pump vary and are a function of pump model, riser material, and depth of installation. Based on data in this report, the lowest priced pump with riser and accessories is the QED T1200 bladder pump. However, to achieve waste minimization (recycling) and cost savings, it was suggested by staff at Duratek Federal Services, Inc., Northwest Operations; Bechtel Hanford, Inc.; and Pacific Northwest National Laboratory that the stainless steel riser pipe left over from the existing HydroStar pumps should be used for the VFD submersibles. This would reduce the total cost of the Redi-Flo2 pump, with accessories, to near the cost of the bladder pump. Both of these pumps are about half the price of the double-action piston pump. Comparing the total cost of pump and riser with accessories at 90 m in depth, the bladder pump costs substantially less than the VFD submersible and double-action piston pumps, but the current, high-purge rates needed are not possible with the bladder pump. Where various low-volume-purging techniques (e.g., low flow, minimal purge, no purge, or “micropurge”) are suitable for some wells and when purging policies change to allow their use, the best choice of pump would more likely be the bladder pump. The bladder pump is available in inexpensive flexible, fused discharge riser and air pressurization hose that keeps it very cost competitive.

3.0 Sampling Conditions

Selection of an appropriate sampling pump for use at the Hanford Site must account for the physical and chemical properties of the groundwater system being monitored, well construction, and sampling equipment parameters. Water samples, with a broad range of chemical composition, must be brought to the surface from wells of varying size, depth, and construction. These conditions are the basis for establishing the requirements that pumps must meet for groundwater sampling. The two main categories of conditions that might affect pump selection are groundwater characteristics and equipment constraints.

3.1 Groundwater System Characteristics

The main groundwater system characteristics that might affect pump selection fall into two categories: water chemistry and its related parameters (e.g., temperature, turbidity) and depth to water, including sample extraction points.

3.1.1 Groundwater Chemistry

The chemical composition of the groundwater to be sampled is an important consideration in the selection of sample pumps because the pump and riser surfaces must not react with the water between sampling events and as samples are collected. Most sampling pumps are composed of materials that minimize their reaction with the water and dissolved constituents.

Groundwater at the site can be characterized as neutral-alkaline, calcium carbonate-rich water of reasonably low specific conductance (250 to 500 μS/cm), except in some contaminant plumes. Most of the groundwater system contains dissolved oxygen up to saturation levels (8 ppm). Reducing conditions may exist in isolated locations near the bottom of the aquifer, and some areas have a sulfate component (Williams et al. 2000). Given these general characteristics, the water could be considered only mildly reactive to the stainless steel materials recently used in the wells and pump systems, but is fairly oxidizing toward the carbon steel casings used in the past (discussed in Chapter 5.0).

Contaminants that can be found and for which the groundwater is monitored include metals, nitrate, organic solvents (principally carbon tetrachloride and trichloroethylene) and various radioactive species. The radioactive species may be of anionic, cationic, and complexed neutral form. Tritium, nitrate, and iodine-129 are the most widespread contaminants associated with past Hanford operations (Hartman et al. 2000). Chromium contamination is widespread in several of the 100 Areas and extends into the surrounding areas. Strontium-90 contamination is present, but less extensive, in the 100 Areas as well. Technetium-99, uranium, cyanide, and cobalt-60 are present in limited areas in the central portions of the site, known as the 200 Areas. The highest concentrations of organic contaminants are found in the 200 West Area and consist primarily of carbon tetrachloride and associated minor amounts of trichloroethylene and chloroform. Other isotopes found rarely or sporadically and in limited groundwater areas include selenium-79; ruthenium-101; uranium-235, -236, and -238; neptunium-237; and americium-239. Pump and riser surfaces must not react with these or other constituents so that the sample composition is not changed. The potential alteration is discussed in Chapter 4.0.

3.1.2 Turbidity and Other Field Parameters

Only three field parameters are used at Hanford to meet stabilization criteria: temperature, pH, and specific conductance. It is believed that these parameters, when stabilized, help ensure that a representative sample is being collected. These criteria can be found in procedure SP: 3-1 (Waste Management Federal Services 1999). Stabilization is achieved when two consecutive measurements agree within an assigned amount or percentage.

Although not mandatory at Hanford, it has been considered desirable to have turbidity (cloudiness of the water) at or below 5 nephelometric turbidity units (NTU) before sampling begins. Turbidity is measured by directing a light beam into a sample of water and measuring the amount of light reflected back into a detector. Turbidity increases as the particulate concentration increases and is important because it can indicate the suspended content of water samples and affect the operation and maintenance of pumps. During the purging cycle, particulate and colloidal materials removed from the well and formation by various processes produce minor amounts of trace elements and potentially large amounts of iron, aluminum, and silicon (Kearl et al. 1992; Oneacre and Figueras 1996; Gibs et al. 2000). For sampling, turbidity should be kept as low as possible to minimize the inclusion of immobile particulates that are not representative of water flowing through the aquifer. Organic and inorganic particulates in the water samples are acidified when put into the sample bottles, which contain concentrated acid, and may release constituents that are not actually transported in the aquifer. When large purge volumes are mandated, it is often desirable to pump at high rates (e.g., 8 to 20 L/min). If turbidity remains low during the purging cycle, the amount of time is reduced before sampling can begin. Reducing the time needed to remove the required amount of purge water also reduces effort, cost, and safety hazards. In some monitoring wells that were incompletely developed, turbidity sometimes is elevated during the purging cycle and, sometimes, even during the sampling cycle. The 25-NTU is an important threshold that can impact metal concentrations in acidified samples (Oneacre and Figueras 1996). A level of 5 NTU is a common target level in groundwater samples not only at Hanford but throughout the environmental industry. This value was likely derived from the U.S. Environmental Protection Agency's (EPA) national secondary drinking water regulations pertaining to surface treatment of surfacewater or groundwater, "At no time can turbidity (cloudiness of water) go above 5 nephelometric turbidity units NTU." However, unlike primary drinking water standards, the regulations are nonenforceable guidelines that regulate contaminants that may cause cosmetic or aesthetic effects (EPA 1994). Furthermore, the 5-NTU target has no scientific basis because there is no evidence that turbidity of groundwater samples between 6 and 24 NTU has any impact on water-sample accuracy. In fact, what field evidence has been published (Oneacre and Figueras 1996) indicates that there is no significant effect on analyses for metals below 25 NTU. A field study of residual contamination from the monitoring wells themselves indicate levels need to be 10 NTU or less (Oakley and Korte 1996). Unfiltered sample results in this range (i.e., 6 to 24 NTU) should be given the same credibility as those at 5 NTU or less. However, to provide a cushion, 5 NTU or less is a goal (not a requirement) for turbidity in samples. If turbidity remains below 25 NTU during sampling, there is no need for turbidity to stabilize. However, where turbidity is >24 NTU during the sampling cycle, a consistent turbidity may have some importance for multiple bottle comparisons or independent laboratory quality control analyses.

All pumps are affected negatively in some way by turbidity and associated fine particulates. Between sampling events, the bladder pump and inertial lift pumps are subject to jamming of the check valves, as sediment-laden water settles in the nondraining or slowly draining column of water in the pump riser (see Chapter 5.0 for a more detailed discussion of pump characteristics). Except for high turbidity wells with coarse silt, jamming or poor seating of the check valve can be overcome in the bladder pump by use of a 0.25-mm inlet filter. Agitation by the inertial lift pump can increase the turbidity in samples, particularly in 10-cm or larger diameter wells, and may contribute to errors in analytical results (Puls et al. 1992; Powell and Puls 1993; Oneacre and Figueras 1996).

To minimize turbidity, it is important that purging be conducted at a fraction of the discharge rate used during well development. It is equally important that sampling be conducted at a discharge rate that is less than the purge rate, unless the purge rate is only a few hundred milliliters per minute or if turbidity is low at the higher initial discharge rate during purging. Also, initial water pump extraction rates must be controllable to prevent high turbidity caused by excessively high start up rates. The pump chosen must have the ability to meet these requirements.

3.1.3 Depth to Water and Extraction Points

Wells at the site can be divided into three depth-to-water ranges of 0 to 30, 30 to 60, and 60 to 125 m. To simplify the evaluation process, the largest expected pump-intake depth was used for each depth group. Three maximum depths are 30 m for the shallow group, 60 m for the intermediate group, and 90 m for the deep group. This grouping of shallow, intermediate, and deep wells is convenient because it reflects depth to water common to certain areas and relates to the performance range and operating cost of some sampling devices. For example, nearly all wells in the 100 and 300 Areas fall into the shallow range and most 200 West and 200 East Area wells fall into the deep range. Because of their wide distribution throughout the site, 600 Area wells fall into all three categories. The groupings allow for evaluation and recommendations for sampling devices that are suitable for the depth ranges at each area. These depth ranges and their importance are addressed further in Chapter 5.0. Actual extraction points are where the pump intakes are set to extract water, and should be located opposite the preferential contaminant flow path.

3.2 Monitoring System Constraints

There are two issues that pertain to monitoring system constraints: lift requirements for pumps and physical dimensions of the well and screen.

3.2.1 Lift Requirements

Lift is the vertical distance over which the pump must move water to enable a sample to be collected. Often, lift is equated to depth to water below the top of the well casing but, as will be discussed, this is not always the case, depending on the characteristics of each pump. Lift represents the actual work required for a pump to lift water to ground surface. For example, if the depth to water in a well is 30 m but the screened interval to be sampled is 60 to 65 m below ground surface, the pump intake may likely be placed at 63 m. For some pumps, the additional submergence would allow it to perform as though it were pumping from only 30 m, but other types of pumps could not take advantage of this potential efficiency and would have to lift the water 63 m. Most wells used to monitor groundwater beneath the site are completed near the water table; therefore, submergence is a significant factor for only a small number of wells.

The depth-to-water measurement is important because it represents the hydraulic head and, therefore, the lift capability required by the collection pump to obtain samples from the greatest depth in each area. It should be noted that ~90% of the monitoring wells have depths to water that are <75 m below the top of the casing. At the greater depths, 60 to 90 m, some types of devices would not be able to purge stagnant water at reasonable rates or may not even have the lift capacity to discharge water at the surface. The lift capacities of various pumps are discussed in Chapter 5.0.

3.2.2 Dimensions and Composition of Well Casing and Screen

The accessibility and ease of pump deployment in monitoring wells at Hanford are practical limitations related to the inside diameter (ID) of well screen, screen length, slot size, and slot type (turbidity during purging; see Chapter 4.0 for discussion of induced turbidity). At a minimum, the pump diameter must be small enough to fit inside the well screen and casing.

Before the new monitoring requirements were implemented in 1986, monitoring wells were constructed primarily of 15-cm-ID carbon steel casing with either 15-cm-ID perforated carbon steel casing or 12.4-cm-ID stainless steel telescoping well screen. Well-design changes were initiated in late 1986 as part of the Resource Conservation and Recovery Act (RCRA) requirements. These changes were to comply with guidance and requirements for groundwater monitoring in RCRA; Title 40, Code of Federal Regulations, Chapter 265.90; EPA (1986); and Washington Administrative Code, Chapter 173-303.

These design and construction changes were initiated in September 1986 for the RCRA permit of the 183-H solar evaporation basins and 300 Area process trenches with the installation of 30 new monitoring wells (Liikala et al. 1988; Schalla et al. 1988a, 1988b). These design improvements allowed for better hydrologic testing, reduced the purge volume and turbidity of samples, and minimized the effect of materials used in well and pump construction on the quality of groundwater samples. To allow for single pumps, most of the newer wells were initially 15-cm ID; then reduced to 10-cm ID. Diameters of most wells were constructed of 10 cm diameter casing and screen after 1988, therefore, the available pumps that could fit into the well and pump water at variable rates for the range of depths were limited to one device, the single-action piston pump. Not until 1992 was the variable-speed, small-diameter, submersible pump introduced commercially to the environmental marketplace. These pumps and others are described in Chapter 5.0.

Under current practices at Hanford, the well dimension is the primary factor used to determine the minimal amount of water that must be purged from the well screen and casing before it can be sampled. The volume of water to be removed is based on the height of the water in the well screen and the inside diameter of the well screen. Under current sampling practices at the site, three or more well volumes are removed before samples are collected. Well construction for the last 12 years has consisted primarily of stainless steel casing and well screen with an inside diameters of 10 cm. The volume contained in a given length of a 20-cm well is four times greater than that for a 10-cm well. Purge volumes range from ~40 L for some partially full well screens in 10-cm-dia. wells to >2,000 L for a few 30-cm-dia. wells. In practice, the purge volume is not actually measured, but the well is pumped at a predetermined, maximum pumping rate for a specified time to reach the require purge volume.

Therefore, the purge volume is important because if a large volume purge is required before sampling, a pump with a high maximum discharge rate is needed to minimize the purging time.
A strategy that may be applied in the future would enable groundwater samples to be collected with “no-flow,” “minimal-flow,” or “low-flow” purging procedures. Under these conditions, the purge volume would be small and the need for a high-discharge-rate pump becomes less important or even unnecessary.

Well-construction materials at Hanford since 1988 have consisted primarily of the 10-cm, flush-threaded, schedule 10/40, type 304 stainless steel casing and V-wire wrap well screen. The stainless steel was chosen because of its ease of assembly, strength, durability (particularly during maintenance), and relatively nonreactive behavior. The V-wire wrap screen was chosen because its high-percentage open area makes for better hydraulic interconnection with the aquifer. A detailed discussion of the impact of materials used in equipment in groundwater-sampling wells is presented in Chapter 4.0.

4.0 Potential Influences on Sample Characteristics

Sample quality and, ultimately, the chemical composition of the samples collected are factors in the comparison of the sampling pumps. Included in this category of comparisons are well-bore mixing, induced turbidity, pressure changes, seal leakage, temperature, and well/pump/riser composition. In the process of lifting water to the ground surface, pumps can impact characteristics of water in the well bore and riser pipe that adversely affect the chemical composition of the water. This ultimately affects how representative the sample is of the water residing in the aquifer.

4.1 Well-Bore Mixing

Ideally, water samples should be drawn from the producing zone within the screened interval, but each pump has different characteristics regarding mixing of water in the well bore prior to drawing the water into the pump. Some pumps draw water in a smooth action that minimizes mixing, while others mix the water in the well bore surrounding the pump intake before the sample is drawn into the pump. Agitation by the inertial lift pumps not only mixes water in the well bore but also can increase the turbidity in samples.

4.2 Induced Turbidity

Turbidity affects sample quality as well as pump performance. This section addresses only the increase in turbidity resulting from the sampling process and does not consider the baseline turbidity resulting from well construction and development. A goal of the sampling process is to minimize the removal of formation particles from the well that would not normally be transported with the natural groundwater flow. Some pump systems are constructed in such a way as to resuspend sediment within the well bore, where it is captured by the pump system. All pumps are affected negatively in some way by particulates associated with turbidity. Between sampling events, check valves on the pumps are subject to jamming, as particulates from the sediment-laden water settles in the pump or column of water in the pump riser. Wear of parts are likely to increase if the pump induces increased turbidity.

4.3 Pressure Changes

All of the pumps evaluated in this report are positive pressure pumps and, therefore, pressure changes are not a factor in the decision process. A negative pressure pump, such as centrifugal or peristaltic pumps, could not be used for sampling where volatile constituents are important parameters in the monitoring activity. A negative pressure will cause volatile constituents to be lost from the sample, lowering its apparent concentration (Barcelona et al. 1984, 1994). Although there is some suggestion that cavitation can occur in the impeller section of submersible pumps, the water in the discharge riser is pressurized usually far above the ambient water pressure in the well. There are no data to support a claim that volatile constituents are lost when samples are collected with VFD submersible pumps.

4.4 Seal Leakage

Seal leakage is a concern where material could be introduced to the sample from the pump. For example, some electric submersible pumps contain lubricating fluids that can leak into the well, contaminating the sample. However, no variation from historical data suggests seal leakage has not altered results for contaminants of concern at Hanford (Liikala et al. 1988; Smith 1988; Schalla et al. 1988a, 1988b; Smith et al. 1989), and other locations (Knobel and Mann 1993).

4.5 Temperature

Because the solubility of dissolved constituents is temperature dependent, a change in sample temperature can result in changes in the dissolved chemical content of the sample. Some pumps heat the sample during the pumping process and possibly change the chemical composition of the sample. However, no adverse effects of this small amount of heating on contaminants of concern have been documented in the literature (Gass et al. 1991; Parker 1994; Schalla 1996).

4.6 Well, Pump, and Riser Material

Any materials with which the water comes into contact can affect groundwater sample quality. Most manufacturers of sampling devices use materials that are the least reactive, minimally absorptive, and for which leaching are slow that still meet the functional needs of the device. Stainless steel, certain fluoropolymers, and one type of fiberglass-reinforced epoxy (FRE) are the most commonly used materials for groundwater-monitoring wells. However, some contaminants have affinities for some of these materials and may not be equally nonreactive, nonsorptive, and nonleaching. Potential sorption or leaching, with respect to these materials, is complex because the process is material type and chemical concentration specific. These materials and their suitability for use in monitoring equipment and wells are discussed in detail in Appendix A.

4.6.1 Polymeric Materials

Polymeric materials used in sampling devices and monitoring wells may include thermoplastics (e.g., PVC, chlorinated polyvinyl chloride [CPVC], and polytetrafluoroethylene [PTFE]), thermosets (e.g., FRE), and elastomers (e.g., nitrile [buna-N], silicone rubber, Viton®). Among the most popular thermoplastics, because of their stability at high temperatures and corrosion resistance, are a subgroup called fluoropolymers. A material type could be one of several commonly used fluoropolymers, such as PTFE Teflon® by Dupont; fluorinated ethylene propylene (FEP) Teflon by Dupont (also called Neoflon® by Daikin, Japan); perfluoroalkoxy alkane (PFA) by Dupont; ethylene-tetrafluoro-ethylene (ETFE) Tefzel® by Dupont; polyvinylidene fluoride (PVDF) Kynar® by Penn Walt; polyethylene (PE); high-density polyethylene (HDPE); low-density polyethylene (LDPE); polypropylene (PP); acrylonitrile, butadiene, and styrene (ABS) (Nielsen and Schalla 1991).

Thermosets, such as epoxies, require curing, and for monitoring well casing and screen are fiberglass reinforced. FRE is very durable, strong, and lightweight slotted pipe and casing compared to stainless steel, but its popularity has been limited largely because only one supplier is available that has had its materials tested for leaching and sorption. These FRE resins are resistant to acids and alkali and are almost immune to attack from most petroleum products and hydrocarbons but vulnerable to certain oxidizing agents.

Elastomers and flexible polymers (i.e., finger pressure can collapse tubing) are used where elastic and flexible properties are needed to seal joints or allow bending and flexing. Elastomers generally are far less resistant to degradation, particularly for many hydrocarbons even in dilute aqueous solutions (Nielsen and Schalla 1991; Chawla and Gupta 1993). As a consequence, only a few of these rubber products have come into common use in the environmental industry. Among the more popular elastomers are nitrile (buna-N), Viton, polysulfide, and EPDM® Rubber (Nordel®). Flexible polymers include ethylene propylene (EP), polypropylene with plasticizers (FPP), flexible polyvinyl chloride with plasticizers (FPVC), and polyvinyldine fluoride-hexaethylpropylene (P[VDF-HFP]) (a copolymer of vinylidene fluoride and hexafluoropropylene).

4.6.2 Stainless Steel Material Families

Stainless steel comes in many families and types according to AISI specifications (Chawla and Gupta 1993). The family used for groundwater-monitoring wells is known as the 300 Series. The stainless steel used in most monitoring well products are austenitic and duplex stainless steels. The most common types of stainless steels used for sampling pumps are types 302, 303, 304, 316, 321, and 329. The L that sometimes appears at the end of the stainless steel number stands for low carbon. In general, the higher the 300 number, the higher the cost of the stainless steel and the greater its corrosion resistance. Despite the higher cost, manufacturers use these higher grades in environmental sampling devices to prevent impact on sampling results. Passivation and electropolishing of these high-grade stainless steels practiced by some sampling device manufacturers further reduce the chances of influencing analytical results.

4.6.3 Potential Influence of Polymeric and Stainless Steel Materials

To obtain a representative sample, the well, pump, riser, or sampling device material must be inert to the extent that it will not significantly alter analyte concentrations as a result of sorption on, degradation (e.g., corrosion or leaching) from, or chemical interaction with well and pump materials. Historically, in the environmental industry, the preferred materials for most groundwater-monitoring wells and sampling equipment when sampling for most organic and inorganic contaminants were 300-Series stainless steels (most commonly used types are 304, 304L and 316L), rigid PVC and Teflon (actually PTFE and FEP) (Miller 1982; Barcelona et al. 1983, 1985a, 1988; Pearsall and Eckhardt 1987; Pohlmann and Hess 1988). Subsequent comprehensive studies have been published that show PVC or FRE may not be equal to fluorocarbon polymers or stainless steel for obtaining representative samples, depending on the constituents contained in the groundwater (Barcelona and Helfrich 1986; Liikala et al. 1988; Paul et al. 1988; Schalla et al. 1988a; Smith 1988; Smith et al. 1989; Hewitt 1989a, 1989b, 1992, 1994; Chamness et al. 1990; Parker et al. 1990; Parker 1992, 1995; Parker and Ranney 1994, 1997a, 1997b, 2000; Oakley and Korte 1996).

In general, studies have shown that there is relatively little sorption of cations (e.g., various metals) by PTFE compared with rigid PVC or stainless steel casings. Anions (e.g., nitrate) do not associate significantly with polymers, such as PTFE, PVC, and HDPE. Sorption of organic solvents is often group or compound specific (e.g., aliphatic halogenated hydrocarbons, trichloroethylene). A composite qualitative summary of reactivity, based on a composite of numerous references is provided in Table 4.1. Twelve primary contaminants of concern, four contaminant categories, and the suitability of specific polymeric materials and metals for use in sampling equipment and well construction are listed in the table. Based on historical information on groundwater chemistry at Hanford, this table assumes that the groundwater temperature does not exceed 22°C and the pH is >5 but <10. At higher temperatures or pH values outside of the range specified, the materials may be subject to more severe effects than noted in the table. The material in the table should only be used to alert the reader of the potential impact on sample quality and not necessarily the actual impact on sample quality. In real-time conditions, sample quality is determined more by site-specific conditions at the time of sampling, maximum sorption, desorption, or leaching potential of these materials (Robin and Gillham 1987). A detailed discussion of these issues is presented in Appendix A.

4.7 Pumps and Riser Materials in Use at the Hanford Site

In spite of its greater cost, stainless steel was selected as the material of choice over PVC and other thermoplastic materials for use on the Hanford Site because of its superior strength, ability to be passivated to reduce sorption of cations (i.e., metals and radioisotopes) and corrosion, and lower potential of altering the chemistry in the wells contaminated with organic compounds. Not only are almost all well screens and most casings currently used at Hanford composed of types 304, 304L, 316, or 316L stainless steel, so also are the sampling devices and discharge riser materials. For example are:

- Fixed rate Grundfos® pump (304 stainless steel) and riser (galvanized pipe with or without ABS pipe)

- HydroStar™ pump (Teflon, passivated 304 stainless steel) and riser (304 or 304L pipe with 302 and 303 rod and coupling nuts)

- Variable Frequency Drive (VFD) Grundfos submersible pumps (304 and 329 or 316L and 329 stainless steel, Teflon or PVDF and FPM® Rubber and riser (304 or 304L pipe)

- Kabis™ sampling device (321 stainless steel)

- The Fultz gear-driven pump is composed of 316L stainless steel with Teflon rotors. Discharge hose consists of either a flexible, 1.3-cm inside diameter Teflon hose, or 1-cm diameter vinyl hose.

Table 4.1. Contaminants and Interactions with Metals and Polymeric Materials

	Metals						Polymeric Materials												
	Stainless Steel				Carbon Steel		Thermoplastics/Fluoropolymers								Thermoset	Elastomers			
	Standard		Passivated	Special															
Constituent	304	316	304L, 316L	321, 329	A53gB	Galv.	PTF	TEF	ETF	PVC	PVD	HDPE	PP	AB	FRE	VDF-HEP	Viton	Nitril	FPVC
Carbon Tetrachloride	1d*	1d*	1d*	1d*	1o	1d*	1a*	1a*	1a*	2o*	1d*	1a	2o	3a	1d	?	1a	1a	2o*
Chloroform	--	--	--	--	1o	--	1a	1a	?	1a	1a	1a	1a	3a	1d	?	1a	1a	2o*
cis-1,2-Dichloroethylene	--	--	--	--	1o	--	1a	--	?	2o*	--	?	?	3a	1d	--	1a	1a	2o*
Cesium-137	1a	1a	--	?	1a	?	--	--	--	--	--	--	--	?	--	?	--	--	?
Cobalt-60 and -57	2a	?	?	?	2a	?	--	?	?	--	?	?	?	?	?	?	?	?	?
Hexavalent Chromium	1d	1a	--	--	3o	2o	--	--	?	--	--	?	?	1d	1d	?	?	?	?
Nitrate	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Strontium-90	3a	3a	--	--	3a	1a	1o	1o	--	1o	1o	1o	1o	1o	?	?	--	--	?
Technetium-99	1a	1a	--	--	1a	1a	1o	1o	--	1o	1o	1o	1o	1o	?	?	--	?	?
Trichloroethylene	--	--	--	--	3o	?	2a	2a	?	2o*	?	2a	2a	3a	1d	--	1a	1o*	3o
Tritium	--	--	--	--	--	--	1o	1o	--	--	?	1o	?	?	--	?	--	--	?
Uranium	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
Weak Acids	--	--	--	--	1c	2c	--	--	--	--	--	--	--	--	1o	?	--	1o	?
Weak Bases	--	--	--	--	--	1o	--	--	--	--	--	--	--	--	1o	?	--	--	?
Petroleum and Fuels	1c*	1a*	--	--	3o*	1d	--	--	--	1a	--	1o	2o	2o	--	?	--	--	3o
Weak Oxidizing Agent	--	1o*	--	--	3c	2c	--	--	--	--	--	2o	2o	1o	2o	?	--	2o	?

-- = No effect.
1 = Minor potential effect.
2 = Moderate and likely significant effect.
3 = Severe effect.
a = Adsorption is most significant effect.
d = Desorption is primary effect.
o = Other interactions that degrade the material and potentially affect sample accuracy.
c = Used in place of o when corrosion is most important form of degradation.
* = Free-phase organic, implying contaminant does not have a significant effect or reaction with material.
? = No data available to define material performance or relation to contaminant of concern.

The risers on the fixed discharge rate submersible pumps currently used at Hanford are sometimes made of 304 or 304L stainless steel, but more commonly the risers are composed of either Acrylonitrile-Butadiene-Styrene (ABS) or galvanized carbon steel pipe. The use of galvanized steel risers is a poor choice because of the potential for galvanic and other forms of corrosion (Barcelona et al. 1983, Nielsen and Schalla 1991). While the electroplating process of galvanizing (application of a zinc coating) somewhat improves the corrosion resistance of either carbon steel, in many environments the improvement is only slight and short-term. The products of corrosion of galvanized steel include iron, manganese, zinc, and cadmium (Barcelona et al. 1983). Elevated levels of zinc have been detected in groundwater samples from wells with galvanized steel risers at the Hanford Site. ABS riser has been used below the water level in some wells to prevent or reduce galvanic corrosion. However, this non-food grade ABS has been considered such a poor choice for monitoring wells that little research had been published on it for a decade. Even PVC of a particular type that is stamped with the NSF logo showing that is approved by the National Sanitation Foundation (NSF) is limited to use for cold water pipes.

The HydroStar piston pump is the most commonly used pump in use at the Hanford Site. It is composed of passivated 304L stainless steel and Teflon. The 1.9-cm inside diameter riser is composed of passivated 304L stainless steel, and the 0.64-cm piston rod and nuts are made of either 302 or 303 stainless steel.

At Hanford the power cable for the submersible pump is composed of either twisted, rubber coated solid core or double sheathed, flexible PVC. The PVC wire is preferable for monitoring wells because it is less reactive and more durable. Even so, the PVC wire should primarily be used above the water level in the well, and Teflon or better still Tefzel used below the water table.

In addition, to the Hydrostar and the fixed discharge rate submersible pump, the Variable Frequency Drive (VFD) Grundfos submersible pumps have been installed this year for the first time in new and existing wells at the Hanford site. Previously, it had been used for special sampling applications on a limited basis and had never been used as a dedicated pump. For these new pumps there are a variety of materials to choose from for discharge risers. Even though Polytetrafluoroethylene (PTFE) Teflon, Fluorinated Ethylene Propylene (FEP) Teflon lined Polyethylene (PE), High Density Polyethylene (HDPE), and polypropylene (PPE) are used commonly in the environmental industry, the stainless steel risers were chosen because they are available.

Neither the Kabis device, which is a differential pressure bailer, nor the Fultz pump are used as dedicated sampling devices. These two sampling systems are used only for special sampling situations in the existing wells.

4.8 Pumps and Riser Materials Considered for Use at the Hanford Site

The six sampling pumps listed in Table 2.1 are constructed from materials that are considered chemically inert for purposes of groundwater sampling. A comparison of materials used and their relative inertness under various conditions is presented in Table 4.1 The discharge riser is a matter of choice, but Polytetrafluoroethylene (PTFE) Teflon, Fluorinated Ethylene Propylene (FEP) Teflon lined Polyethylene

(PE), High Density Polyethylene (HDPE), and polypropylene (PP) are used commonly. These alternative materials used for discharge risers are discussed in detail in Appendix A.

The body and impellers of the Redi-Flo2® and Redi-Flo4™ Variable Frequency Drive (VFD) Grundfos submersible pumps are composed primarily of 316 or 304 stainless steel, respectively. The splined shaft of the Redi-Flo2 and Redi-Flo4 are composed of 329 and 304 stainless steel respectively with spacer and wear rings of the pump composed of virgin PTFE Teflon. The pump motors are surrounded by deionized water. The Redi-Flo3® is composed of 316 and 316L stainless steel with some internal parts composed of PVDF and FPM® Rubber (Viton equivalent). Either deionized water, or more commonly, a mixture of mineral free water and propylene glycol surrounds the pump motor of the Redi-Flo3.

The Well Wizard® bladder pump by QED Environmental Services, Inc. is composed of either rigid Polyvinyl Chloride (PVC) with Teflon bladder or electro-polished 316L stainless steel with Teflon bladder and parts. The discharge riser is a matter of choice, but PTFE Teflon, FEP Teflon lined Polyethylene (PE), HDPE, and Polypropylene (PP) are used commonly.

The Bennett piston pump is composed of 304 stainless steel, polypropylene, Nylon, and Teflon. The water discharge tube is commonly composed of FEP Teflon.

The HydroStar piston pump in use at the Hanford Site is composed of passivated 304L stainless steel and Teflon. The 1.9-cm inside diameter riser is composed of passivated 304L stainless steel, and the 0.64-cm piston rod and nuts are made of either 302 or 303 stainless steel.

The Keck, Inc. progressive cavity pump is composed of 303 and 304 stainless steel with Viton O-rings and EPDM flexible rubber rotor or screw. The discharge riser is composed of PTFE Teflon, FEP Teflon lined Polyethylene (PE), HDPE, or Low Density Polyethylene (LDPE).

The Fultz gear-drive pump is composed of 316L stainless steel with Teflon rotors. Discharge hose consists of either a flexible, 1.3-cm inside diameter Teflon hose, or 1-cm diameter vinyl hose.

5.0 Comparison and Selection of Sampling Pumps

Groundwater-sampling pumps vary in their basic design, their dimension, their operational needs (i.e., electricity, compressed air, actuator rods), their capabilities (i.e., lift, variation in flow rate), and their relative cost. From a wide array of sampling pumps, six types of pumps that are commonly used in groundwater sampling were selected for a detailed evaluation against seven criteria. The seven pump criteria included physical dimension, lift capability, effect on sample quality, flow-rate range, power requirements, maintenance, and cost.

5.1 Basic Types of Groundwater Pumps for Sampling

Groundwater-sampling pumps vary in their basic design, their dimension, their operational needs (i.e., electricity, compressed air, actuator rods), their capabilities (i.e., lift, variation in flow rate), and their relative cost. Three broad categories of sample-collection devices are described in the literature (Nielsen and Yeates 1985; Pohlmann and Hess 1988; Herzog et al. 1991). The three sample-collection categories are grab mechanisms, suction-lift mechanisms, and fixed and variable discharge-rate pumps.

Common grab mechanisms, such as bailers and syringe pumps, deploy a sampling device to the sample interval, where it is passively or actively filled with water. Most of these devices have capacity (volume) limitations that are important when purging is required because they are slow and cumbersome. Repeated introduction may disturb the environment, making it impossible to collect a representative sample.

Suction-lift mechanisms include centrifugal and peristaltic pumps that pull the sample up to the surface by decreasing the head, or pressure, over the sample (Barcelona et al. 1984; Imbrigiotta et al. 1988; Puls and Barcelona 1989a, 1989b). Potential losses of some volatile constituents may occur when samples are collected by these types of pumps. Also, the maximum lift of these devices is <32 ft.

For these reasons, grab mechanisms and suction-lift mechanisms are eliminated from further consideration for routine sampling at the Hanford Site.

The variable discharge-rate pump category includes variable- and positive-displacement pumps and consists of nine commonly used pumps:

1. gas-lift devices, such as the Hammerhead®
2. gas-driven (gas-displacement) devices, such as the MonoFlex®
3. inertial lift pumps, such as the Waterra®
4. VFD electric submersible pumps, such as the Redi-Flo2® or the Flint & Walling Company equivalent
5. gas-operated bladder pumps, such as the QED Well Wizard® or Isomega®
6. compressor-operated, double-action, piston pumps, such as the Bennett
7. compressor-operated, single-action, piston pumps such as the HydroStar™
8. progressive cavity pumps, such as the Keck
9. gear-driven pumps, such as the Fultz.

The first three types of pumps on the list of nine can be quickly eliminated from further consideration. The gas-driven and -lift pumps are not suitable for most environmental sampling applications because an interface exists between the drive gas and the water to be sampled. This situation causes a potential for loss of dissolved gases and volatile constituents across the interface and for contamination to enter the sampled water from the drive gas (Barcelona et al. 1985a, 1985b). However, under certain circumstances, the impact may not be statistically significant (Schalla et al. 1988b).

The inertial lift pumps are reciprocating pumps, where the pump and the entire length of tubing move up and down on each stroke. A rapid upstroke closes the foot valve, which prevents the water from draining out of the tube, and lifts the water column inside the tubing a distance equal to the stroke. On the downstroke, water in the pump and riser column continues moving upward as the pump descends. In wells larger than 2-in. dia., the tube tends to whip against the inside of the well casing, agitating and mixing the water and increasing the turbidity.

Conventional fixed discharge rate submersible pumps are not suitable because they do not fit safely into wells with 4-in. screen or 5-in. telescoping screen and, more important, their discharge rate can not be varied significantly without damage to the pump motor. Also, it is not possible to change the discharge rate by varying the current frequency sent to the pump. The discharge rate can only be adjusted in a standard submersible by applying back pressure to the pump or by using a bypass or bleed valve to obtain water at a lower flow rate. This bleed valve does not actually change the discharge rate, it only changes the sample flow rate.

5.2 Description of Six Pumps Evaluated for Groundwater Sampling

The remaining six types of pumps on the list of nine are commonly used in the environmental industry to obtain representative groundwater samples. Descriptions of their basic operation or how they work are provided in the following paragraphs.

The first of the six pumps is a VFD submersible. Both models of this device consists of an electric motor that drives two or more sets of impellers at high rates of rotation, bringing water to the surface at a continuous discharge rate (Figure 5.1). The power source is either a 110- or 220-V vehicle mounted generator. Water can be transported to the surface with 1.9-cm-dia. stainless steel riser commonly used on the Hydrostar pump, or small diameter flexible polymer tubing.

The second type of pump, and perhaps the most commonly used type of dedicated sampling pump in the environmental industry, is the bladder pump. Bladder pumps are available in numerous design configurations to fit almost any condition. The most common and least expensive is shown in Figure 5.2. The device is operated using compressed air that squeezes a flexible bladder to displace water out of the pump chamber into the riser and above a one-way check valve (i.e., not shown, but the top of the pump housing). The air chamber outside the bladder is deflated and the pump chamber is allowed to refill with water from the well through an intake valve (i.e., lower ball valve), and the cycle is repeated. The pumping operation is accomplished in cycles and therefore surface discharge is discontinuous. Discharge

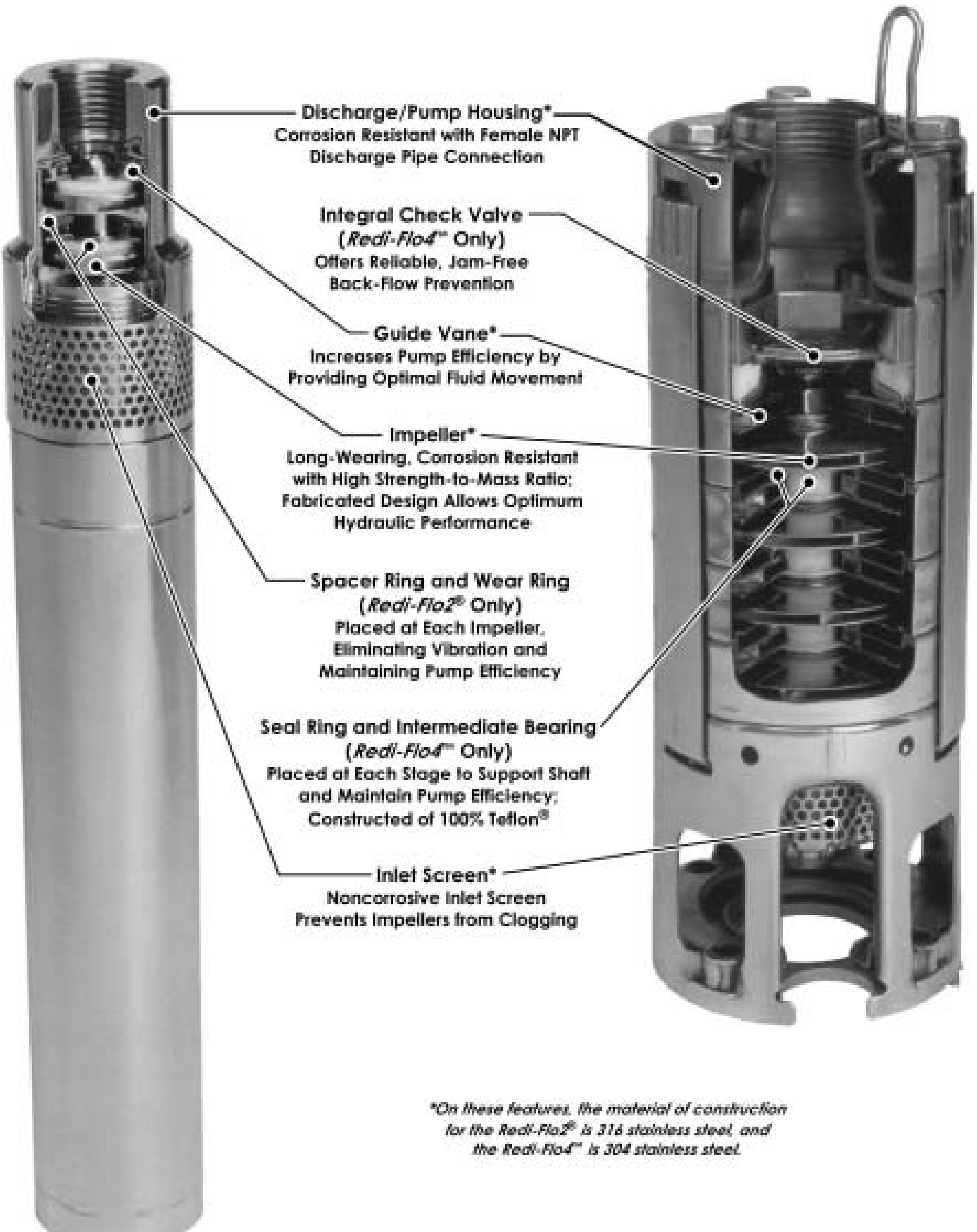

Figure 5.1. Variable Frequency Drive Submersible Pump (Redi-Flo2 and Redi-Flo4)

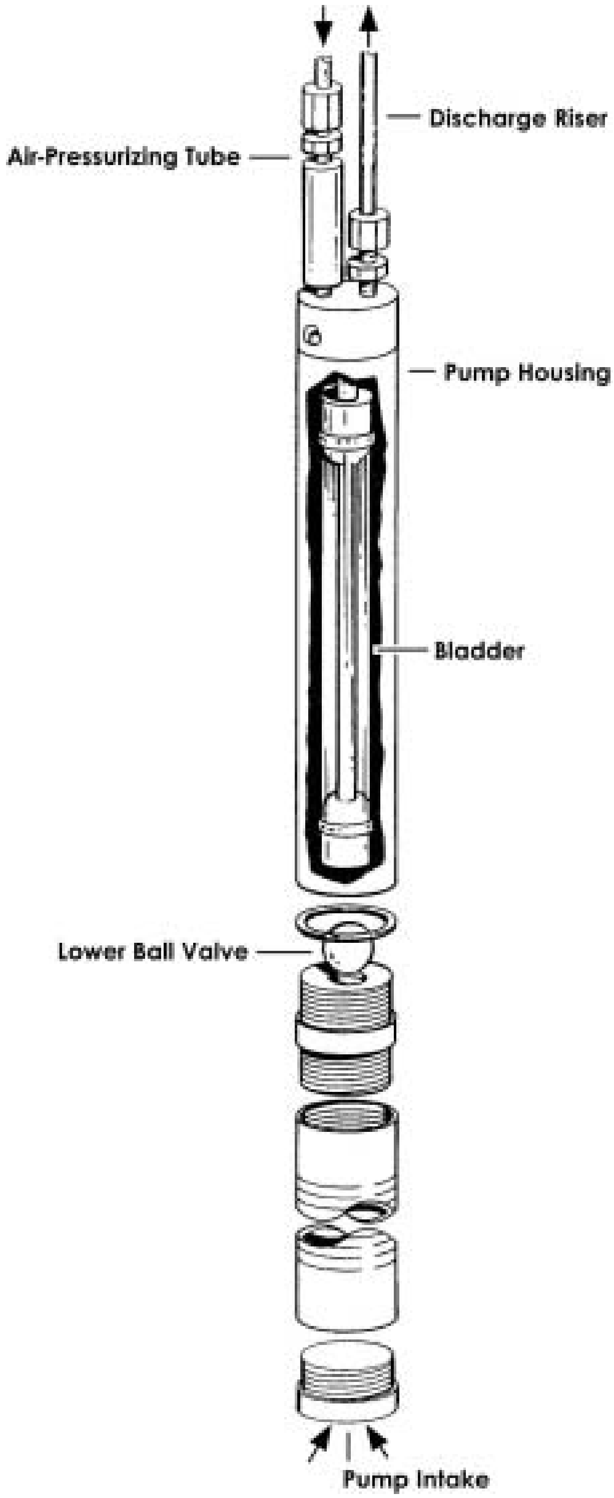

Figure 5.2. Bladder Pump (QED)

risers are generally comprised of flexible tubing in 1.3-, 0.9-, or 0.6-cm ID sizes. The compressed air-supply tube is 0.6-cm ID. The device is operated at the surface by a controller that determines flow rates by varying cycle speeds and compressed air pressure.

The third type of pump is a double-action piston pump manufactured by Bennett (Figure 5.3). The water is pumped during both the forward and return strokes of the piston. Compressed air, delivered to the pump at depth, is used to actuate the pump. Maximum discharge rates are 12% to 45% less than the currently used single-action piston pump, the HydroStar, at similar depths. Again, surface-flow-restriction methods are used to make the surface discharge a more continuous stream of water.

The fourth type of pump is also a piston pump. This type is a single-action HydroStar, which is the most commonly used sampling pump at Hanford (Figure 5.4). The HydroStar is a mechanically driven, positive displacement, piston pump that uses traditional s*ucker-rod* technology. A rigid rod assembly that actuates the piston is driven from the surface by a portable air motor. The motor provides the reciprocating action to operate the piston. Orifice restrictors on the air motor control the pump discharge rate. The spring is now rarely included in these pumps because they have a rigid rod that replaces the flexible cable and its weight helps drive down the piston. Also, it is operated by compressed air rather than hand pumping in earlier versions. No air is introduced into the well to operate this pump. Both the Bennett and the HydroStar provide a cyclic, discontinuous sampling stream at the surface.

The fifth type of pump is the Keck progressive cavity pump (Figure 5.5) and is similar in concept to the Moyno pump used in the drilling and oil industry. The design may have had its roots based on the Archimedes screw that raises water by means of a rotating, broad-threaded screw inside an inclined hollow cylinder. The progressive cavity pump uses a vertical cylinder with a spirally bent flexible EPDM® Rubber (Nordel®) tube that rotates at high speed. A 12-V car alternator that produces 14.3 to 14.5 V when running operates the rotating motor. It is necessary to have the engine running in the vehicle to have the higher voltage or the lift capability drops and discharge rates are reduced.[1] Flow of water through the pump and at ground surface is continuous through either a 1.3-cm polyethylene or 1-cm-dia. Teflon® hose.

A gear-driven pump (Figure 5.6), as manufactured by Fultz, is the sixth type of pump. The device consists of a gear-driven set of two rotors in a type 316L stainless steel pump chamber. The rotors are turned by an electric motor than can be operated by a 12-, 24-, or 36-V battery or 110-V power source with an inverter.[2] The device provides a steady stream of water for both of the models shown in Table 5.1. The discharge riser consists of a flexible, 1.3-cm-ID Teflon hose or 1-cm-dia. vinyl hose.

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[1] Personal communication with Mr. Don Fogle of Keck Instruments, Inc., February 23-24, 1999.

[2] Personal communication with Ms. Candy Steinway of Fultz Pumps, Inc., February 22 and 24, 1999.

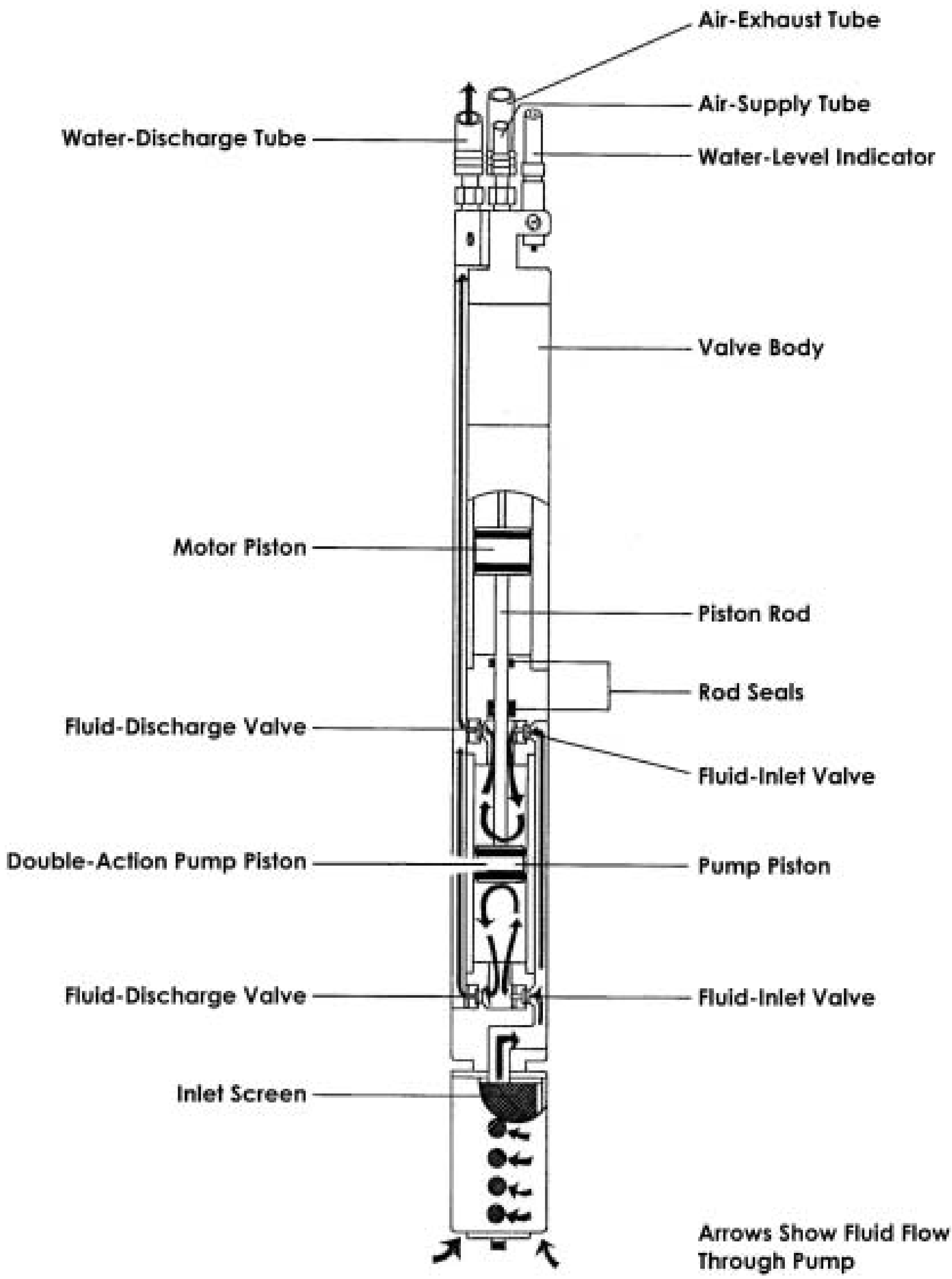

Figure 5.3. Double-Action Piston Pump (Bennett)

Figure 5.4. Single-Action Piston Pump (HydroStar)

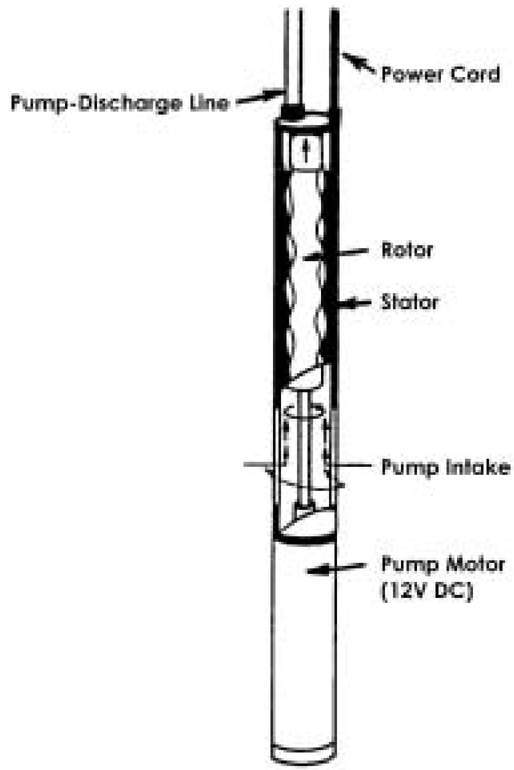

Figure 5.5. Progressive Cavity Pump (Keck)

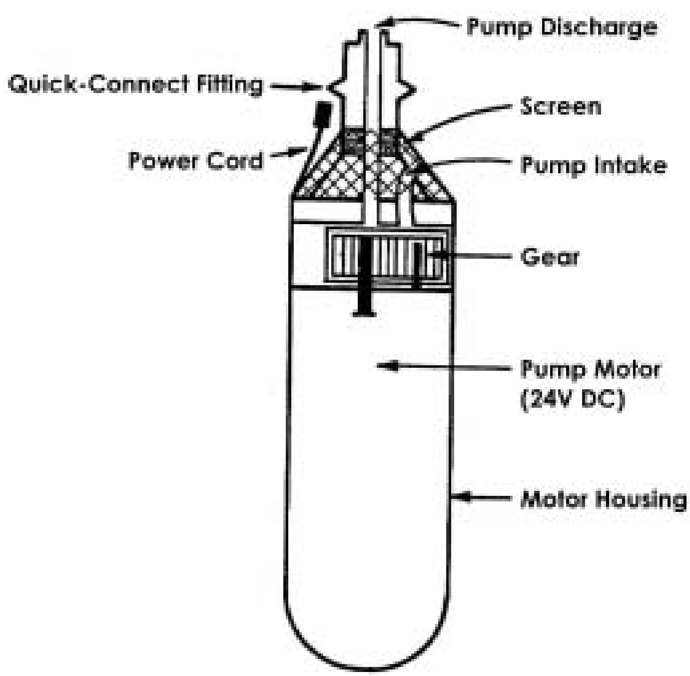

Figure 5.6. Gear-Driven Pump (Fultz)

Table 5.1. Physical Dimension – Outside Diameter

Characteristic	Redi-Flo2® (3™) [4™] Submersible Pump	QED Bladder Pump	Bennett Piston Pump 1800-8	HydroStar Single-Action Piston Pump	Keck Progressive Cavity Pump	Fultz SP201 [SP300] Gear-Driven Pump
Outside Diameter (cm)	4.6 (7.4) [9.7]	3.8	4.3	4.3	4.5	4.5 [6.4]

The material presented herein describes how well each of the pump types and models meet the performance criteria. Additional details for the sample representativeness criterion can be found in the preceding chapters and Appendix A. The seven criteria are listed below:

1. physical dimensions
2. lift capability
3. effect on sample quality
4. flow-rate range
5. power requirements
6. maintenance
7. cost.

For this selection process, each pump is judged individually, based solely on the characteristics of each pump. Even though some of the pumps are gradually eliminated from consideration as we progress through the evaluation criteria, they continue to be included in subsequent tables and the narrative for completeness and consistency. Also, they will continue to be considered for special groundwater sampling applications where portability, discrete zone sampling, or low-flow sampling is required.

5.3 Physical Dimensions

The most important and restrictive dimension is the largest outside diameter of the pump plus at least 2 cm of clearance (i.e., 1 cm all around) between the smallest inside diameter of the well casing and screen. At least one model of each pump type must be able to fit inside a 10.1-cm-dia. well, because the majority of monitoring wells at Hanford have this inside diameter as a limiting dimension at the pipe couplings. Also, certain manufacturers of stainless steel continuous wire wrap well screen have inner diameters of 10.1-cm well screen slightly less because of the placement of the vertical support rods and protruding welds between couplings and well screen. All of the models of pumps evaluated, with the exception of the Redi-Flo4™, meet this requirement. The physical dimensions of the pumps in relation to the well were considered and are given in Table 5.1. In general, the VFD centrifugal submersible pump (Redi-Flo2® and Redi-Flo3® by Grundfos), bladder pump (Well Wizard® T1200 by QED Environmental Systems, Inc.), double-action piston pump (Bennett 180 and 1800 by Bennett), single-action piston pump (HydroStar™ 8001 by Instrumentation Northwest, Inc.), progressive cavity pump (Keck, Inc.), and gear-driven pump (SP201 or SP300 by Fultz Pumps, Inc.) will fit easily into the well dimensions and type of construction of Hanford monitoring wells. The only exception was the larger diameter, VFD submersible pump (Redi-Flo4™) that would not provide sufficient clearance (i.e., <0.25 cm) in the well screen of a 10.1-cm-dia. well. Therefore, this version should only be used in wells with 12.7-cm ID or larger. At Hanford there are many monitoring wells with the internal diameters of 12.7, 15.2, and 20.2-cm. A small number of monitoring wells even have larger diameters. In many of these larger diameter wells that currently require removal of hundreds of gallons before samples can be collected, the VFD submersible pump Redi-Flo4™ is superior to all the other pumps because of its high discharge rate even at great depths.

Although adequate clearance for insertion and removal of the pump is the most important dimension considered, submergence of the pump can be important if water levels in the well are a few feet or less. With less than 30 cm of water in the well, none of these devices can pump water effectively for sampling. If only 60 cm of water is in the well screen and assuming no measurable drawdown occurs during pumping, certain models of all six pumps can pump water to the surface. Specific models suitable are the Redi-Flo2 submersible, the T1250 QED bladder pump, the Bennett piston pump 1800-8, the model 8001 HydroStar piston pump, the field portable version of the progressive cavity pump, and the Fultz SP 201 gear driven pump.

5.4 Lift Capability

The pump must be able to provide lift of up to 90 m. While pumps that cannot meet this lift capacity could be used at many locations where the water table is closer to ground surface, they could not be used as an exclusive standard across the entire monitoring network. However, a pump type may meet this requirement using more than one model, but at least one model must meet this requirement.

The ability of the pump to lift water to the surface in all areas at Hanford is an important consideration (Table 5.2). Currently, 90% or more of all monitoring wells at the site have depths to water of 76 m or less. Several of the remaining 10% were originally designed as piezometers, completed at various depths, but have since been used to collect samples to evaluate groundwater chemistry. Many of these are 5.1 cm dia. (and smaller) wells and would likely be suitable to other small-diameter pumps. Many other deeper wells, exceeding 90 m, are 15 cm and larger in diameter and currently contain fixed-discharge-rate, 10-cm-dia., submersible pumps. In these wells, the Red-Flo4 would be an ideal substitute because of its lift capacity and variable discharge rate. However, the focus of this report was to select a single type of pump that would perform over a large range of depths for the 10-cm and larger diameter wells. Neither the progressive cavity pump nor the gear-driven pump can perform in the majority of wells that have depths >76 m. This effectively eliminates these two devices from further consideration. Both the RediFlo2 of the VFD submersible pump and the QED Model T1200 bladder pump approach the end of their normal performance range at 76 m, and the ability to pump water to the surface declines rapidly to zero as a lift nears 90 m. The QED also has a high-pressure model that can pump from much greater depths. Also, both the RediFlo3 and 4 can pump from almost any deep well at Hanford.

Table 5.2. Lift Capability

Characteristic	Redi-Flo2® (3™) [4™] Submersible Pump	QED low [high] pressure Bladder Pump	Bennett Piston Pump 1800-8	HydroStar Single-Action Piston Pump	Keck Progressive Cavity Pump	Fultz SP201 [SP300] Gear-Driven Pump
Maximum Lift (m)	85 (110)[183]	82 [305]	305	122	46	61

5.5 Effect on Sample Quality

In the process of lifting water to the ground surface, pumps have the potential to impact characteristics of water in the well bore and riser pipe that adversely affect the chemical composition of the water. This ultimately affects how representative the sample is of the water residing in the aquifer. Based on the published literature, there appears to be no significant difference in the quality of contaminants of concern obtainable between the six sampling devices evaluated; however, there can be an impact on certain indicator parameters. A comparison of the devices in this category does not provide a basis for disqualification using current purging and sampling procedures. Table 5.3 summarizes seven factors relating to sample representativeness that may be affected by the pump.

The first factor considered is mixing. None of the six pumps cause mixing of air and water when properly maintained. Water samples should be drawn from the producing zone within the screened interval, but each pump has different characteristics regarding mixing of water in the well bore prior to drawing the water into the pump. Some pumps draw water in a smooth action that minimizes mixing, while others mix the water in the well bore surrounding the pump intake before the sample is drawn into the pump.

Second is agitation by the pump, which can increase the turbidity in samples. This turbidity may contribute to errors in analytical results, particularly in unfiltered samples (Puls et al. 1992; Powell and Puls 1993; Oneacre and Figueras 1996). The ability to control the rate of fluid extracted from the well screen is limited to some extent by the pumping device. The VFD submersible pumps initially will draw in water at excessively high rates if the control knob is turned up too rapidly. Pumping rates can exceed 30 liters per minute and produce an initially high turbidity until head builds up in the discharge riser and thus slowing the discharge rate to more reasonable flow rates. For example, the RediFlo2 should only be turned up to 47 to 49 hertz initially to begin pumping water even if the final lift will require 300 hertz to discharge the water at the surface at less than one liter/minute. A similar approach at even lower hertz is required for the Redi-Flo4. The Redi-Flo3 starts at 70% of its maximum hertz and will always produce initially high turbidities if sufficient quantities of particulates are in the filter pack or formation. Initially high turbidities can also be caused using the progressive cavity pump and the gear driven pump. The piston pumps can also cause turbidity if started at too high a rate. The bladder pump is unlikely to cause a significant increase in turbidity unless the amount of submergence is great, and the fill and discharge cycles are set incorrectly.

Turbidity can be indicative of abrasive materials in suspension that can damage a pump’s vulnerable, soft, moving parts. The progressive cavity pump has a rubber drive tube that can wear from abrasives. In the gear-driven pump, fluid is carried between gear teeth and displaced when they mesh. The gears wear rapidly from abrasive particles in turbid water. Running tolerances are very close and performance quickly drops off. The single-action piston pump has delicate Teflon U-cups, and the double-action piston pump has acetyl plastic check-ball valves. Both pumps drawn in and force out fluids by pistons, which reciprocate in the cylinders. The pumps require seals that have very close running tolerances that are rapidly degraded in high turbidity wells. The elastomeric rod seals that prevent air in the motor from entering the fluid pump are vulnerable to particulates. Perhaps the least vulnerable of the six pumps appears to be the submersible when no check valves are installed, which allows the water to drain out of

Table 5.3. Effect of Pumps on Sample Representativeness

Representativeness Factor	Redi-Flo2 (3) [4] Submersible Pump	QED Bladder Pump	Bennett Piston Pump 1800-8	HydroStar Single-Acting Piston Pump	Keck Progressive Cavity Pump	Fultz SP201 [SP300] Gear-Drive Pump
Well Bore Mixing	No Mixing	No Mixing	No Mixing	No Mixing	No Mixing	No Mixing
Induced Turbidity	Initially High	Initially High	Initially High	Initially High	Low	Low
Pressure Changes	Positive Pressure	Positive Pressure	Positive Pressure	Positive Pressure	Positive Pressure	Positive Pressure
Low-Flow Sampling	Yes (No) [Yes]	Yes	Yes	Yes	Yes	Yes
Seal Leakage	Possible	Low	Possible Air Leakage	Possible	Low	Low
Temperature	Increase Possible	No Increase	Increase Possible	Increase Possible	Increase Possible	No Increase
Pump/Riser Surface Composition	316, 329/304 SS, Teflon; (316, 316L/304 SS, PVDF, PP FPM Rubber); [304 SS/304 SS, Teflon]	316 SS, Teflon, HDPE, PPE	304 SS, Teflon, PPE, Nylon	Passivated 304L SS, Teflon, 302 or 303 SS	303/304 SS, Viton®, EPDM, HDPE, LDPE	316L SS, Teflon, Vinyl, Nylon

the riser in less than a minute after the pump is shut off. Even though the impellers and chamber are all made of durable stainless steel, the Teflon washers between the metal impellers and the pump motor wear after extended use from large quantities of fine particles.

Pressure changes are the third factor in Table 5.3. Pressure changes in pumps previously disqualified, which are not part of the six considered here, have been known to have significant effects on water chemistry (Barcelona et al. 1984). Based on the relevant literature the pressure changes that occur in the six pumps considered here have never been shown to have a significant effect on contaminants of concern. In the risers of all these pumps the pressure is positive, however, there are some slight to significant drops in pressure in all these devices. Five of these pumps have slight drops in pressure in the water as it enters or passes through the pump depending on the pumping rate and depth of submergence in the water. These are usually trivial changes having no effect on water chemistry. Only the VFD submersible pump has the potential to cause substantial drops in pressure and actually cause momentary cavitation.

The fourth factor is low-flow sampling. Even though under current practice, the pump must be capable of purging large quantities of water (20 to 250 gallons) in about 30 to 60 minutes, the pump should also sample at a low flow rate during sample collection. The currently accepted sampling technique of purging the well of a specified large volume makes essential the upper flow rate at which a pump can discharge water from a well. Equally important is the ability to reduce the flow rate to between 100 and 500 mL/min during sampling. Because the flow rate that each pump is capable of producing decreases as the lift distance increases, flow rates at three lift distances (discussed in Section 5.6 and shown in Table 5.4) are used as representative of vertical lift thresholds or maximum lifts required at areas at Hanford.

Table 5.4. Flow-Rate Ranges

Characteristic	Redi-Flo2® (3^{TM}) [4^{TM}] Submersible Pump	QED Bladder Pump	Bennett Piston Pump 1800-8	HydroStar Single-Action Piston Pump	Keck Progressive Cavity Pump	Fultz SP201 [SP300] Gear-Driven Pump
Maximum Design Flow Rate (L/min)	30 (29) [39]	5.7	10	19	4.6	9.1 [10.2]
Typical Flow Rate @ 30 m of Lift (L/min)	29	2	10	18	2	8 [10]
Typical Flow Rate @ 60 m of Lift (L/min)	8	1.6	9	12	Lift Capacity Exceeded	4 [8]
Typical Flow Rate @ 90 m of Lift (L/min)	(14) [39]	1	7	8	Lift Capacity Exceeded	Lift Capacity Exceeded
Minimum Achievable Flow Rate (L/min)	0.1 (10) [0.2]	0.1	0.1	0.2	0.1	0.1

If purge rates are too high, the possibility of altering sample chemistry caused by purging with positive displacement sample pumps has been suggested (Puls and Barcelona 1989a, 1989b; Puls and Powell 1992; Puls et al. 1992). Also if the rate of groundwater withdrawal from the aquifer is too great vertical gradients may result in flow from undesired portions of the aquifer. The purge and sample extraction rate must be controlled such that water is collected from the target zone.

Studies conducted by Gass et al. (1991) and Knobel and Mann (1993) concluded that low-flow-rate, submersible pumps could deliver representative groundwater samples. A study conducted by Paul and Puls (1992), comparing a low-flow-rate, submersible pump; a bladder pump; and a peristaltic pump, concluded the submersible produced the fewest negative impacts when trying to obtain representative and reproducible groundwater samples at the particular site for the wells investigated. However, it is very difficult to control the initial and sustained extraction rates at 100 mL/min with the VFD submersible, the progressive cavity pump, or the gear-driven pump. Piston pumps also have some difficulty with close control of discharge rates. Although initial and sustained discharge rates are partially empirically estimated for the bladder pump, the new bladder pump control system by QED allows for programming the appropriate settings for each well. During subsequent sampling visits to the well a code number is entered and the control system automatically makes the pump remove water at the desired discharge rate plus or minus less than 10%. While research performed by Yeskis et al. (1988) indicates that even conventional submersibles perform similarly to bladder pumps when collecting samples for volatile organic compound analysis, bladder pumps have been generally considered the type of sampling pump that perturbs groundwater samples the least, and studies tend to use it as a reference standard (Barcelona et al. 1984; Unwin 1984; Nielsen and Yeates 1985; Muska et al. 1986; Keely and Boateng 1987a, 1987b; Pearsall and Eckhardt 1987; Imbrigiotta et al. 1988; Liikala et al. 1988; Schalla et al. 1988b; Yeskis et al. 1988; Gass et al. 1991; Paul and Puls 1992; Parker et al. 1993; Knobal and Mann 1993; Puls and Paul 1995).

Conventional submersibles and the Rediflo3 that are capable only of high discharge rates are capable of obtaining representative samples in some hydrogeologic settings (Muska et al. 1986; Liikala et al. 1988). However, some authors have expressed concerns about the high discharge submersibles (Puls et al. 1992; Parker 1994). The possibility exists that sampling at other than low flow rates may alter the concentration of volatile constituents in samples or draw water from zones other than the target sample interval.

Seal leakage is the fifth factor in Table 5.3. Historically, the primary difficulty with the HydroStar has been leakage at the top of the riser as the Teflon gasket wears against the stainless steel drive rod. This allows air to leak into the discharge riser on the down stroke and to a limited extent may add air to the sample during the upstroke (i.e., discharge stroke). No impact has ever been noted on samples at Hanford. Usually, current maintenance practices prevent this type of leakage continuing for more than one or two sampling events. A similar concern has been expressed for the Bennett that has a potential air contact point if the seals leak. The air contact would occur deep in the well inside the pump. If such leakage occurred, water chemistry results could be altered, but this scenario has never been documented in the literature. Unlike the piston pumps, seal leakage that would allow air to enter the water is not really a significant concern or likely possibility in the other four types of pumps. Although not a disqualifying factor, the potential for such leakage should be noted at least as a factor in maintenance.

Heating caused by the pump is the sixth factor in Table 5.3. Pumps that incorporate energy transferred down into the well can transfer heat to the groundwater. The amount of sample heating is a function of the flow rate and the lift required for the sample to reach ground surface. Generally, the harder the pump has to work to get the sample to the surface, the greater will be the heating. Only the VFD submersible pump creates potentially significant heating of the sample water ranging from near zero to 3.5°C (Gass et al. 1991; Parker 1994; Schalla 1996). The highest discharge riser temperature usually occurs during the sampling cycle when the discharge rate is reduced (Schalla 1996). The pump motor actually generates less heat at the lower discharge rate, but less cool water is available for dissipating the heat from the pump motor. No significant adverse effects of this heating phenomenon on values obtained for contaminants of concern have ever been documented in the literature.

In general, studies have shown that, if adequate purging is done and sampling follows immediately, the nature of the materials used in the pump and riser (i.e., factor 7 in Table 5.3) may have little impact on water chemistry (Robin and Gillham 1987). However, a goal for groundwater monitoring at Hanford is waste minimization, not waste proliferation by creating a need to purge large volumes of water. Therefore, the use of non-reactive materials to obtain groundwater samples that accurately reflect the aquifer's groundwater chemistry is important. Excluding the pump risers, the six pumps considered can be obtained in some type of 300-Series stainless steel, Teflon, and other thermoplastics that are generally acceptable under current sampling procedures. The small contact surface and extensive flushing that occur for these sampling devices composed of nearly inert materials (i.e., with respect to Hanford contaminants of concern) when sampling begins almost eliminates concerns regarding alteration of water chemistry in the pump or sample chambers. Specific conditions at certain wells may mandate specific purging, sampling procedures, and requirements to obtain groundwater samples representative of the formation. However, we do not believe that significant differences in concentrations of constituents would be obtained in groundwater samples regardless of which type of new pump is installed at the same intake depth. Based on an evaluation of the literature, we do not believe the functioning of the devices or the materials that they are composed of would alter sample results significantly using current procedures.

Material used in the pump riser are of significant concern if unsuitable materials (e.g., carbon steel, galvanized steel, ABS, FPVC) are used rather than less reactive materials discussed in Chapter 4.0 and in detail in Appendix A. Discharge riser materials that have significant potential or are likely to cause significant changes in the concentration of contaminants in groundwater samples should not be used, specifically, carbon or galvanized steel, ABS, or FPVC. Sorption, desorption, and leaching vary with material type, the contaminant, surface contact time, concentration, and dynamics of fluid movement (flow rate) during purging and sampling. At much slower purging and sampling rates, such as low-flow purging, it is of greater significance which materials are used in the discharge risers. Under low-flow purging, only the least sorptive polymeric materials or stainless steel should be used for pump discharge risers as shown in Table 4.1 and discussed in Appendix A.

5.6 Flow-Rate Range

Variable extraction rates are essential for removal of large volumes of purge water from the well prior to sampling, as well as small volumes for low-flow sampling (Table 5.4). Standard submersible pumps in use at Hanford cannot be throttled back to <~10 L/min without causing damage to the pump and heating of the sample. Unlike standard submersibles, the discharge rate of the VFD submersible is controllable over a wide range (from 0.1 L/min to many liters per minute), depending on the amount of lift. Conventional submersibles cannot be adjusted over a wide range, and low flow rates using backpressure can damage the pump motor and may affect sample quality.

The extraction rate of the HydroStar is difficult to adjust, and its riser does not drain to the existing water level. Therefore, several liters must be removed each time the well is sampled just to purge the riser. The bladder pump has a very limited purge discharge rate of only 1 to 2 L/min at depths from 30 to 90 m. Although this type of pump may have the best performance for low-flow purging, low-flow purging has not been approved for Hanford monitoring wells. With conventional purging still the accepted practice, the bladder pump would not be practical for purging 100 to 400 liters, which is common for almost all monitoring wells. The excessive amount of field time for purging with the bladder pump eliminates the device for further consideration until no-flow and low-flow purging are accepted sampling methods for many monitoring wells at the site. However, because it is likely that these new purging methods will be adopted at Hanford, the bladder pump is represented in subsequent sections of this chapter.

The remaining riser materials for the submersible pumps should be either 1.9-cm-dia. stainless steel or Teflon. Neither the 3.8-cm-ID ABS nor the 2.5-cm-ID galvanized steel pipe currently in use is recommended for water chemistry sampling. Also, these large-diameter pipes make it impractical to use low-flow purging, and reduce the options for no-flow purging.

Riser materials for Hanford groundwater-monitoring applications should be of rigid or semi-rigid tubing, 300-Series stainless steel, PTFE Teflon, FEP Teflon, FEP Teflon-lined polyethylene (PE), LDPE, or PVDF. The best choice for flexible tubing is P(VDF-HEP). Based on the published literature and studies to date, all six of the sampling pumps are capable of providing representative samples if properly maintained, deployed, and operated within the optimal operation range of the pump.

5.7 Power Requirements

The method by which the pumps are powered is important in determining if special devices are required. In all cases, the pumps can be powered with standard batteries, generators, and compressors. The pumps that are electrically powered also require a control box to adjust the flow rate. The control boxes for these pumps are portable and do not need to be dedicated to a specific well. The pneumatically controlled pumps require an actuator assembly by which the pump is controlled.

Power requirements are more a matter of ease of setup and use. In general, the easiest to set up and connect to power is the VFD submersible pump that is powered by an electrical generator (Table 5.5). The progressive cavity pump is also easy to set up and operate.

Table 5.5. Power Requirement of Pumps

Characteristic	Redi-Flo2® (3™) [4™] Submersible Pump	QED Bladder Pump	Bennett Piston Pump 1800-8	HydroStar Single-Action Piston Pump	Keck Progressive Cavity Pump	Fultz SP201 [SP300] Gear-Driven Pump
Power Requirement	Electric 110 or 220 volt (220)	Pneumatic/ Compressor	Pneumatic/ Compressor	Pneumatic/ Compressor	Electric 12 to 14.5 volt	Electric 12, 24, 36 or 110 volt

Next easiest would be the portable control system for the QED bladder pump followed by the double-action piston pump. The gear driven pump is similar to the set up to the Keck and submersible in that they are controlled at the surface, but it is more time consuming and complicated because not all of the control components are integrated into a single unit. Most difficult to set up because of the most elaborate surface assembly is the single-action piston pump, the HydroStar. Air compressors power both types of piston pumps. This relative setup time difference is not sufficient grounds for eliminating any of the devices for use at Hanford. However, over an entire year and more than 1,600 sampling events in a year the amount of set up time will add measurably to the cost of sampling.

5.8 Maintenance

Maintenance and ease of use are also important factors in pump selection. Maintenance issues include reliability, ease of installation and removal, and ability to make necessary repairs on the site. Some sense of reliability can be assessed from the service warranty provided by the manufacturer. Most of the warranties for the pumps have few exclusions, other than abusive handling or negligence when using the device. Most of the pump manufacturers provide a one-year warranty. Only the QED bladder pump has a 10-year warranty (if accessory pump inlet filter is used), and the Redi-Flo4 submersible has a 2-year warranty from suppliers in the United States.

With respect to field maintenance or replacement of the pump or riser components, it is easiest for the bladder pump, more difficult for the VFD submersible, very difficult for the single-action piston pump, and extremely difficult for the double-action piston pump. This estimate is based on personal experience and shared experiences of others, who have used these devices. During removal of the pump for servicing, the primary disadvantage of the bladder pump is dealing with the water left in the riser when the pump is pulled for servicing. Although the volume is usually less than a liter, highly contaminated water may pose a safety problem at ground surface. The same nuisance affects the current servicing of the single-action piston pump, but service is usually required because the pump seals are leaking, as a result the pump drains into the well. The VFD submersible pump without a check valve is self-draining, and the double-action piston pump has a reverse switch for pumping water out of the line either before or as it is removed. The single-action piston pump not only leaks eventually at the Teflon piston seal in the pump chamber but also at the surface where Teflon packing is used to prevent leaks around the rod assembly.

All of the devices usually do or can, for convenience, come pre-assembled on a spool or feed box for easy installation. Each pump, riser, and accessories are factory assembled to the desired initial pump depth for installation. At depths of 90 m or less, all of these pumps and accessories are generally easy to install in <30 minutes. If not pre-assembled and if stainless steel risers are used for the submersibles, additional work is required before installation. For depths >30 m, a work-over device is generally needed because of the weight of the stainless steel tubing, and the electrical cable in the well must be mechanically supported. Again, maintenance and ease of servicing and use are important considerations. Based on this alone, both piston pumps might be eliminated. However, in the single-action piston pump, it may not be known for some time after sampling begins whether water discharged at the surface is from the well or riser because the volume in the riser cannot be determined in advance of pumping. This is an unacceptable condition for low-flow or no-purge methods.

5.9 Cost Comparisons

Ultimately, capital cost, as well as maintenance and operational cost, will be factors that weigh heavily on the choice of pump type. For capital costs, the prices of the sampling pumps and accessories for the VFD submersible, bladder, and double-action piston pump are presented in Table 5.6 for a standard 46-m depth installation. The prices shown in the table are based on list prices. Discounted, bid, or General Services Administration and local (Washington State) business considerations are not included in the prices.

Table 5.6. Cost Comparisons

Characteristic	Redi-Flo2® (3™) [4™] Submersible Pump	QED Bladder Pump	Bennett Piston Pump 1800-8	HydroStar Single-Acting Piston Pump	Keck Progressive Cavity Pump	Fultz SP201 [SP300] Gear-Driven Pump
Capital Cost	$1,200 (1,500) [$1,500]	$900	$2,500	$1,500	$4,000	$1,900
Operating Cost	Moderate	Moderate	High	High	Low	Low
Maintenance Cost	Moderate	Low	High	High	Moderate	Moderate

The depth at which a pump will be set is important in the cost of the system because the performance, price, and type of pump and ancillary equipment change for the VFD submersibles and bladder pumps somewhere between 75 and 85 m in depth. Specifically, the RediFlo2 must be replaced with a Rediflo4 or Rediflo3 to lift water to the surface, and a high-pressure controller is required below 80 m in depth for operating the bladder pump. Discharge risers for the pumps are commonly Teflon or Teflon-lined, high-density, flexible, polyethylene tubing. The tubing is either 0.95 or 1.27 cm ID for depths up to 90 m. Deeper than 90 m, 1.91-cm ID risers should be used for the Redi-Flo4 because of the weight and strain from torque shock imparted to the discharge riser when the pump is first turned on. Based on the prices shown in Table 5.6, the lowest price for these three pumps with riser and accessories is the QED T1200 bladder pump. However, to achieve waste minimization (recycling) and cost savings, it was suggested by staff at Duratek, Bechtel Hanford, Inc., and Pacific Northwest National Laboratory that the stainless steel riser pipe left over from the existing HydroStar pumps should be used for the submersibles. Both of these pumps are about half the price of the $2,486 double-action piston pump, which so expensive because the control system is built into each unit. Comparing the total cost of pump and riser with accessories at 90 m in depth, the bladder pump costs substantially less than the submersible and piston pump. If existing stainless steel pipe is used with the Redi-Flo4 submersible pump, the cost of each dedicated system decreases substantially. The cost of controllers and ancillary equipment for the submersibles and bladder pumps are an insignificant $30 to $50 per well, when averaged over 50 dedicated pumps that could be operated by one unit. It should be remembered that all the pump costs discussed herein are high compared to their actual bid or General Services Administration prices. Although the Bennett double-action piston pump meets essentially all of the performance requirements, its high cost of procurement eliminates it from consideration.

6.0 Future Sampling Pump Considerations

Selection of the appropriate technology for future sampling will be impacted by the ability to determine that a sufficient number of wells are amenable to low-volume-purging techniques. Information from time series sampling conducted at the Hanford site has determined that many wells in the monitoring network are purged excessively before sampling begins. The primary purging technique currently in use is the conventional purge method based on a specific number of well volumes. For removing lesser volumes from wells before sampling, there are two aspects to be addressed. The first is to determine if the well is suitable for one of the low-volume purging methods. Second, how suitable is the pump for the low-volume-purging method.

There are basically three types of low-purge-volume sampling methods, which may include some purging, and each method is defined as follows by ASTM D4448 with modifications:

- low-flow sampling (sometimes referred to as micropurge®) is a groundwater-sampling technique where the purge and sampling rates do not exceed the natural flux of the desired sample interval flowing into the monitoring well during evacuation of stagnant water (if any) from the sampling interval and during sample extraction.

- minimal purge sampling is the collection of groundwater that is representative of the formation by purging only the volume of water contained by the sampling equipment (i.e., tubing, pump chamber). This assumes that there is no stagnant water in the well screen; therefore, the well is defined as a no-purge well because purging is not needed to obtain a representative sample from the well.

- no-purge sampling is a technique where neither the sampling device nor the well needs to be purged before obtaining a representative sample.

Based on previous discussions of pumps in this report, the most suitable pumps for low-flow purging would be the VFD submersible pump (Redi-Flo2® by Grundfos) and the bladder pump (Well Wizard® T1200 by QED Environmental Systems, Inc.). These were also the two pumps that were rated as the most appropriate for Hanford use for standard purging techniques. The greater depth range of the bladder pump in relation to the Redi-Flo2 makes it the best overall pump for low-flow purging and probably for minimal purging as well. The lower capital and maintenance costs are important considerations. The operational costs are similar to the double-action piston pump by Bennett and the Redi-Flo2.

It should be noted that neither the Redi-Flo2 nor the bladder pumps qualify as no-purge devices because both retain some water in the pump chamber and riser between sampling events. Of the pumps available, only the double-action piston pump by Bennett qualifies as a no-purge device because flow can be reversed after sampling, thereby emptying the discharge riser and most of the pump chamber.

The Redi-Flo2 and Redi-Flo4 offer the greatest flexibility for most groundwater sample collection, including limited aquifer testing; however, the bladder pump is best for true low flow purging.

7.0 References

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Appendix A

Interactions and Recommendations of Materials

Appendix A

Interactions and Recommendations of Materials

This appendix gives an introduction to the types of materials commonly used in monitoring wells and sampling equipment, and a synopsis of how the materials used in well screens, casings, and sampling devices may influence the results obtained from groundwater during purging and sampling. A summary of general recommendations regarding materials (e.g., for pump and riser) used in groundwater-monitoring wells is presented in the last section. A glossary of acronyms is included for ease of reference.

A.1 Interaction of Materials with Contaminants in Groundwater

There are many published laboratory studies and field reports on the actual and potential impact of sorption, desorption, degradation, and leaching on groundwater sample accuracy with respect to the interaction of materials used in monitoring wells and metals and organic chemicals in solution (Barcelona and Helfrich 1986; Barcelona et al. 1985a, 1985b; Chamness et al. 1990; Gillham and O'Hannesin 1990; Gross et al. 1974; Hewitt 1989a, 1989b, 1992, 1994; Liikala et al. 1988; McCaulou et al. 1996; Miller 1982; Moehrl 1961; Oakley and Korte 1996; Packham 1971a, 1971b; Parker 1992, 1995; Parker and Ranney 1994, 1997a, 1997b, 1998, 2000; Parker et al. 1990; Patton et al. 2001; Paul et al. 1988; Ranney and Parker 1997, 1998a, 1998b; Reynolds and Gillham 1986; Schalla et al. 1988; Smith 1988; Smith et al. 1989). However, relatively few pertain to the interaction with radionuclides (Anno 1984; Coles et al. 1980; DOE 2000a, 2000b; Kircher and Bowman 1964; Raber et al. 1983; Serne et al. 1977; Skulskii and Lyubimov 1971).

For the Hanford Site, the presence of radionuclides in the subsurface and groundwater is an issue because degradation may be caused by the continuous exposure to radiation, as well as corrosion or fluid penetration of materials in monitoring wells and the dedicated equipment installed in them. Potential interactions with metals, radionuclides, and organic compounds in aqueous phase differ, depending on water chemistry, aqueous concentration, free-phase components, and form of contamination. Degradation may result in deterioration in material strength and integrity such as flaking, swelling, softening, or dissolution, and concomitant leaching of components from the materials in the well or part of the pump. These chemical or physical interactions that degrade the materials have the potential to alter significantly the accuracy of groundwater samples. Many studies have shown significant sorption, desorption, leaching, or degradation for materials currently used in equipment and monitoring wells at Hanford under static batch or even under dynamic conditions. However, the studies cited in this appendix should only be used to alert the reader of the potential impact on sample quality and, not necessarily, the actual impact on sample quality. In real-time conditions, sample quality is usually determined more by site-specific sampling conditions, the sampling methods and procedures used, and how well they were followed than by the maximum sorption, desorption, or degradation potential of these materials (Humenick et al. 1980; Robin and Gillham 1987).

A.1.1 Polymeric Materials

Polymeric materials used in sampling devices and monitoring wells may include thermoplastics (e.g., PVC, chlorinated polyvinyl chloride [CPVC], and polytetrafluoroethylene [PTFE]), thermosets (e.g., FRE), and elastomers (e.g., nitrile [buna-N], silicone rubber, Viton®). Among the most popular thermoplastics, because of their stability at high temperatures and corrosion resistance, are a subgroup called fluoropolymers. A material type could be one of several commonly used fluoropolymers, such as PTFE Teflon® by Dupont; fluorinated ethylene propylene (FEP) Teflon by Dupont (also called Neoflon® by Daikin, Japan); perfluoroalkoxy alkane (PFA) by Dupont; ethylene-tetrafluoro-ethylene (ETFE) Tefzel® by Dupont; polyvinylidene fluoride (PVDF) Kynar® by Penn Walt; polyethylene (PE); high-density polyethylene (HDPE); low-density polyethylene (LDPE); acrylonitrile, butadiene, and styrene (ABS) (Nielsen and Schalla 1991). PTFE and FEP Teflon are the most popular of the fluoropolymers for environmental work because of their wide range of temperatures and superior resistance to chemical attack from acids, alkali, oxidizing agents, petroleum products, various hydrocarbons, including the halogenated volatiles. PVDF Kynar, which is another fluoropolymer, is highly resistant to chemical attack by a number of aggressive corrosives, including halogenated solvents and strong oxidants, except certain volatile aromatic hydrocarbons in nonaqueous phase at temperatures >5°C. Also, PVDF is comparable to the more costly FEP Teflon but is stronger and less permeable and sorptive than Teflon (Chawla and Gupta 1993). Because PVDF can be produced in ultrapure form, it is recommended for liquids and deoinized water that must remain free of contaminants (e.g., pthalates) often associated with thermoplastic materials. All of these polymeric materials have been used in monitoring wells, and sometimes nearly all at a single site to meet specific performance needs (Gauglitz et al. 1994).

Thermosets, such as epoxies, require curing, and for monitoring well casing and screen are fiberglass reinforced. FRE is very durable, strong, and lightweight slotted pipe and casing compared to stainless steel, but its popularity has been limited largely because only one supplier is available that has had its materials tested for leaching and sorption. These FRE resins are resistant to acids and alkali and are almost immune to attack from most petroleum products and hydrocarbons but vulnerable to certain oxidizing agents.

Elastomers and flexible polymers (i.e., finger pressure can collapse tubing) are used where elastic and flexible properties are needed to seal joints or allow bending and flexing. Elastomers generally are far less resistant to degradation, particularly for many hydrocarbons even in dilute aqueous solutions (Nielsen and Schalla 1991; Chawla and Gupta 1993). As a consequence, only a few of these rubber products have come into common use in the environmental industry. Among the more popular elastomers are nitrile (buna-N), Viton, polysulfide, and EPDM® Rubber (Nordel®). Flexible polymers include ethylene propylene (EP), polypropylene with plasticizers (FPP), flexible polyvinyl chloride with plasticizers (FPVC), and polyvinyldine fluoride-hexaethylpropylene (P[VDF-HFP]) (a copolymer of vinylidene fluoride and hexafluoropropylene). Nitrile is resistant to fairly resistant to acids and alkali and is almost impervious to petroleum products even in pure form but vulnerable to oxidizing agents and certain hydrocarbons. Viton is the most resistant to aliphatics, aromatics, petroleum, and most halogenated hydrocarbons, with a few exceptions, but somewhat susceptible to degradation from acids, salt solutions, and oxidizing agents. Polysulfide is fairly resistant to alkali, petroleum products, and hydrocarbons and is especially resistant to lacquer solvents, but vulnerable to acids and oxidizing agents. EPDM is popular for a number of its elastic and durability properties over a large temperature range and is resistant to acids and alkali and is moderately resistant to oxidizing agents. EPDM severely swells in contact with certain petroleum products, but this swelling occurs primarily at temperatures well above most natural groundwater temperatures, excluding thermal springs. EPDM is very vulnerable to a number of organics. FEP and FPP are very resistant to acids, alkali, and salt solutions and is fairly resistant to most oxidizing agents, but vulnerable to degradation by certain petroleum products and is extremely vulnerable to many hydrocarbon contaminants, such as halogenated volatiles (perchloroethylene and trichloroethylene) while very resistant to ketones, furans, and methylene chloride. Flexible PVC is still in common use despite its vulnerability to hydrocarbons and a few components of petroleum products. P(VDF-HEP) is extremely resistant to acids, alkali, oxidizing agents, petroleum products, and most hydrocarbons and is only moderately vulnerable to some of those.

A.1.2 Stainless Steel Material Families

Stainless steel comes in many families and types according to AISI specifications (Chawla and Gupta 1993). The family used for groundwater-monitoring wells is known as the 300 Series. The stainless steel used in most monitoring well products are austenitic and duplex stainless steels, known as the 18-8 family because most of the austenitic types have 18% chromium and 8% nickel, except for 316, which has 12% nickel. Austenitic stainless steel is composed of austenite (a high temperature form of gamma iron with carbon in solution) that is made stable by alloying with chromium and nickel. Duplex stainless steels have a ferrite-austenite microstructure that accommodates high percentages of chromium and molybdenum but low nickel content. The most common types of austenitic stainless steels used are types 302, 303, and 304 because they are less expensive and generally easier to machine. Some austenitic types of 300-Series stainless steel, such as types 316, 321, and 347 have ~2% to 3% molybdenum, titanium, and niobium, respectively. These small-percentage metals serve as stabilizers to prevent crevice corrosion and intergranular corrosion following welding processes (knife-line attack) and provide specific performance properties, especially higher corrosion resistance (Chawla and Gupta 1993). The L that sometimes appears at the end of the stainless steel number stands for low carbon. Low-carbon 300-Series stainless steels are more resistant to corrosion and are more effectively passivated to improve corrosion resistance. Stainless steel pipe and well screen are sometimes treated by a series of nitric acid and potassium dichromate immersions and rinses that produce a state of passivity or corrosion resistance for certain groundwater environments. A duplex stainless steel, called 329, contains the highest chromium (28%) and nitrogen content but the lowest nickel content (3% to 5%) of any duplex steel. It is somewhat higher in carbon than most 300-Series stainless steels. It is easily machined, very strong, and has an extremely high corrosion resistance.

In general, the higher the 300 number, the higher the cost of the stainless steel and the greater its corrosion resistance. Despite the higher cost, manufacturers use these higher grades in environmental sampling devices to prevent impact on sampling results. Passivation and electropolishing of these high-grade stainless steels practiced by some sampling device manufacturers further reduce the chances of influencing analytical results.

A.1.3 Interactions with Metals

Sorption, desorption, leaching, or degradation (i.e., corrosion) are the potential interactions between the metals used in dedicated sampling equipment or monitoring wells. It is not surprising that metals in groundwater are most reactive with metallic materials.

A.1.3.1 Sorption, Desorption, and Leaching of Metals in Groundwater

Polymeric materials, particularly polytetrafluoroethylene (PTFE), show essentially no significant sorption of cations when compared to stainless steel casings. However, some polymers, such as polyvinyl chloride (PVC), show some sorption (Parker et al. 1990; Hewitt 1992). Anionic form metals do not sorb to polyethylene (PE), PTFE, and rigid PVC; as cations, they do sorb (Ranney and Parker 1998b). In field studies at the Hanford Site and other locations, types 304 and 304L stainless steel wells may leach, initially, chromium in 10- to 30-ppb quantities following installation, even when using high-flow purging rates and more than 3 to 5 well volumes (Schalla et al. 1988; Smith 1988; Smith et al. 1989; Chamness et al. 1990; Oakley and Korte 1996). In these studies, groundwater types ranged from calcium or sodium-calcium/carbonate types to calcium sulfate types with pH values ranging from 6.9 to 8.2. Generally, conditions at Hanford fall within these ranges. A study under laboratory conditions shows that type 304 wire wrap leached chromium, while type 316 wire wrap had a slight tendency to sorb chromium (Parker 1992). Other static and dynamic laboratory studies show that several metals (e.g., lead, cadmium, chromium, nickel) are leached from and/or sorbed by type 304 and 316 casings (Hewitt 1989a, 1989b, 1992, 1994; Parker et al. 1990).

A.1.3.2 Corrosion of Materials and Influence of Metals in Groundwater

Corrosion and associated leaching of metals is an important issue, particularly in reducing environments where carbon and stainless steel are vulnerable to attack. Corrosion in well casing and screen material or sampling equipment, such as pump discharge riser, can occur via a number of processes:

- general oxidation or rusting of the metallic surface
- selective corrosion (sometimes biologically accelerated) by the loss of one element (e.g., zinc or iron)
- bimetallic corrosion by creating a galvanic cell
- pitting, crevice, or joint corrosion
- stress corrosion.

The potential for corrosion of metallic materials can be estimated by a list of indicators of corrosive conditions in the natural geochemical environment (Nielsen and Schalla 1991):

- low pH – <7 for carbon or galvanized steel pipe and <5 for common stainless steels
- high dissolved oxygen content – corrosive if oxygen content exceeds 2 ppm
- presence of hydrogen sulfide – severe corrosion with as little as 1 ppm
- total dissolved solids – if >1,000 ppm, the electrical conductivity could cause serious electrolytic corrosion
- carbon dioxide – corrosion likely >50 ppm
- chloride ion content – if 500 ppm or more.

A combination of these corrosive agents generally increases the corrosive effect. However, it is difficult to estimate the actual rate of corrosion because the range of subsurface conditions is so large and conditions are often site or well specific.

Carbon steel was developed to be more resistant to corrosion compared to iron for atmospheric and alternating dry and wet periods. In most monitoring wells, water fluctuations are usually not sufficient to provide these conditions, so corrosion is a common problem. Corrosion products introduced into groundwater include iron, manganese, and trace amounts of other metals. Untreated and corroded steel surfaces can have a significant impact on water chemistry results. In older carbon steel wells at Hanford, the loss of contaminants of concern, such as Cr^{6+} have been as great as 90% (Schalla 1992). Some wells are now constructed using type 316 screens below the highest expected water level but using carbon steel above the water level. Stainless steel submersible pumps are used in these wells with galvanized risers. Considering all this information, the riser represents a much larger and longer contact surface than the pump or even the well screen. Water inside a riser is often altered particularly for metals, but water chemistry in the well screen is usually unaltered, at least during the initial years of use and where the groundwater velocity is sufficiently high (Patton et al. 2001). Galvanized carbon steel has been shown to be reactive or sorptive with contaminants where they have been used in wells (Moehrl 1961; Miller 1982; Raber et al. 1983; Barcelona et al. 1983, 1985a, 1988; Gillham and O'Hannesin 1990; Schalla 1992; Parker 1992, 1994; McCaulou et al. 1996).

The use of galvanized steel risers is a poor choice because of the potential for galvanic corrosion (Barcelona et al. 1983; Nielsen and Schalla 1991). Elevated levels of zinc have been detected in groundwater samples from wells with galvanized steel risers at Hanford. Common corrosion products include iron, manganese, zinc, and cadmium. It has been shown that carbon steel below the water table in wells at Hanford has severely altered water chemistry for metals, particularly chromium (Schalla 1992). Where galvanized carbon steel risers are attached to stainless steel submersible pumps, galvanic corrosion will occur (Nielsen and Schalla 1991; Chawla and Gupta 1993). Even if protection is provided to prevent corrosion, the presence of the zinc and exposed iron threads can alter water chemistry.

With respect to corrosion resistance, stainless steel is far superior to galvanized or carbon steel. The corrosion resistance of stainless steels, particularly types 304 and 316 commonly used at Hanford, can be improved by treatment with nitric acid and potassium dichromate solutions, called passivation. These treatment processes, usually done at steel factories, are referred to as MilSpec or QQ-P-35C. In actual well conditions, these treatment processes can be beneficial for reducing the amount of chromium and nickel leached and released into the water. Under dynamic conditions, PVC and PTFE showed no influence on metal concentrations, but unpassivated types 304 and 316 showed leaching of small concentrations of nickel and chromium that could be significant (Kain 1990; Hewitt 1994; Oakley and Korte 1996). Crevice or joint corrosion may be significant in well joints or couplings composed of type 304 but not 316. If stagnant solutions are allowed to develop, with chloride or sulfate entering the crevice, corrosion and release of nickel and chromium can occur (Kain 1990; Kain et al. 1984; Oakley and Korte 1996). In natural systems, nickel is normally immobile as insoluble hydroxides or sulfates, but once introduced, it can remain mobile in the neutral pH of the groundwater system (Kain et al. 1984). Chromium occurs naturally in groundwater, but precipitation kinetics are so rapid and dissolution so slow that the concentration of Cr^{3+} remains well below drinking water standards, and trace levels of Cr^{6+} are usually below detection (Rai et al. 1989). The stagnant chloride or sulfate solution inside the crevice (e.g., a gap between pipe or casing joints or badly executed welds) causes the metal to act as an anode and the metal outside the crevice becomes a cathode. As anions enter the crevice, the increasing acidity breaks down the protective surface of the stainless steel. Surface corrosion or pitting on stainless steel was believed to be the cause of significant sorption losses of lead and cadmium in dynamic experiments (Hewitt 1994). It is generally considered preferable to have a false-positive for chromium reported with type 304 leaching than a false-negative caused by sorption on type 316L.

The actual impact of metal casings on groundwater samples is sometimes far less under actual Hanford conditions than observed under laboratory conditions or at other field sites (Chamness et al. 1990; Patton et al. 2001). Passivation of casing and well screen does not guarantee that chromium and nickel will not be leached into the groundwater if abrasion of the surfaces occurs after passivation (Chamness et al. 1990; Hartman et al. 2000). Passivation of stainless steel well casing and screen, as well as HydroStar™ pumps and stainless steel risers and rods, became the standard practice in 1988 at Hanford and continued until about 1993 and perhaps another year or two for the stainless steel pipe and rods for the pumps. The HydroStar™ pumps have continued to be passivated by the manufacturer to 2001.

A.1.4 Interactions with Radioisotopes

The interactions of the well construction and sampling system materials with the radioisotopes found in groundwater can have a significant effect on the sampling results. Radioisotopes can be sorbed or degrade materials because of the effects caused by the decay process.

A.1.4.1 Sorption of Radioisotopes by Materials

Certain radioisotopes are sorbed by type 316L stainless steel, including selenium-75, strontium-85, and cesium-137 (Raber et al. 1983). Raber et al. showed that 316 can be one to three orders of magnitude more sorptive than materials such as passivated 304 or 316, PTFE Teflon®, fluorinated ethylene propylene (FEP) Teflon, and Viton® E-60C. In particular, the two Teflon types and Viton E-60C were found to show little or no sorption for any of the radioisotopes. The sorption values for PE and polypropylene (PP) varied with the type of radioisotope but essentially exhibited little sorption of these three radioisotopes. Cold-rolled steel and steel washers showed the greatest sorption. For cesium, it was moderate (one order of magnitude) sorption even for carbon steel. Selenium has extremely high sorption (nearly four orders of magnitude) for both unpassivated stainless steel and carbon steel compared to passivated stainless steel. Sorption for strontium was higher by three orders of magnitude for both unpassivated stainless steel and carbon steel compared to passivated stainless and nearly all thermoplastics discussed in this appendix and the main report. Except for cesium-137, no specific evidence has shown that sorption would occur for the radioactive isotopes of concern in the groundwater at the Hanford Site, including cobalt-60; selenium-79; strontium-90; technetium-99; ruthenium-101; iodine-129; uranium-235, -236, -238; neptunium-237; americium-239; and tritium. A study compared the sorption of three radionuclides (tritium, monovalent cesium-137, and bivalent cobalt-57) for epoxy-coated steel, type 304, fiberglass reinforced epoxy (FRE), and rigid PVC (Thompson 1996). Tritiated water did not react with any of these materials. Cesium-137 sorbed only with the unpassivated stainless steel. Cobalt-57 exhibited a slight reaction with three of the materials, excluding the epoxy-coated steel. Other research shows that, for most constituents, residence time in the short pathway through the well screen should not have any effect on the sample (Robin and Gillham 1987).

Other than the Raber et al. (1983) and Thompson (1996) reports, no studies have been published regarding the sorption and desorption of radionuclides in groundwater with respect to monitoring wells and sampling equipment. Previous studies concerning the sorption of radioisotopes on metals, polymerics, and other materials are very limited and not necessarily applicable to conditions in a groundwater-monitoring well (Skulskii and Lyubimov 1971; Serne et al. 1977; Coles et al. 1980). In studies at Hanford, these radionuclides were measured in groundwater-monitoring wells. Based on many studies of sorption and leaching tests, the sample bias effects resulting from sorption or leaching with well-casing materials are often negligible in common contaminants found in groundwater, excluding radionuclides (Barcelona et al. 1983; Reynolds and Gillham 1986; Liikala et al. 1988).

A.1.4.2 Degradation of Materials by Radioisotopes

While both organic and inorganic chemical compounds in pure form or aqueous solution can degrade many compounds, most of these issues have been accounted for in the open literature (Barcelona et al. 1983, 1985b, 1988; Barcelona and Helfrich 1986; Chawla and Gupta 1993; Hewitt 1989a, 1989b, 1992, 1994; McCaulou et al. 1996; Miller 1982; Moehrl 1961; Nielsen 1991; Parker 1992, 1994; Parker et al. 1990; Parker and Ranney 1997a, 1997b).

Much of the impact of radiation, however, even at low levels, is less widely known. While all materials are affected in some way by high radiation doses, the range of doses under which a material will maintain its desirable properties varies. Even the lowest doses can cause significant changes to the properties of materials. It should be remembered that degradation occurs as a result of continuous attack on material integrity in proximity to materials undergoing radiological decay (DOE 2000a).

It is recommended by the U.S. Department of Energy to avoid using PTFE Teflon components in radiation environments, even at low levels. These “low levels” would be equivalent to significantly contaminated groundwater-monitoring wells that are part of the groundwater-monitoring program. PTFE Teflon experiences significant degradation at lower radiation exposure levels than most thermoplastics and fluoropolymers (Kircher and Bowman 1964; Anno 1984; DOE 2000b). For groundwater-monitoring well applications, Tefzel® is probably a more appropriate substitute, if available, as it has similar physical properties to PTFE Teflon but is more resistant to radiation damage. Studies have also shown that tritium infiltrates PE, allowing beta radiation to attack it from within. The anticipated life and use (e.g., seal or moving part) are factors in determining the longevity of the parts involved and the relevance of this issue.

A.1.5 Interactions with Organic Compounds

In spite of its greater cost, stainless steel was selected as the material of choice over polymer materials for pump discharge risers because it is essentially nonreactive with organic contaminants on the Hanford Site. It was also selected because of its superior strength, ability to be passivated to reduce sorption of cations (i.e., metals and radioisotopes) and corrosion, and ease of use in changing sampling depth. Its lower potential for altering the chemistry in the wells contaminated with organic compounds was a priority. Almost all well screens and most casings currently used at Hanford are composed of types 304, 304L, 316, or 316L. The sampling devices, including discharge riser materials, are given below:

- fixed rate Grundfos® pump (type 304) and riser (type 304 or 304L or galvanized pipe)

- HydroStar pump (Teflon, passivated type 304 and riser, and types 302 and 303 rod and coupling nuts)

- Kabis™ sampling device (type 321)

- Fultz gear-driven pump is composed of type 316L with Teflon rotors. Discharge hoses consist of either flexible, 1.3-cm-ID Teflon or 1-cm-dia. vinyl.

Neither the Kabis device, which is a differential pressure bailer, nor the Fultz pump are used as dedicated sampling devices. These two sampling systems are used only for special sampling situations in the existing wells.

Recently, the variable frequency drive Grundfos submersible pumps have been installed in new and existing wells at Hanford. The body and impellers of the Grundfos Redi-Flo2® and Redi-Flo4® submersible pumps are composed of types 316 and 304, respectively. The splined shafts of the Redi-Flo2 and Redi-Flo4 are composed of types 329 and 304, respectively, with spacer and wear rings of the pump composed of PTFE Teflon. The pump motors are surrounded by deionized water. The Redi-Flo3® is composed of types 316 and 316L, with some internal parts composed of polyvinyldine fluoride (PVDF) and FPM® Rubber (Viton equivalent). Either deionized water, or more commonly, a mixture of mineral-free water and propylene glycol surrounds the pump motor of the Redi-Flo3.

The discharge riser is a matter of choice for these pumps. Even though PTFE Teflon, FEP Teflon-lined PE, high-density polyethylene (HDPE), and PP are used commonly in the environmental industry, the stainless steel risers were chosen because they are more durable, easy to adjust for moving the pump intake, and less reactive with little carryover of organic contaminants.

A.1.5.1 Sorption of Organic Contaminants onto Materials

Dedicated sampling devices composed of nonsorptive materials provide a significant advantage for organic contaminants because carryover is potentially such a significant problem (Parker and Ranney 2000). The largest contact surfaces are the well screen and the pump riser, even when the amount of submergence in the water is only a few feet. In several studies, there was no chemical interaction between the surface of these construction materials and the relatively hydrophilic organic solutes and they are not sorbed at all by impermeable materials such as stainless steel (Barcelona et al. 1983, 1988; Gillham and O’Hannesin 1990; Parker et al. 1990; Parker and Ranney 1994, 2000). Also, stainless steel was not a concern with respect to the organic volatiles (Barcelona et al. 1983, 1988; Gillham and O’Hannesin 1990; Hewitt 1994; Parker 1992; Reynolds and Gillham 1986). Hydrophobic contaminants, including polyaromatic hydrocarbons, chlorinated pesticides, and polychlorinated biphenyls, will sorb onto impermeable materials (Champion and Olsen 1971; Ogan et al. 1978; Jones and Miller 1988). However, because only a residual film remains on the impermeable surface of the stainless steel, aqueous solutes are quickly removed as new fluids pass over the surface, unlike certain polymers that allow the organics to be sorbed into the matrix.

Evidence of sorption is emphasized by the potential difficulty of removing contamination between sampling cycles even among the preferable materials (Parker and Ranney 2000). In general, the rigid polymeric materials, including PTFE, FEP, PVDF, FRE, rigid PVC, and acrylonitrile-butadiene-styrene (ABS), have more carryover (i.e., residual contamination on the surface) to the next sampling cycle and are more sorptive of organic contaminants in aqueous solutions than the nonpermeable metals, such as stainless steel (Parker 1995; Parker and Ranney 1994, 1997a, 1997b, 1998, 2000; Parker et al. 1990; Ranney and Parker 1998a; Reynolds and Gillham 1986; Gillham and O’Hannesin 1990). However, these polymeric materials are not equal in sorption, according to Ranney and Parker (1998), where they ranked these materials with respect to sorption of organic solutes from least affected to most affected as follows: FRE, PVC<FEP, PTFE<<ABS. Work by Gillham and O’Hannesin (1990) for aromatic hydrocarbons generally agree, except that they found sorption was slightly greater for FRE than PVC. The first two materials, FRE (a thermoset) and PVC (a thermoplastic), were the least sorptive because of their smoother, nonporous surfaces. The two Teflons, FEP and PTFE, were more sorptive primarily because of their more porous matrix. The rate to sorb 10% of the part-per-million or -billion concentrations varies by orders of magnitude, even with volatile aromatics that are closely related. For example, tetrachloro-ethylene lost 10% of the dissolved concentration in <5 min compared to trichloroethylene and cis-1,2-dichloroethylene, needing 8 and 168 h, respectively (Gillham and O’Hannesin 1990; Parker and Ranney 1994; Parker et al. 1990; Reynolds and Gillham 1986). In dynamic studies simulating well conditions, trichloroethylene was not sorbed significantly by stainless steel, PVC, or PTFE; however, this exposure was limited to a period of 8 h (Hewitt 1994). ABS absorbed several contaminants and leached several as well, indicating that this material is a poor choice as a well construction material or a discharge riser. If we combine the work by Ranney and Parker (1998a) with Hewitt (1994), Gillham and O’Hannesin (1990) with Jones and Miller (1988) and Barcelona et al. (1985b), we can roughly rank even more materials, ethyl-tetraethyl-ethylene (ETFE), stainless steel (SS), PVC, PVDF, PP, PE, flexible PVC (FPVC), with respect to relative sorption of organic solutes as follows:

SS<FRE, PVC, PVDF<FEP, PTFE, ETFE<PP, PE<FPVC<<ABS.

Materials commonly used in discharge risers for pumps include PTFE Teflon, FEP Teflon, ETFE, FEP Teflon-lined PE, HDPE, low-density polyethylene (LDPE), PVDF, FPVC, PP, and polyvinyldine fluoride-hexaethylpropylene (P[VDF-HEP]). With the exception of P(VDF-HEP), recent research on polymeric tubing indicates that flexible tubing sorbs >95% of the organic solutes in solution in <1 h (Parker and Ranney 1997a). This action includes low concentrations of eight organic compounds, including seven found in groundwater samples from the Hanford Site: nitrotoluene, trans-1,2-dichloroethylene, trichloroethylene, chlorobenzene, o-dichlorobenzene, p-dichlorobenzene, and perchloroethylene. In their experiments, Parker and Ranney found concentrations of these compounds at 10 to 16 mg/L, which would be considered very high compared to the <0.1-µg/L concentrations found in Hanford wells. Results for five rigid and one flexible, common, polymeric tubing indicate that the sorption from least to next to least for perchloroethylene, trichloroethylene, and trans-1,2-dichloroethylene was

PVDF<FEP, FEP-lined PE<ETFE<PTFE<P(VDF-HEP).

P(VDF-HEP) was the only flexible tubing that was close in performance to the five rigid tubings. For the nitrotoluene and the three benzene-based contaminants, the sequence from least to most sorptive materials was

FEP-lined PE, FEP<PVDF<ETFE<PTFE, P(VDF-HEP).

The reason for these differences is that the more polar PVDF was more sorptive of the more polar benzene- and toluene-based chemicals than the FEP. These results need to be put into a proper perspective, and Parker and Ranney (1997a) stated the following:

> "Even though FEP, FEP-lined PE, and PVDF were generally the least sorptive materials tested, they were still highly sorptive of the more hydrophobic analytes such as PCE and PDCB. For example, after 24 hours, losses of these two analytes by these three materials ranged from approximately 60 to 80 percent."

By comparison, sorption by stainless steel riser materials is essentially near zero. One rigid tubing material that performed about as well as the other five rigid tubings was perfluoroalkoxy (PFA) resin, but it is not used by the pump types that were evaluated for this report.

Some mention of the extremely poor performance of less desirable polymeric materials is needed. Rigid tubing with poor performance included PE cross-linked to ethyl vinyl acetate (EVA) shell, PE lining in EVA shell, extra low-density polyethylene (XLPE), LDPE, polyester lining in PVC shell, PP, polyamide. Poor performance of flexible tubing occurred for a specific fluoroelastomer. Other flexible tubing, including polyurethane, plasticized PVC, tetrapolyethylene (TPE), and two formulations of plasticized PP, performed extremely poorly because they sorbed nearly 100% of the chemicals in solution in 8 h or less.

Therefore, water stored in risers composed of even the least sorptive polymeric materials for 1 to 6 months between sampling intervals will not be representative of groundwater removed from the formation. However, this information is still valuable for actual sampling conditions that require removal of the water left in the pump discharge riser between sampling events before new samples are collected. This essential removal of water is called minimal purging. If the effect of sorption of the volatile organic compounds is significant, groundwater samples collected may produce contaminant concentrations that are not representative of the groundwater in the well or aquifer at the time of sampling. For most preferred materials, under current high-volume and high-discharge-rate-purging and -sampling procedures, this is unlikely. However, sorption and effect on water samples vary with material type, type of contaminant, surface contact time, concentration, and dynamics of fluid movement during purging and sampling. Therefore, at much slower purging and sampling rates, such as low-flow purging, it may be important that the discharge risers be composed of either less sorptive polymeric materials or stainless steel. Slower discharge rates are desirable to reduce turbidity and wastewater caused by extensive purging at high rates, but the extended contact time may be a factor if sorptive materials are used.

Overall, for essentially all of the primary organic and inorganic contaminants of concern for the Hanford wells, FEP-lined PE was the best material, even though PVDF was least absorptive for perchloroethylene, trichloroethylene, and dichloroethylene.

A.1.5.2 Desorption of Organic Contaminants from Materials

The relative desorption of the sorbed contaminants must be addressed (e.g., if the contaminant concentration decreases dramatically after the previous sampling). Studies have shown that the organic contaminants in solution that sorbed rapidly may not be the same compounds that desorbed most rapidly or to the greatest extent (Miller 1982; Barcelona et al. 1985b; Parker et al. 1990). At least one chlorinated volatile organic, chloroform, found in the groundwater at the Hanford Site will initially desorb, in a matter of minutes, a small percentage of the total amount sorbed in the polymeric material. However, the remaining chloroform (likely deeper in the polymer matrix) will be desorbed more slowly. This is actually good because the previously high concentrations are less likely to influence the chloroform concentrations in the sample. The discharge risers on most pumps used at Hanford are made of types 304 or 304L, which reduces the amount and expedites desorption of the thin film of volatile organics present on the surface of the metal.8

A.1.5.3 Leaching of Constituents from Materials Caused by Organics

Leaching is the loss of constituents intrinsic to the material by reactions with various aqueous contaminants or simply by the presence of water. The constituents released are often contaminants. Perhaps PVC has the most interesting history. Before 1977, studies showed the release of vinyl chloride, lead, cadmium and other contaminants from PVC (Packham 1971a, 1971b; Gross et al. 1974).

As a result of these studies, the National Sanitation Foundation set forth standards in conjunction with the American Society for Testing and Materials to limit the amount of residual lead and vinyl chloride monomer in PVC (Aller et al. 1989). Even PVC of a particular type that is stamped with the National Sanitation Foundation logo, showing that it is approved to reduce the leaching of metals, is limited to use for cold water pipes in homes and commercial buildings. PVC is still subject to limited attack by a few compounds found in jet and aviation fuel, such as benzene and toluene that may leach vinyl chloride from FPVC. Other types of plastics also leach pthalates. Even FRE, under extreme conditions, will leach diethylpthalate (Cowgill 1988).

Other leaching tests under in situ conditions suggest that this will not occur for at least one type of FRE (Hunkin et al. 1984). Under current production practices, relatively insignificant amounts are leached from rigid PVC because of the lack of plasticizers (<0.01% compared to >30% in FPVC). Leaching also tends to decrease in time for rigid PVC but increase for FPVC (Ranney and Parker 1998a). Stainless steel, FEP, PVDF, and PTFE leach essentially nothing in the presence of organics (Ranney and Parker 1998a). However, they are not equal in leaching characteristics, and Ranney and Parker (1998a, 1998b) ranked these rigid materials with respect to leaching of organic solutes from least to most affected as follows:

PVC<FEP, PTFE<FRE<<ABS.

This is nearly an identical ranking to the sorption ranking by these authors, except that FRE moves from the least affected to the fourth most affected but still well above ABS in terms of suitability for groundwater monitoring. If the effect of leaching of various organic compounds is significant, groundwater samples may produce contaminant concentrations that are not representative of the formation water.

For nearly all of these materials, except ABS, under current dynamic sampling conditions, any significant impact from leaching seems unlikely. ABS has been considered such a poor choice for monitoring wells that little research has been published (Ranney and Parker 1998b).

Flexible types of polymeric tubing, such as FPVC, HDPE, LDPE, and PP, are more likely to leach organic constituents, particularly plasticizers and pthalates than rigid thermoplastic pipe (Junk et al. 1974; Miller 1982; Barcelona et al. 1985b; Gron et al. 1996). Results for flexible tubing are contradictory. Leached constituents were found by Barcelona et al. (1985a) for HDPE and PP, but not by Miller (1982) for LDPE and PP, and not by Devlin (1987) for PE. Even small increases of flow rate, from 20 to 60 mL/minute, may increase leaching by erosion of the polymer matrix in PVC (Junk et al. 1974).

A.1.5.4 Degradation of Materials Caused by Organics

Degradation may result in deterioration in material strength and integrity, such as flaking, swelling, softening, or dissolution, and concomitant leaching of components from the materials in the well or part of the pump. These chemical or physical interactions that degrade the materials have the potential to significantly alter the accuracy of groundwater samples.

Penetration rates by nonaqueous-phase liquids (NAPLs) and other organic compounds are insignificant for types 304 and 316 stainless steel. These two commonly used grades and probably higher grades of stainless steel are resistant to organics (Chawla and Gupta 1993). Penetration rates of 304 and 316 by NAPLs and common organics are generally <2 mils/yr and do not exceed 20 mils/yr except for chloroacetic acid (McCaulou et al. 1996). Carbon steel penetration rates are generally not as low as stainless steel but usually <10 mils/yr for most NAPLs and organics, except for seven common organic chemicals for which they are totally unsuitable: benzaldehyde, chloroacetic acid, chloroform, cyclohexane, ethyl benzene, formaldehyde at 37% or greater, and dilute concentrations of hydrogen peroxide. These chemicals rarely come into consideration unless in situ remediation activities are being conducted in actual wells that contain or are exposed to these chemicals. Metals in sampling equipment, such as pumps and risers, are only affected if used for the collection of samples from wells that contain these high concentrations.

Polymeric materials degrade but do not exhibit a corrosion rate as metals do. The chemical resistance of a polymeric material is its ability to withstand attack by chemicals over time without excessive changes in dimension, weight, or mechanical properties. Polymers are degraded by solvation, which causes swelling, softening, and surface deterioration. If sufficient concentrations in aqueous phase are present or if NAPLs are present, stress cracking of the material can occur.

Polymeric materials commonly used in discharge risers for pumps include PTFE Teflon, FEP Teflon, ETFE, HDPE, LDPE, PVDF, PVC (usually FPVC), PP, and P(VDF-HEP). PTFE and FEP Teflon are very resistant to organic contaminants to the extent that they are almost impervious. ETFE Tefzel and PVDF Kynar® follow close behind with high resistance especially to the NAPLs and organics found in groundwater and the vadose zone at Hanford. Nylon 6/6 is used in some pump components and is very resistant to degradation of nearly all organics except cresol, aqueous chlorophenol, and acidic organics (McCaulou et al. 1996). With respect to common Hanford halogenated hydrocarbons, nylon 6/6 is not recommended if the concentrations are high or dense nonaqueous-phase liquids (DNAPLs) are present (Chawla and Gupta 1993). Most of the other rigid polymers (rigid PVC, chlorinated polyvinyl chloride [CPVC], PP, HDPE) are subject to degradation by several to many organics and NAPLs. However, ABS stands out as the most vulnerable materials to NAPL degradation. ABS is not suitable for monitoring organic solutes and degrades by most organic solvents (Ranney and Parker 1997, 1998a; McCaulou et al. 1996). Also, ABS well casing is no longer commercially available, and rigid, nonfood-grade ABS pipe, as used for discharge risers at Hanford, is not allowed for use in drinking water. ABS is only allowed in home plumbing for carrying sewage and wastewater because it is resistant to common household products containing acids, bases, inorganic salts, alcohols, and nonhalogenated aliphatic hydrocarbons (Chawla and Gupta 1993).

Flexible polymers are more vulnerable to degradation than rigid pipe materials. FPVC and PP are the most vulnerable to degradation by NAPLs.

Elastomers span a wide range of corrosion resistance from essentially inert Kalrez® (a special fluoroelastomer) to very vulnerable polyeurethane. The range is surprising for such elastic materials, but the most resistant were all developed in the last 50 years. In between, there is highly resistant Viton, which is widely used in environmental monitoring. Some polyacrylates and polysulfides are resistant to several organics, but far less than Viton. EPDM is vulnerable to severe swelling with certain petroleum products, but this swelling occurs primarily at temperatures well above most conditions. EPDM is vulnerable to a number of organics, including carbon tetrachloride, methyl-isobutyl-ketone (MIK), perchloroethylene, and trichloroethylene in high-concentration aqueous phase or as NAPLs. Most of the other elastomers (i.e., nitrile buna-N, silicone rubber, neoprene [chloroprene], butyl, ethylene propylene, polyacrylate, and polysulfide) are corrosion resistant to only a few of the common organic contaminants.

A.2 Recommendations for Materials Used in Groundwater Sampling

This section provides the summary of the potential impacts of materials specific to Hanford Site groundwater sampling. General guidance is provided for suitable materials for use in several sampling pumps and recommendations are given as to the best choices of materials for discharge risers and power cables.

The six sampling pumps discussed in the main text and described below are constructed from materials that are generally considered relatively chemically inert for the purpose of groundwater sampling. From the list below, it is obvious that the materials selected by each of the major manufacturers of each type of pump have been carefully chosen. For example, pump manufacturers, who use metal in their pumps, only use the best and most tested stainless steels. Some even passivate the stainless steels by chemical processes or electropolishing. Rigid polymeric components are generally composed of PTFE Teflon, FEP Teflon, PVDF, or ETFE, which are considered to be the most inert and least subject to degradation. When elastomers are used, the manufacturers choose the most resistant, with the required material properties such as Viton or its equivalents. Realizing that many hazardous waste sites have contaminant concentrations in groundwater far <1 mg/L, a few manufacturers provide pumps in some alternate materials such as rigid PVC for the bladder pump. Considering that most monitoring wells sampled at Hanford have few contaminants of concern or are generally at fairly low concentrations with respect to sorption, desorption, leaching, and degradation potential, under most circumstances, material impacts are negligible, except for the most reactive materials, such as carbon steel, galvanized steel, or ABS. Even with these materials, appropriate purging procedures will generally negate their potential effect. However, because pumps and ancillary submerged components (e.g., risers, cable) may be moved from one well to another after a well is abandoned or because the conditions in the well are not known in advance of purchase of the pump equipment, the recommended composition for each of the six pumps evaluated is noted below.

- The body and impellers of the Grundfos Redi-Flo2 and Redi-Flo4 submersible pumps are composed of types 316 and 304 stainless steel, respectively. The drive shaft of the Redi-Flo2 and Redi-Flo4 is composed of types 329 and 304; the remaining parts of the pump are PTFE Teflon. The pump motors are surrounded by deionized water. The Redi-Flo3 is composed of types 316 and 316L stainless steel, with some internal parts composed of PVDF and FPM rubber (Viton equivalent). Either deionized water or, more commonly, a mixture of mineral-free water and propylene glycol surrounds the pump motor of the Redi-Flo3. The discharge risers for these pumps are usually PTFE Teflon, FEP Teflon-lined PE, HDPE, or LDPE, but stainless steel riser pipe has also been used.

- The Well Wizard® bladder pump by QED® is composed of electropolished type 316L stainless steel with Teflon bladder and parts. The discharge riser is a matter of choice from the manufacturer, but PTFE Teflon, FEP Teflon-lined PE, HDPE, and PP are used commonly.

- The Bennett piston pump is composed of type 304 stainless steel, PP, nylon, and Teflon. The water-discharge tube is commonly composed of FEP Teflon.

- The HydroStar piston pump is composed of passivated type 304L stainless steel and Teflon. The 1.9-cm ID riser is composed of passivated 304L. The 0.64-cm piston rod and nuts are made of either 302 or 303.

- The Keck progressive cavity pump is composed of types 303 and 304 stainless steel with Viton O-rings and EPDM flexible rubber rotor or screw. The discharge riser is composed of PTFE Teflon, FEP Teflon-lined PE, HDPE, or LDPE.

- The Fultz gear-driven pump is composed of type 316L stainless steel with Teflon rotors. The discharge hose is made of either flexible 1.3-cm ID Teflon or 1-cm-dia. vinyl.

The manufacturers provide a variety of materials for discharge risers, as noted in the pump descriptions above. These materials have been provided and used for sampling at many hazardous waste sites with minimal or no significant effect. However, for Hanford groundwater monitoring, the materials recommended for use as discharge risers, including seals or other surfaces in contact with the sample water, to minimize any potential effect on sample results are the following:

- passivated types 304, 304L, 316, or 316L stainless steel for corrosive groundwater conditions or monitoring adsorptive radioisotopes

- rigid polymer pipe; actually includes bendable forms of pipe, including PTFE Teflon, FEP Teflon, FEP Teflon-lined PE, PVDF and Tefzel ETFE

- flexible polymer tubing, if needed for discharge risers, includes P(VDF-HEP), nylon 6/6, HDPE, and PP

- elastomeric materials used inside the pump or as seals in contact with the water should be limited to Viton, or equivalents, or EPDM.

Historically, at Hanford, the pump power cables are composed of either twisted, rubber-coated, solid core, or double sheathed, FPVC-coated wire for submersible pumps. For all pumps used to sample monitoring wells, the PVC-coated wire is preferable because it is more chemically resistant and durable than rubber coatings. Double-sheathed, PVC-coated, multistrand wire is recommended for all pumps for durability and flexibility and ease of installation above the highest water level in the well. Below the water level, Tefzel- (or Teflon as a second choice) coated multistrand wire should be used. In highly radioactive water, Tefzel should be used wherever possible rather than Teflon.

A.3 Glossary of Acronyms

ABS	-	acrylonitrile-butadiene-styrene
CPVC	-	chlorinated polyvinyl chloride
DNAPL	-	dense nonaqueous-phase liquid(s)
ETFE	-	ethyl-tetraethyl-ethylene
EVA	-	ethyl vinyl acetate
FEP	-	fluorinated ethylene propylene
FPVC	-	flexible polyvinyl chloride
FRE	-	fiberglass reinforced epoxy
HDPE	-	high-density polyethylene
ID	-	inner diameter
LDPE	-	low-density polyethylene
MIK	-	methyl-isobutyl-ketone
NAPL	-	nonaqueous-phase liquid(s)
PE	-	polyethylene
PFA	-	perfluoroalkoxy (resin)
PP	-	polypropylene
PTFE	-	polytetrafluoroethylene
PVC	-	polyvinyl chloride
PVDF	-	polyvinyldine fluoride
P(VDF-HEP)	-	polyvinyldine fluoride-hexaethylpropylene
SS	-	stainless steel
TPE	-	tetrapolyethylene
XLPE	-	extra-low-density polyethylene

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Appendix B

Variable Frequency Drive Pump and Groundwater-Sampling System Accessories

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Variable Frequency Drive Pump and Groundwater-Sampling System Accessories

This appendix provides guidance on the purchase and use of the variable frequency drive (VFD) submersible pumps recommended for sampling of groundwater-monitoring wells at the Hanford Site. Specific operational guidance is provided, as well as detailed specifications and drawings.

Five primary components make up the recommended sampling system:

- the VDR pump that extracts the water from the well
- the discharge riser that brings the purge and sample water to the surface for collection
- the power cable from the pump motor to the support platform
- the power converter, or control system, that regulates the discharge rate
- the pump-support platform (well seal) that supports the pump and riser, allows access to the well, and provides safe electrical connections.

B.1 Recommended Pumps

The pumps recommended for use at the Hanford Site are the environmental models of the VFD submersibles manufactured by Grundfos® Pumps Corporation. There are three versions (types) suitable for environmental sampling: two are designed specifically for environmental sampling, the MP1 Redi-Flo2® and the Redi-Flo4®; the third is the Redi-Flo3®, which is compatible with the chemistry of groundwater and current purging and sampling practices at Hanford.

Redi-Flo2 – Despite its depth and discharge-rate limitations, the Redi-Flo2 is the preferred pump because its discharge can be more easily adjusted to low-flow rates for both purging and sampling needs because less hydraulic pressure is generated even at its higher revolutions per minute. **The Redi-Flo2 is recommended if lift (depth to water-table surface) is <250 ft, depth of the pump intake is <300 ft, and diameter of the well is >2 in. but <5 in.** The Redi-Flo2 has no check valve. To ensure adequate cooling of the Redi-Flo2, a stainless steel shroud (either type 304 or 316) must be added that directs flow past the motor for 4-in.-dia. wells.

Redi-Flo3 – For depths to water >220 ft but <325 ft for 4- or 5-in. well diameters, the Redi-Flo3 (model 5SQE05B-250NE) pump and motor are recommended. A check valve must not to be used on any dedicated VFD pump. The Redi-Flo3 does have a spring-loaded polyvinyldine chloride (PVDF) check valve. The supplier shall remove this check valve to allow for drainage of the discharge riser after the pump is shut off.

Redi-Flo4 – For depths to water >220 ft and up to 550 ft and for 5-in. or larger well diameters, the Redi-Flo4 (model 5E8 with a Grundfos MS402E motor) is recommended. Note that telescoping screens, called nominal 5-in., have actually only a 4-in. inside diameter. A check valve must not be used on any dedicated VFD pump. The Redi-Flo4 has a check valve, but must be removed by the supplier to allow for drainage of the riser after the pump is shut off. To ensure adequate cooling of the pump, a stainless steel shroud (either type 304 or 316) must be added that directs flow past the motor. For wells where the water level is far above the well screen, a stinger shroud should be used on the Redi-Flo2 pumps. The stinger should extend into the well screen interval to avoid the need to purge water above the well screen and maximize the efficiency of the pumps and minimize the cost of the riser and electrical cable.

B.2 Recommended Supplemental Components

Discharge Riser – All three types of pumps shall use a 0.75-in. discharge riser made of schedule 40 type 304 or 304L stainless steel pipe and couplings secured to the pump-support platform assembly using a stainless steel coupling.

Power Cable – The power cable for the **Redi-Flo2** shall consist of a 50-ft-long, stranded, 16-gauge Tefzel® motor lead manufactured by Grundfos or equivalent. Additional 16-gauge, stranded cable suitable for monitoring wells shall be spliced to the motor lead and shrink-wrapped to provide a total length equal to the planned length of the discharge riser from the support plate to the pump motor plus an additional 15 ft. The additional 15 ft is a service loop that allows for lowering the pump without additional splicing of the cable and can be stored in the annular space between the 4- and 6-in. well casing.

Similarly, the power cable for the **Redi-Flo3** shall consist of a 50-ft-long, stranded, 12-gauge, Tefzel motor lead manufactured by Grundfos or equivalent. Additional 12-gauge, polyvinyl chloride- (PVC-) coated, copper-stranded cable suitable for monitoring wells shall be spliced to the motor lead and shrink-wrapped to provide a total length equal to the planned length of the discharge riser from the support plate to the pump motor plus an additional 15 ft.

The power cable for the **Redi-Flo4** shall consist of a 50-ft-long, copper-stranded, 12-gauge, Teflon® motor lead manufactured by Grundfos or equivalent. Additional 12-gauge, PVC-coated, copper-stranded cable suitable for monitoring wells shall be spliced to the motor lead and shrink-wrapped to provide a total length equal to the planned length of the discharge riser from the support plate to the pump motor plus an additional 15 ft.

Control System – The fourth component is the power converter, or control system, that regulates the discharge rate. For the **Redi-Flo2 or Redi-Flo4**, the newer, 10-turn-control version shall be used to control the discharge rate. The power converter connects to the pump by a 12-ft-long converter cable. The cable receptacle on the support plate and cable connector shall be a round BradHarrison, four-pin connector or equivalent. The 230-V power source for both the **Redi-Flo2** or **Redi-Flo4** shall have, as a minimum, a 3,500-W power generator with automatic voltage regulation. The generator plug used for these pumps should not have a Ground Fault Circuit Interrupter (GFCI), which would interfere with the

GFCI already in the control system. The power converter is connected to the power source by a 12-ft-long power cable. The 230-V male plug on the power cable shall have a configuration compatible with the 230-V outlet on the generator. Under no circumstances should the older type control boxes with a single-turn control knob be used with a **Redi-Flo4**. The newer control box has a mode switch for selecting RF2M for operating the **Redi-Flo2** and an RF4M for the **Redi-Flo4**. Using an older control box, designed to operate only the **Redi-Flo2**, will severely damage the pump motor of the **Redi-Flo4**. Starting these pumps using the Start, Stop, and Reset switch is accomplished by turning the pump-control knob to the start position and gradually turning the knob to the desired hertz on the light-emitting diode (LED) display to the desired discharge rate. The control knob should start at the 47-hz minimum and be gradually turned up to achieve an initial surface discharge rate of ~2 gal/min. Under current purging practices, this gradual buildup of power will avoid excess turbidity in the groundwater discharged. The total time from the minimum to the desired discharge rate will take ~15 to 60 sec, depending on the depth of the well. For example, using a **Redi-Flo2** will require ~9 turns to achieve ~350 hz at a depth to water (lift) of 250 ft to produce ~2 gal/min. Without pausing significantly, the control knob should be gradually turned to the desired 350-hz display in ~30 to 60 sec. For the **Redi-Flo4**, the hertz range goes from 0 to 100, so a setting of ~50 is probably what would be needed for the same lift conditions and discharge rate.

The **Redi-Flo3** uses a CU-300 Status Box with remote control and potentiometer to change or preset the discharge rate of the pump. The power converter connects to the pump by a 12-ft-long converter cable. The cable receptacle on the support plate and cable connector shall be a round, BradHarrison, four-pin connector or equivalent. The required power source for the **Redi-Flo3** is the same as for the **Redi-Flo2** and **Redi-Flo4,** and the power outlet on the CU-300 Status Box is connected to the power source by a 12-ft-long power cable. The 230-V male plug on the power cable shall have a configuration compatible with the 230-V outlet on the generator.

Support Platform – The recommended design for the pump-support platform is shown in Figure B.1. Looking down at the top of the support plates for the **Redi-Flo2**, **Redi-Flo3**, and **Redi-Flo4**, they will appear identical; therefore, an aluminum tag attached by a lanyard to the cap of the electrical connector shall be stamped with pump model and well number. No damage will occur to the pump or components if the dial is set to the wrong pump on the converter. However, the pump will not function until it is set to RF2M for the **Redi-Flo2** or RF4M for the **Redi-Flo4**. The platform and seal consist of a stainless steel plate with a stainless steel ring, with an O-ring groove and O-ring compression seal that fit easily inside the protective well casing diameter of 6.065 in. The 0.25-in.-thick top plate rests flat on top of the protective well casing, with a diameter identical to the 6.625-in. outside diameter of the schedule 40 protective casing. In the center of the platform is a 1.065-in.-dia. opening to allow passage of the 1.050-in. outside diameter of the 0.75-in. inside diameter stainless steel pipe. The pipe will be supported using a 1.375-in. outside diameter stainless steel coupling resting on the upper support plate as shown in Figure B.1. Two 1.1-in.-dia. access ports for water-level measurement and sensors are provided (see Figure B.1). Caps are provided for the access ports and the electrical connection. A BradHarrison four-pin receptacle (only 3 pins for the **Redi-Flo3** receptacle) is attached to the top plate. Support cable is not needed because stainless steel riser pipe and couplings are used. To ensure proper performance, the pump system, excluding the riser, shall be tested under load (at least 100 lb/in.^{2}) by the supplier after assembly and before shipment to the installer (e.g., driller). The supplier shall use the well-identification number to

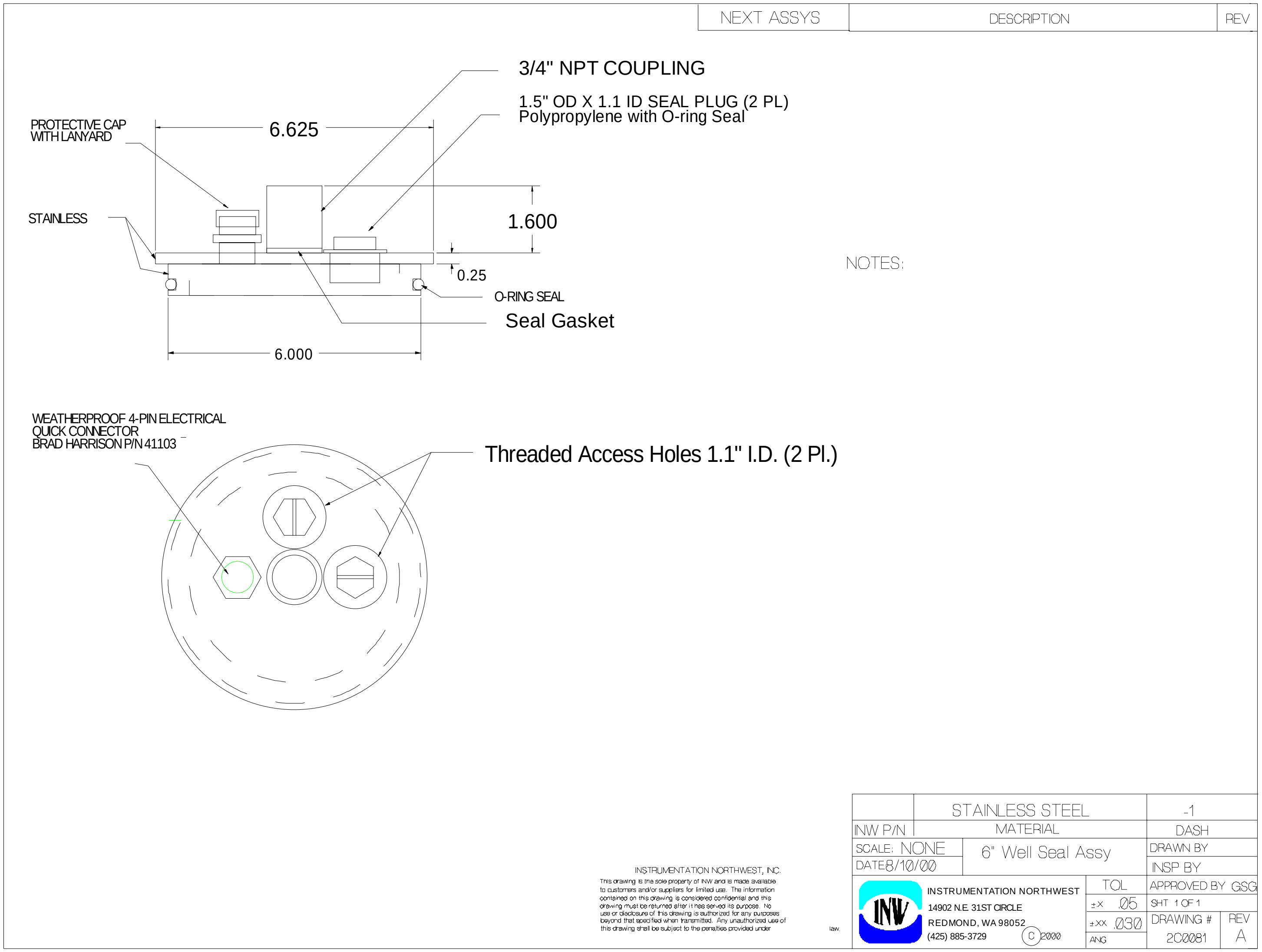

Figure B.1. Details of the Support Platform for the Groundwater-Sampling Pump System ensure that the pump system is installed in the correct well. In addition to these specifications, the buyer (e.g., driller) must provide the following information to the supplier for each well:

- pump type (**Redi-Flo2**, **Redi-Flo3** [Model 5SQE05B-250NE], or **Redi-Flo4** [Model 5E8 with a Grundfos MS402E motor]) with appropriate National Pipe Thread stainless steel reducers installed to accommodate the 0.75-in. riser pipe

- the inside and outside diameters of the protective well casing

- specifications regarding the stainless steel support platform and other components

- length from the top of the well casing to the pump intake and well number.

B.3 Recommended Individual Well Pump Type

Selection of the most appropriate pump type (i.e., **Redi-Flo2**, **Redi-Flo3**, or **Redi-Flo4**) was based primarily on the depth to water, or lift, and the well screen, or perforated pipe, diameter. The lift capabilities of each type of pump were given in Section B.1 but are summarized below:

- **Redi-Flo2** should be used if lift (depth to water-table surface from top of casing) is <250 ft, depth of the pump intake is <300 ft, and the inside diameter of the well is >2 in. but <5 in.

- **Redi-Flo3** should be used if lift (depth to water-table surface from top of casing) is >250 ft but <325 ft, depth of the pump intake is <600 ft, and the inside diameter of the well is at least 4 in. but <5.3 in.

- **Redi-Flo4** should be used if lift (depth to water-table surface from top of casing) is >50 ft but <550 ft, depth of the pump intake is <580 ft, and the inside diameter of the well is 5 in. or more.

As noted above, there are no overlapping performance areas based on lift and well diameter for the **Redi-Flo2** and **Redi-Flo4** and very little between the **Redi-Flo3** and the **Redi-Flo2** or **Redi-Flo4**. Many wells at Hanford are screened with stainless steel, telescoping screens that have smaller inside and outside diameters than standard size pipe screens. Specifically, 6-in.-dia., telescoping screen has a 4.875-in. inside diameter, not 6.0-in. as in standard size pipe screen, and 5-in.-dia. telescoping screen has 4.0-in. not 5.0-in. inside diameter. In wells with the 6-in. telescoping screen, all three pumps would work; however, the **Redi-Flo2** would the best alternative for shallow wells (<250 ft) and the **Redi-Flo4** for deeper wells up to 550 ft. A few of these wells have one or two, 1.5-in. inside diameter piezometers in the 8-in.-dia. casing above the well screen. Such obstruction may necessitate the use of the **Redi-Flo2** rather than the **Redi-Flo4** in these wells. If the well has 5-in. telescoping screen, then the **Redi-Flo2** is still the best alternative for shallow wells, but the **Redi-Flo3** must be used for wells deeper than 250 ft to water.

B.4 Specifications and Drawings

Separate sets of specifications are provided for each of the three types of VFD pumps recommended for use at the Hanford Site.

B.4.1 Specifications for Redi-Flo2 Pump and Associated Equipment

- **Redi-Flo2 submersible pump** to be supplied for each well is a model MP1 wired for 230 V supplied to the VFD power converter. To ensure adequate cooling of the **Redi-Flo2** pump in 4-in.-dia. wells, a stainless steel shroud (either type 304 or 316) must be added that directs water flow past the motor.

- **Discharge riser** for each well shall be 0.75-in. dia. and made of schedule 40, type 304 or 304L stainless steel pipe and couplings secured to the pump-support platform assembly using a stainless steel coupling. **The pipe and couplings for the discharge riser shall be supplied by others.**

- **Power motor lead** for each well shall consist of a 50-ft-long, stranded, 16-gauge Tefzel motor lead, manufactured by Grundfos or equivalent. Additional wire cable shall consist of MILSPEC® PVC flat submersible pump cable (600V, AWG14/3) with #14 ground size (Stock No. 31714C10) as manufactured by MILSPEC Industries, 5825 South Greenwood Avenue, Los Angeles, California (phone 1-800-234-8910). Proper wiring between the Tefzel motor lead and the BradHarrison connection (platform outlet) is shown in Figure B.2.

- **Power converter cable** is 12 ft long. The receptacle on the support plate and the cable connector shall be a round, BradHarrison, four-pin connector. The control system, to be supplied by others, is the 10-turn version. The 230-V male plug on the power cable shall have a configuration compatible with the 230-V outlet on the generator.

- **Support platform** is manufactured by Instrumentation Northwest, Inc., Redmond, Washington (phone 1-800-776-9355 or 1-425-885-3729) (see Figure B.1). An aluminum tag, attached by a lanyard to the cap of the electrical connector, shall be stamped with pump model and well number. The support platform and seal consist of a stainless steel plate with a stainless steel ring, with an O-ring groove and O-ring compression seal that fit easily inside the protective 6.065-in.-dia. well casing schedule 40 or 6.0627-in. schedule 10. The 0.25-in.-thick top plate rests flat on top of the protective well casing with a diameter identical to the 6.625-in. outside diameter of the schedule 40 protective casing. In the center of the support platform is a 1.065-in.-dia. opening to allow passage of the 1.050-in. outside diameter of the 0.75-in. inside diameter stainless steel pipe. The pipe will be supported using a 1.375-in. outside diameter stainless steel coupling resting on the upper support plate. A 2-in., stainless steel, schedule 40, pipe nipple shall also be provided. Two 1.1-in.-dia. access ports for water-level measurement and sensors are provided (see Figure B.1). Caps shall be provided for the access ports and the electrical connection. A BradHarrison four-pin receptacle is attached to the top plate. The stainless steel riser pipe and couplings shall be used to support the cable.

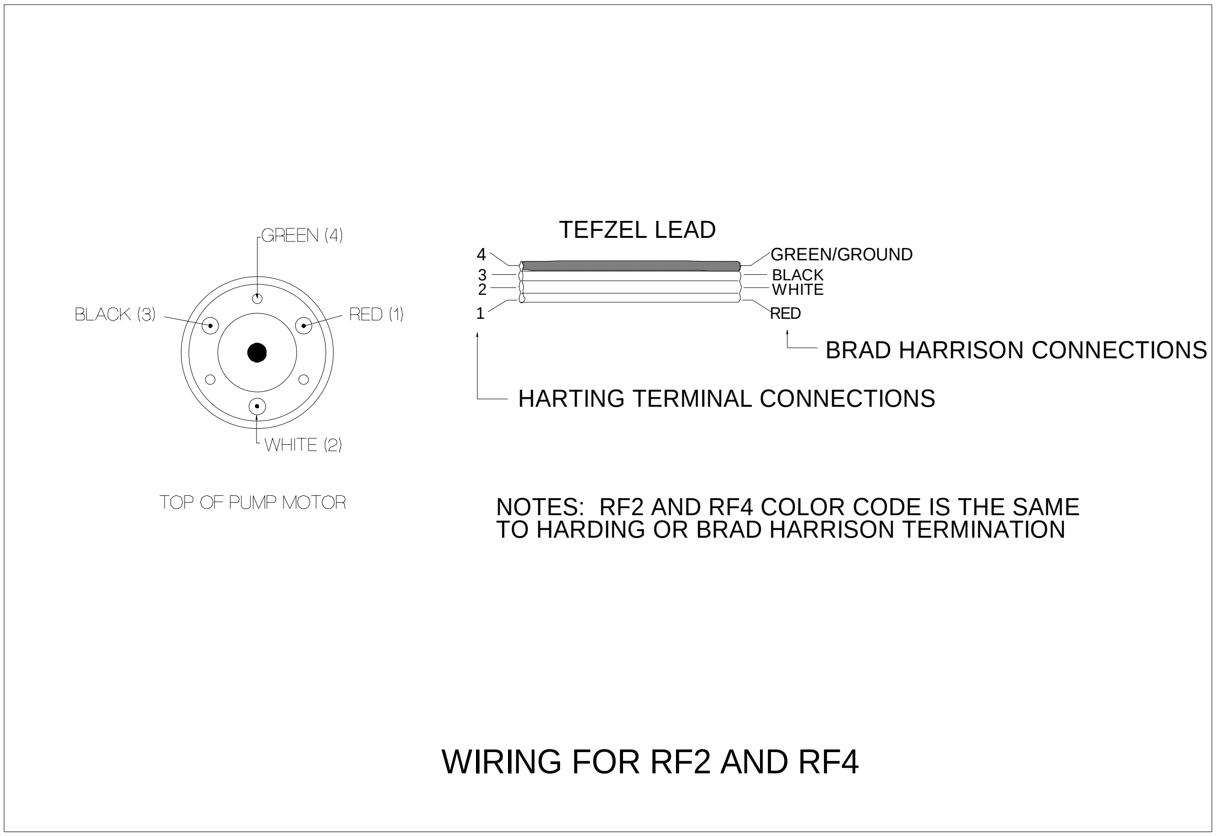

Figure B.2. Correct Wiring Diagram for Tefzel or Teflon Motor Leads to BradHarrison Outlet on Support Platform for Groundwater-Sampling Pump System

- **Assembly by supplier** shall include attaching the electrical outlet and aluminum tag to the support-platform receptacle and the Tefzel motor lead to the pump. Also, the proper connections shall be installed on the power converter cable.

- **Field support** shall be provided to ensure proper installation of the pump, accessories, and, in particular, the pump-support platform.

B.4.2 Specifications for Redi-Flo3 Pump and Associated Equipment

- **Redi-Flo3 submersible pump** to be supplied for each well is model 5SQE05B-250NE (Product No. 96033956) wired for 230 V. Check valves shall not be used and, therefore, shall be removed by the supplier before shipping.

- **Discharge riser** for each well shall be 0.75-in. dia. and made of schedule 40, type 304 or 304L stainless steel pipe and couplings secured to the pump-support platform assembly using a stainless steel coupling. The pipe for the discharge riser shall be supplier by others.

- **Status box** shall be model CU-300 (Product No. 96440289) with an SPP1, RF3 potentiometer (Product No. 625468)

- **Power cable (motor lead)** for each well shall consist of a 50-ft-long, stranded, 12-gauge Tefzel cable kit (Product No. 96037429) manufactured by Grundfos. Additional wire cable shall consist of MILSPEC PVC flat submersible pump cable (600V, AWG12/2) with #12 ground size (Stock No. 31612C10) as manufactured by MILSPEC Industries, 5825 South Greenwood Avenue, Los Angeles, California (phone 1-800-234-8910).

- **Remote control system** is model R100 Infrared remote (Product No. 625333) for utilizing the status box. In addition, the power cables shall be provided for connecting to the pump and generator. The 230-V male plug on the power cable shall have a configuration compatible with the 230-V outlet on the generator.

- **Support platform** is manufactured by Instrumentation Northwest, Inc., Redmond, Washington (phone 1-800-776-9355 or 1-425-885-3729) (see Figure B.1). An aluminum tag, attached by a lanyard to the cap of the electrical connector, shall be stamped with pump model and well number. The support platform and seal consist of a stainless steel plate with a stainless steel ring, with an O-ring groove and O-ring compression seal that fit easily inside the protective 6.065-in.-dia. well casing schedule 40 or 6.0627-in. schedule 10. The 0.25-in.-thick top plate rests flat on top of the protective well casing with a diameter identical to the 6.625-in. outside diameter of the schedule 40 protective casing. Adaptors may be specified for larger diameter wells. In the center of the support platform is a 1.065-in.-dia. opening to allow passage of the 1.050-in. outside diameter of the 0.75-in. inside diameter stainless steel pipe. The pipe will be supported using a 1.375-in. outside diameter stainless steel coupling resting on the upper support plate. A 2-in., stainless steel, schedule 40, pipe nipple shall also be provided. Two 1.1-in.-dia. access ports for water-level measurement and sensors are provided (see Figure B.1). Caps shall be provided for the access ports and the electrical connection. A BradHarrison four-pin receptacle is attached to the top plate. The stainless steel riser pipe and couplings shall be used to support the cable.

- **Assembly by supplier** shall include attaching the electrical outlet and aluminum tag to the support-platform receptacle and the Tefzel motor lead to the pump. The status box (CU-300) and potentiometer shall be installed and properly wired together, including the power cable to the pump and generator. All these components, including the remote control, shall be fitted into a waterproof Pelican (or equivalent) watertight carrying case.

B.4.3 Specifications for Redi-Flo4 Pump and Associated Equipment

- **Redi-Flo4 submersible pump** to be supplied for each well is model 5E8 with a Grundfos MS402E motor wired for 230 V supplied to the VFD power converter. Check valves shall not be used and, therefore, shall be removed by the supplier before shipping.

- **Discharge riser** for each well shall be 0.75-in. dia. and made of schedule 40, type 304 or 304L stainless steel pipe and couplings secured to the pump-support platform assembly using a stainless steel coupling. The pipe and couplings for the discharge riser shall be supplier by others.

- **Power motor lead** for each well shall consist of a 50-ft-long, stranded, 12-gauge Teflon motor lead, manufactured by Grundfos. Additional wire cable shall consist of MILSPEC® PVC flat submersible pump cable (600V, AWG12/3) with #12 ground size (Stock No. 31712C10) as manufactured by MILSPEC Industries, 5825 South Greenwood Avenue, Los Angeles, California (phone 1-800-234-8910). Proper wiring between the Teflon motor lead and the BradHarrison connection (platform outlet) is shown in Figure B.2.

- **Power converter cable** is 12 ft long. The receptacle on the support plate and the cable connector shall be a round, BradHarrison, four-pin connector. The control system, to be supplied by others, is the 10-turn version. The 230-V male plug on the power cable shall have a configuration compatible with the 230-V outlet on the generator.

- **Support platform** is manufactured by Instrumentation Northwest, Inc., Redmond, Washington (phone 1-800-776-9355 or 1-425-885-3729) (see Figure B.1). An aluminum tag, attached by a lanyard to the cap of the electrical connector, shall be stamped with pump model and well number. The support platform and seal consist of a stainless steel plate with a stainless steel ring, with an O-ring groove and O-ring compression seal that fit easily inside the protective 6.065-in.-dia. well casing schedule 40 or 6.0627-in. schedule 10 or an 8.0-in. schedule 40 or 80 steel casing. The 0.25-in.-thick top plate rests flat on top of the protective well casing with a diameter identical to the 6.625-in. outside diameter of the schedule 40 protective casing or the outside diameter of the 8-in. casing. In the center of the support platform is a 1.065-in.-dia. opening to allow passage of the 1.050-in. outside diameter of the 0.75-in. inside diameter stainless steel pipe. The pipe will be supported using a 1.375-in. outside diameter stainless steel coupling resting on the upper support plate. A 2-in., stainless steel, schedule 40, pipe nipple shall also be provided. Two 1.1-in.-dia. access ports for water-level measurement and sensors are provided (see Figure B.1). Caps shall be provided for the access ports and the electrical connection. A BradHarrison four-pin receptacle is attached to the top plate. The stainless steel riser pipe and couplings shall be used to support the cable.

- **Assembly by supplier** shall include attaching the electrical outlet and aluminum tag to the support-platform receptacle and the Teflon motor lead to the pump. Also, the proper connections shall be installed on the power converter cable.

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