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Purge Water Minimization at LEHR

R. Schalla

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(HSUs) that comprise the upper aquifer system under the LEHR facility. The anticipated and actual benefits of the PurgeLess device differed because of actual site/formation conditions, such as high hydraulic conductivity in the lower hydrogeologic unit.

Based on results of the sampling comparison, the new technology and, more importantly, the purging procedures, were shown to be superior to those previously used in monitoring wells at LEHR. Although the new technology exhibited reduced volumes, the procedures could be modified to reduce purge water even more with no detrimental effect on the accuracy of groundwater samples. Most of the cost savings resulted from improved purging procedures determined from the field tests and existing scientific literature. Overall cost of purging was reduced generally in proportion to the total volume reduction. Purge volumes for wells screened in HSU-1 and HSU-2 can be reduced to less than 10% of previous volumes. Proper deployment of the pump intakes relative to screened intervals, known vertical concentration distribution, and reduced discharge rates during purging contribute to cost savings and assurance of representative samples.

Reference:

Schalla, R. L. 1994. Designing an Enhanced Groundwater Sample Collection System. PNL-10182, Pacific Northwest National Laboratory, Richland, Washington.

Acronyms

ASTM	American Society for Testing and Materials
bgs	below ground surface
BV	purge volume in screened interval, sand pack, and casing volume
ft/ft	foot/foot
HSU	hydrogeologic unit
LEHR	Laboratory for Energy-Related Health Research
ntu	nephelometric turbidity unit
PTFE	polytetrafluoroethylene
PVC	polyvinyl chloride
SC	purge volume in screened interval
SPSC	purge volume in screened interval and filter pack
SWAT	Site Wide Assessment Team
TEGD	Technical Enforcement Guidance Document
UCD	University of California, Davis
VOC	volatile organic contaminant

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1.0 Introduction

1.1 Programmatic Background

The field demonstration described in this report is being conducted as part of the Environmental Restoration Program at the Laboratory for Energy-Related Health Research (LEHR). The Environmental Restoration Program is one of several U.S. Department of Energy (DOE) waste cleanup projects designed to support by the actual use of emerging environmental management and restoration technologies. As part of an ongoing technical support mission to achieve excellence and efficiency in environmental restoration activities at LEHR, DOE requested Pacific Northwest National Laboratory's (PNNL's) guidance to identify the most efficient way of reducing purge water extracted by sampling pumps while still obtaining representative samples from LEHR monitoring wells.

The purpose of this particular demonstration is to determine to what extent reduction of purge water is possible with the PurgeLess (U.S. Patent 5,450,900) device (a well volume isolation system) and proper purging practices (purge rate, duration, pump intake deployment, etc.) to obtain representative samples year round for all parameters of interest. Specifically, the goal is to minimize the production of waste water from purging by demonstrating this new and innovative technology coupled with recommended practices based on current research of purging and sampling practices and actual field data including time series sampling of contaminants of concern. The primary radiological and chemical constituents of concern in the groundwater at LEHR are: chloroform, tritium, hexavalent chromium, and nitrate. Therefore, the time series sampling was directed toward analysis of these constituents. It is important to ensure that high quality groundwater samples that are representative of ambient aquifer conditions are collected.

Although it was anticipated that the PurgeLess device would be beneficial and needed for most or possibly all LEHR wells, initially the focus was primarily on the hydrogeologic (formerly referred to as hydrostratigraphic) unit-2 (HSU-2) with two test wells containing the device and a control well without the device, and only one PurgeLess device in the hydrogeologic unit-1 (HSU-1) (Figure 1.1). The explanation of the two HSUs can be found in Section 1.3.1. The PurgeLess device was installed only in recently constructed monitoring wells because these new wells exhibited reduced turbidity and improved access for instrumentation and hydrologic testing.

A variable frequency submersible pump was selected as the best choice of several alternative devices for obtaining groundwater samples following results of a literature review and because of the large range of discharge rates and the ease of changing and maintaining various continuous discharge rates during purging and sampling (Schalla 1994). It was also suspected that the duration and rate of discharge during purging and sampling was important for obtaining representative samples.

This report focuses primarily on purging and sampling of LEHR groundwater monitoring wells. Pertinent objectives of the study include: the basis of purging, procedures and criteria for purging, and site-specific procedures and equipment for reducing the amount of purge water. A description of field tests conducted within six monitoring wells, the results, and potential reductions in purge water requirements are also included. Conclusions are based on actual field tests and observations of current procedures. The literature review of references is listed in Section 7.0. This report also includes a brief description of the hydrogeologic setting and a discussion of the construction and development of monitoring wells used for tests to determine purging requirements. Some discussion is also provided regarding regulatory requirements and guidance and contaminants of concern at LEHR.

EXPLANATION

- HSU-1 Monitoring Well
- ✱ HSU-2 Monitoring Well
- ⊙ Surface Water Monitoring Point
- ▲ Storm Water Runoff Monitoring Point

LOCATION MAP
WATER MONITORING POINTS

Figure 1.1. Groundwater Wells and Surface Sampling Locations for LEHR

1.2 Purpose

The purpose of this report is to present the results of the design, installation, and actual experience of purge-water minimization demonstrations at the LEHR groundwater sample collection network. The information presents the rationale used for purge-water reduction improvements and delineates cost savings.

1.3 Hydrogeologic Setting

The two most shallow HSUs and their hydraulic characteristics comprise the hydrogeologic setting of interest at the time the first 24 monitoring wells were installed. Descriptions of these HSUs are provided in the following subsections.

1.3.1 Hydrogeologic Units

At the time of this effort, the focus was on the most likely contaminant transport pathways within the most shallow aquifer system at the site. During this investigation, the focus was on two HSUs that comprise the uppermost system beneath LEHR. The shallowest unit, HSU-1, extends from 10- to 80-ft below ground surface (bgs), and consists of very fine-grained sandy silt or silty sand to sandy clay. The second unit, HSU-2, consists of coarse sand and gravel, and is relatively extensive. The HSU-2 unit occurs between 80- and 135-ft bgs. Because groundwater depths range from approximately 30- to 70-ft bgs, HSU-1 is generally thought of as unconfined, and the deeper HSU-2 layer is generally thought of as confined. Actually, the two units are hydraulically interconnected and the amount of isolation is minor. The character of these units not only affects the contaminant residence and travel times, but also may impact the sample collection system. Below HSU-2 is a lower clayey zone that is several tens of feet thick. Figure 1.2 is a generalized cross-section of the LEHR site.

1.3.2 Hydraulic Characteristics

Groundwater elevations beneath the site vary from approximately 5-ft above to 20-ft below mean sea level throughout the year. Generally, water levels are at their highest level in early spring and at their lowest in late summer. Lateral groundwater gradients in HSU-1 vary from 0.0001 to 0.0015 ft/ft, and are typically 0.0015 ft/ft in HSU-2. Generally, groundwater flow direction is toward the northeast, but temporary local changes in flow direction occur, particularly in the HSU-1. Putah Creek recharges locally and creates a groundwater flow barrier in HSU-1. Horizontal hydraulic conductivities average 1.3×10^{-3} cm/sec (4.2×10^{-5} ft/sec) for HSU-1 and 7.0×10^{-2} cm/sec (4.3×10^{-3} ft/sec) for HSU-2 (Liikala et al. 1996).

1.4 Well Locations

The locations of existing LEHR monitoring wells University of California, Davis (UCD)1-1 through UCD2-35 are shown in Figure 1.1. Wells with the number 1 after the letters UCD were screened in the fine-grained, silt-rich sand of the HSU-1 unit. If a 2 is present, wells are screened in the deeper, coarse-grained sequence of sand and gravel of HSU-2. Table 1.1 provides a summary of monitoring wells constructed to date. In the database, the well designation format includes a "0" preceding the well number (i.e., UCD2-027 instead of UCD2-27).

Figure 1.2. Typical Cross-Section of Hydrogeologic Units and Wells at LEHR

1.5 History of Operations

The LEHR is located on the University of California, Davis (UCD) campus. During the 30-year operation of the LEHR facility, a variety of wastes were generated and disposed of onsite. These wastes included radioactive, biological, chemical, municipal, and laboratory debris. A brief summary of waste generating processes or potential environmental impacts on groundwater at the LEHR facility are presented in the following paragraphs.

UCD has conducted radiological studies on laboratory animals for the DOE since the 1950s. The initial studies, conducted for the U.S. Atomic Energy Commission (AEC, now DOE), involved the irradiation of beagles at the UCD main campus. Full-scale experimental use of radioactive materials, including strontium-90 and radium-226, began at LEHR in 1960. Disposal at the LEHR facility included the two disposal units of the UCD campus landfill. Disposal Unit No. 1 was used during the 1940s and 1950s. Disposal Unit No. 2 was used from 1956 to 1967. A third landfill disposal unit was used by LEHR from 1963 to 1967. The combined total acreage of the three landfills is approximately six acres.

Table 1.1. Hydrogeologic Contacts in the LEHR Site Wells

Hydrogeologic Contacts in the LEHR Site Wells

Well Number	Former Well Number	Coordinates		Elevations			Drill		Casing		Screen			Date Completed	Depth to Top of HSU-2 (ft bgs)		Depth to Top of Unnamed Aquitard (ft bgs)		Thickness of HSU-2 (ft)	
				Ground Surface	Top of Pro. Casing	Top of Perm. Casing	Method	Depth (ft bgs)	Size (in.)	Type	Interval (ft bgs)	Slot Size	Type		Drill Log (X-Section)	Drill Log (X-Section)	Drill Log (X-Section)	Drill Log (X-Section)	Drill Log (X-Section)	Drill Log (X-Section)
UCD1-001	UCD-01	1951329.71	6631236.04	47.9	50.05	49.53	HSA ⁽¹⁾	56.5	2	PVC ⁽²⁾	46.5-56.5	20	PVC	10/9/87	ND	(86)	ND	(117)		(31)
UCD1-002	UCD-02	Abandoned		Abandoned			HSA	60.0	Abandoned		Abandoned			10/9/87	ND		ND			
UCD1-003	UCD-03	1951078.26	6631651.85	48.2	50.05	49.43	HSA	51.5	2	PVC	39-49	20	PVC	10/23/87	ND	(77)	ND	(115)		(38)
UCD1-004	UCD-04	1950651.45	6631315.64	49.4	51.69	51.20	HSA	56.5	2	PVC	45-55	20	PVC	10/14/87	ND	(83)	ND	(117)		(34)
UCD1-005	UCD-05	1951113.02	6631453.57	48.4	48.44	47.92	HSA	48.5	2	PVC	38-48	20	PVC	10/22/87	ND	(80)	ND	(117)		(37)
UCD1-006	UCD-06	1951048.00	6631270.45	49.0	50.94	50.50	HSA	52.5	2	PVC	40-50	20	PVC	10/21/87	ND	(82)	ND	(118)		(36)
UCD2-007	UCD-07	1951086.35	6631684.02	49.3	51.65	51.25	HSA	90.0	2	PVC	80-90	20	PVC	11/5/87	78	(77)	90	(116)	12	(39)
UCD1-008	UCD-08	1950694.34	6631902.08	49.2	51.51	51.05	HSA	56.0	2	PVC	43.5-53.5	20	PVC	11/3/87	ND		ND			
UCD1-009	UCD-09	1950989.69	6631932.52	49.0	51.39	51.00	HSA	51.5	2	PVC	40-50	20	PVC	11/4/87	ND		ND			
UCD1-010	UCD-10	1950805.37	6633117.83	47.4	49.87	49.34	HSA	70.0	4	PVC	54-69	10	PVC	10/11/89	ND	(71)	ND			
UCD1-011	UCD-11	1950855.20	6632272.51	47.6	50.67	50.19	HSA	66.5	4	PVC	50-65	10	PVC	10/17/89	ND	(78)	ND			
UCD1-012	UCD-12	1951000.90	6631936.63	48.8	51.76	51.42	HSA	65.0	4	PVC	49.5-64.5	10	PVC	10/19/89	ND	(81)	ND	(117)		(36)
UCD1-013	UCD-13	1950684.47	6631899.88	49.2	52.19	51.65	HSA	65.0	4	PVC	50-65	10	PVC	10/26/89	ND	(80)	ND			
UCD2-014	UCD-14	1950661.72	6631894.94	49.0	51.72	51.29	HSA	86.0	4	PVC	75-85		PVC	11/15/89	80	(80)	86		86	
UCD2-015	UCD-15	1950663.47	6631326.11	49.4	51.49	50.94	Air Rotary	120.5	4	PVC	91-116	20	SS	3/30/90	85	(83)	118	(117)	33	(34)
UCD2-016	UCD-16	1951437.57	6631291.46	48.2	49.95	49.18	Air Rotary	122.0	4	PVC	92-117	20	SS	4/4/90	88	(87)	119	(118)	31	(31)
UCD2-017	UCD-17	1950946.59	6630689.15	49.6	51.83	51.48	Air Rotary	143.0	4	PVC	88-113	20	SS	4/10/90	85	(84)	138	(139)	53	(55)
UCD1-018	UCD-18	1950715.24	6630679.76	46.7	48.56	47.75	HSA	70.0	4	PVC	54-69	10	SS	10/4/90	ND	(81)	ND			
UCD1-019	UCD-19	1951333.01	6631882.93	49.3	51.33	50.49	HSA	74.5	4	PVC	56.6-71.5	10	SS	10/1/90	ND	(78)	ND			
UCD1-020	UCD-20	1951079.65	6631641.81	48.0	49.78	48.94	HSA	71.5	4	PVC	57-72	10	SS	10/9/90	ND	(77)	ND	(115)		(38)
UCD1-021	UCD-21	1951099.81	6631478.44	48.7	48.73	48.00	HSA	73.5	4	PVC	57-72	10	SS	10/11/90	ND	(80)	ND	(117)		(37)
UCD1-022	UCD-22	1951043.57	6631257.33	49.0	49.06	48.40	HSA	71.5	4	PVC	57-72	10	SS	10/25/90	ND	(82)	ND	(118)		(36)
UCD1-023	UCD-23	1950761.52	6631387.22	49.2	49.39	48.60	HSA	76.5	4	PVC	56.5-71.5	10	SS	10/17/90	ND	(83)	ND	(117)		(34)
UCD1-024	UCD-24	1950879.02	6631636.90	48.8	48.91	48.22	HSA	71.5	4	PVC	57-72	10	SS	10/22/90	ND	(81)	ND			
UCD1-025		1951145.77	6632484.43		48.80	47.92	Air Rotary	75.0	4	SS ⁽³⁾	60-75	10	SS	10/6/95	ND	(82)	ND	(126)		(44)
UCD2-026		1951146.05	6632479.37		48.79	48.23	Air Rotary	102.0	4	SS	87-102	20	SS	10/6/95		(82)	ND	(126)		(44)
UCD2-027		1951146.73	6632499.66		48.78	47.79	Air Rotary	136.0	5	SS	Westbay	10/20	SS	10/6/95	82		126		44	
UCD1-034		1950452.03	6631692.18		55.70	54.94	Air Rotary	80.0	4	SS	61-76	10	SS	10/6/95		(76)	ND	(130)		(54)
UCD2-035		1950454.48	6631696.24		55.71	55.03	Air Rotary	130.0	4	SS	107-122	20	SS	10/6/95	76		130		54	

Notes:

1. HSA = Hollow Stem Auger
2. PVC = Polyvinyl Chloride
3. SS = Stainless Steel
4. ND = Not Determined
5. (86) = Extrapolated Value

Radiologic wastes generated from animal experiments using bone-seeking radionuclides were treated using two primary systems. From 1960 to 1987, effluent from strontium-90 experiments was processed through an Imhoff sewage treatment system. From 1982 to 1984, a total of 39.59 μCi of plutonium-241 and 0.136 μCi of americium-241 were processed through the Imhoff treatment system. This system uses a series of settling tanks and cation exchange columns to treat approximately 200 to 500 gal of waste per day, prior to discharge to leach fields. The total throughput of strontium-90 to the Imhoff system is estimated at 943.2 mCi. After treatment through the Imhoff system, an estimated 2.55 mCi of strontium-90 was released to the Imhoff leach field and subsurface soil. The half-life of strontium-90 is 29 years.

In March 1990, DOE assumed responsibility for UCD1-11 to UCD1-24 site characterization at LEHR. The purpose was to continue to support ongoing characterization and assessment of possible impacts, remediation of soil and groundwater, and decontamination and decommissioning of buildings, as required at the LEHR site. The goal was to further characterize potential contaminant sources and evaluate the geologic and hydrologic relationships at the site. The design of monitoring wells and suitability of sample collection equipment were evaluated with respect to contaminants of concern at LEHR. Monitoring well design and selection of sample collection equipment were also evaluated with respect to suitability of the materials and design that would facilitate cost-effective collection of representative samples of groundwater contaminants.

1.6 Contaminants of Concern in Groundwater

Hazardous constituents, or indicators of potentially hazardous constituents related to past LEHR site operations, fall into the following general categories: heavy metals (such as chromium, hexavalent chromium, barium, thallium, and selenium), anions (such as chloride, nitrate, phosphate, and sulfate), radionuclides (such as tritium, carbon-14, and strontium-90), and organics. The organic constituents of concern can be divided into volatile organic contaminants (VOCs) such as 1,1-dichloroethane, 1,1-dichloroethene, 1,2-dichloroethane, methylene chloride, chloroform, benzene, and toluene; and semi-VOCs such as di-n-butylthalate, bis phthalate, and diethylphthalate. Of all of these, the four primary contaminants of concern are tritium, hexavalent chromium, chloroform, and nitrate. They represent the most significant contaminants in terms of concentration, volume, distribution, and mobility. These constituents were identified as possible contaminants of concern and were considered in the design of the groundwater sample collection system. Sampling of the UCD wells installed in 1995 and Hydropunch samples collected in 1995 and 1996 delineated both the vertical and horizontal extent of chloroform, hexavalent chromium, tritium, and nitrate (Stewart et al. 1996).

1.7 Monitoring Well Design

Problems with high turbidity in 2-in. diameter monitoring wells (UCD1-1 to UCD1-10) that were screened in HSU-1, and with large water level fluctuations during the year, necessitated design changes in the fourteen UCD1-11 to UCD1-24 and subsequent wells. The goal for the monitoring wells was to use a design that would allow for hydrologic testing and reduce the turbidity to minimize the impact on groundwater sample accuracy (Paul et al. 1988). In the previously installed monitoring wells, the turbidity exceeded regulatory levels for drinking water during the purging and sometimes the sampling cycle. The earlier wells, UCD1-1 to UCD1-10, were installed at shallower depths and only partially penetrated the saturated thickness of the aquifer, particularly in the HSU-1 unit. During the summer, some of these wells would become dry. To deal with seasonal water-level

fluctuations, wells screened in the HSU-1 unit were completed slightly deeper in the UCD1-11 to UCD1-24 wells. Expertise available and American Society for Testing and Materials (ASTM) standards were used as a basis to design, construct, and develop the monitoring wells (ASTM 1990; Nielsen 1991; Williams 1981). Detailed discussion of the changes in well design, construction, and development have been previously published (Schalla 1994). Because of the improved well design, wells used in the tests were limited to the newer UCD1-11 to UCD1-24 monitoring wells, specifically wells UCD2-15, 2-16, 2-17, 2-26, 1-12, and 1-20.

Before 1990, wells were typically constructed with slotted 2-in. (for the UCD1-1 to UCD1-10 wells) or 4-in. diameter (for the Site Wide Assessment Team [SWAT] wells) polyvinyl chloride (PVC) casing used as well screen and PVC casing. The 4-in. diameter was selected for newer wells to support a greater variety of hydraulic testing methods, a greater variety of pumps to be used for development and sampling to facilitate well development with conventional methods and tools for easy access for water level measurements, and for the placement of in situ instrumentation. To reduce turbidity and expedite development in both zones, UCD1-11 to UCD1-24 monitoring wells were constructed of 4-in. diameter, 304 stainless steel, continuous wire-wrap screen (Bikis 1979; Clark and Turner 1983; Jackson 1983; Rinaldo-Lee 1983; Paul et al. 1988; Schalla and Walters 1989; Nielsen 1991). This type of screen has a larger open area, even in the smaller slot sizes selected (Nielsen 1991). Slot size chosen for wells screened in HSU-1 was 0.010-in. (10-slot), and an appropriate filter pack, Lonestar 1C sand (a 16-40 mesh gradation), was selected on the basis of recommendations set forth in consensus society standards and recognized publications (ASTM 1990; Nielsen 1991; Schalla and Walters 1989). Wells screened in HSU-2 used 0.020-in. slot openings of 4-in. diameter, 316 stainless steel, continuous wire-wrap screen with a number 2/12 filter pack sand (a 12-20 mesh gradation). 4-in. diameter, Schedule 40 PVC casing, 4-in. in diameter, was used from the top of the screened interval to above the ground surface for all wells to reduce the cost of the well while retaining the desirable characteristics of stainless steel wire-wrap screen. Flush-threaded casing was used for all screen and casing conforming to ASTM F480-90. To avoid a stagnant zone, no sediment trap or silt trap was added to the bottom of the well (Nielsen 1991; Yu 1989).

UCD1-11 to UCD1-24 groundwater monitoring wells at the LEHR site were based on the recommended practice in ASTM D5092-90. They also comply generally with the primary federal guidance document (EPA 1986). The 1986 Technical Enforcement Guidance Document (TEGD) recommends that all well materials used be constructed of inert material, such as fluorocarbon or stainless steel. More research, published after issuance of that document, showed that PVC was an equal or superior choice, depending on the constituents contained in the groundwater (Barcelona and Helfrich 1986; Barcelona et al. 1988; Dunbar et al. 1985; Gillham and Ohannesin 1990; Miller 1982; Nielsen 1991; Parker 1992).

1.8 Sampling Pump Considerations

Groundwater sample collection from monitoring wells requires basically two activities (sometimes referred to as cycles): purging and sampling. Purging is the activity of removal of stagnant surrounding water that is in the well casing and screen (and sometimes in the filter pack surrounding the well screen) that must be removed before sampling in order to obtain a representative sample from the water-bearing layers. Purging most monitoring wells (excluding wells with high groundwater velocities) is necessary to remove stagnant water, usually at as high a rate as is practical to minimize time and associated labor cost. Sample collection (or sampling) is the removal of specified quantities of groundwater from the well (after purging) in order to obtain samples for analysis. The goal of purging and sampling is to obtain analyses of constituents that are representative of the formation

groundwater composition in the immediate vicinity of the well site. A single device to perform both activities, rather than two separate devices, was the desired choice to minimize costs and equipment in the wells.

To achieve variation in purging and sampling rates that are necessary for the 4-in. diameter wells, the pump must be able to discharge water at the surface over an extensive range of flow rates while purging. In 4-in. diameter wells, the range of discharge flow rates at the surface needed to be from as little as 0.1 L/min for sampling volatiles to a high of 19 L/min for purging. To achieve this end, pumps must have adequate lift and corresponding discharge capabilities to pump from depths as deep as 120 ft.

To obtain a representative sample, the pump construction material must be inert to the extent that it will not significantly alter analyte concentrations through loss of concentration as a result of sorption, degradation, or chemical interaction with pump materials. The preferred materials were 300 series stainless steels (most commonly used types are 304 and 316L) and Teflon, actually polytetrafluoroethylene (PTFE) (Barcelona et al. 1985; Barcelona et al. 1983; Barcelona et al. 1988). Sampling equipment may include discharge tubing that is Teflon-lined. Rigid PVC is acceptable, but flexible PVC is not (Barcelona et al. 1985). The suitable materials include rigid PVC, 300-series stainless steel, and Teflon for most organic and inorganic compounds (Barcelona et al. 1985; Barcelona et al. 1988; Miller 1982; Parker 1992; Pearsall and Eckhardt 1987; Pohlmann and Hess 1988). However, studies have shown that if adequate purging is done and sampling follows immediately, the nature of the materials will have no significant impact on water chemistry (Robin and Gillham 1987).

If purge rates are excessive, the alteration of sample chemistry caused by purging with positive displacement sample pumps has been suggested (Barcelona et al. 1990; Puls and Powell 1992; Puls et al. 1992; Puls and Barcelona 1989a,b). The possibility exists of some volatile loss from groundwater by some sampling devices, including a few positive displacement devices. However, most variable discharge pumps (variable displacement and positive displacement pumps) perform purging and sampling functions without evidence of volatile loss. This statement is supported by numerous reports of relevant research in the scientific literature (Barcelona et al. 1985, 1988; Garske and Schock 1986; Gass et al. 1991; Gibbs and Imbrigiotta 1990; Gibbs et al. 1993; Ho 1983; Knobel and Mann 1993; Imbrigiotta et al. 1988; Liikala et al. 1988; Miller 1982; Muska et al. 1986; Panko and Barth 1988; Parker et al. 1993; Pearsall and Eckhardt 1987; Pohlmann and Hess 1988; Schalla et al. 1988; Stolzenburg and Nichols 1985) as well as findings in this study.

Studies conducted by Gass et al. (1991) and Knobel and Mann (1993) concluded that low flow rate submersible centrifugal pumps such as the Grundfos Rediflo2 can deliver representative groundwater samples. A study conducted by Paul and Puls (1992), comparing a low flow rate submersible centrifugal pump, a bladder pump, and a peristaltic pump, concluded the low discharge, flow rate submersible centrifugal pump produced the least negative impacts when trying to obtain representative and reproducible groundwater samples at the particular site and wells investigated. Turbidity tended to be higher in samples from low discharge submersible pumps when pumped at near maximum discharge rates during the purging cycle. Research performed by Yeskis et al. (1988) indicates that submersible impeller pumps perform similar to bladder pumps when collecting samples for volatile organics analysis. Higher discharge rate submersible pumps also have shown to be capable of obtaining representative samples (Liikala et al. 1988; Muska et al. 1986). However, concerns have been expressed by other authors for high discharge submersible pumps (Parker 1994; Puls et al. 1992).

Based on the literature review, only one sample collection pump fully met the requirements to completely satisfy the desired purge performance range, even though several pumps could obtain representative groundwater samples consistently and reliably. This sample collection pump, a variable speed (variable frequency) submersible pump, had just become available by Grundfos. The commercial unit is called the Grundfos MP1 Rediflo2.

1.9 Current Deployment of Pumps in Monitoring Wells

Proper deployment of sampling devices in the monitoring wells requires an understanding of the hydrogeology, the layers that transport the contaminants of interest, and the vertical distribution of the contaminants. The placement of pumps in screened intervals may have large effects (order of magnitude) in concentration of contaminants and general water quality parameters during purging (Barcelona and Helfrich 1992; Schalla 1992). Even small-scale vertical variations in well-screen inflow rates and placement of pump intakes may have large effects on the capability to collect representative groundwater samples (Gibs et al. 1993). The lack of discrete sampling intervals and the determination of equivalence intervals can lead to erroneous results and conclusions (Barcelona and Helfrich 1992; Barcelona et al. 1994).

To assure representative sampling by selecting optimal placement of the pump depth, the following were considered: the seasonal changes in water levels, the hydrogeology based on well logs, vertical and horizontal distribution of contaminants of concern, and the stagnant water intervals present in the wells. By considering these factors, the amount of purge water could be reduced to obtain a representative sample. The resulting depths of installation and present location of pump intake in relation to screened interval for December 1995 are shown in Table 1.2. These values have remained the same since the date of installation of the pump, which was within a few weeks after the completion of each group of wells. The only exception is well UCD2-16 which was set at a depth of 93 ft in 1990 to October 1995 when a longer discharge riser was installed. Well UCD1-12 (not presented in Table 1.2) is believed to have its pump intake set at approximately 2-to 3-ft above the bottom of the well screen. The bottom of the well screen is 64.5-ft bgs, with the located pump intake at about 62.5 ft. When HSU-1 wells other than those listed in Table 1.2 were refitted with Rediflo2 pumps, they were generally set as low as practical to permit sampling during periods of low water levels. Insufficient data is available for the newest wells (i.e., wells numbered 25 and higher) to determine a reasonable low water level. It is estimated that a lowest water level would be about 70-ft bgs.

Table 1.2. Well Construction Information and Pump Depths at LEHR (December 1995)

Well Name	Screened Interval bgs ^(a) (ft)	PVC Casing Above (+) or bgs (-) (ft)	Height of Top of 4-in. Pipe Elevation (ft)	Lowest Water Level Depth bgs (ft)	Pump Intake Depth Below Top of 4-in. (ft) ^(b)	Pump Intake Depth Below bgs (ft) ^(b)
UCD2-15	116.0 - 91.0	+1.6	50.94	70.94	91.3	89.7
UCD2-16	116.5 - 91.5	+1.0	49.18	69.18	104.3	103.3
UCD2-17	113.0 - 88.0	+1.7	51.48	70.48	89.3	87.6
UCD1-18	70.9 - 55.9	+0.9	47.75	64.75	66.3	65.4
UCD1-19	72.5 - 57.5	+1.2	50.49	70.49	71.3	70.1
UCD1-20	72.5 - 57.5	+1.0	48.94	68.94	69.3	68.3
UCD1-21	74.5 - 59.5	-0.8	48.01	67.00	69.3	70.0
UCD1-22	72.0 - 57.0	-0.8	48.40	68.36	69.3	69.9
UCD1-23	71.5 - 56.5	-0.8	48.60	67.57	69.3	69.9
UCD1-24	72.0 - 57.0	-0.7	48.22	68.16	69.3	69.9
UCD1-25	75.0 - 60.0	-0.9	47.92	NA ^(c)	71.3	72.0
UCD2-26	102.0 - 87.0	-0.6	48.23	NA	92.3	92.9
UCD1-34	76.0 - 61.0	-0.8	54.94	NA	71.3	72.1
UCD2-35	122.0 - 107.0	-0.7	55.03	NA	111.3	112.0
(a) bgs = below ground surface.						
(b) Bottom of pump is approximately 0.7 ft below the pump intake.						
(c) NA = not applicable.						
Note: All deep wells have 25 ft of 304SS screen. All shallow wells have 15 ft of 304SS screen.						

2.0 Well Purging and Issues

The intent of pumping groundwater from monitoring wells is to obtain a volume of groundwater that is representative of aquifer conditions. The importance and necessity for well purging to obtain representative samples or measurements is based on the assumption that the quality of the water in the monitoring well casing and screened interval is not representative of groundwater in the immediate surrounding formation. This historic assumption that purging is always essential, particularly large volumes, is disputed by actual site investigations and published literature. Even when purging is required, the preferable procedures and criteria for determining and obtaining a representative sample will vary with well design, pump deployment, parameters of interest, and site-specific conditions. Because purge-water disposal is time consuming and costly, ways to reduce purge water without sacrificing accuracy of sample measurement is an important accomplishment.

Two fundamental issues of purging are: 1) Does the water in the well need to be removed before sampling?, and 2) If purging is necessary, what are the best procedures and criteria to achieve obtaining a representative sample? Key to making these determinations is the ability to determine if the sample is representative of temporal and spatial conditions in the groundwater zone of interest. Empirical data collected and evaluated by various authors for cations, anions, and VOCs suggest there are errors that may vary from the representative or stable value by a significant percentage (Gibs and Imbriotta 1990; Unwin and Maltby 1988; Maltby and Unwin 1992; Schalla 1992). There are several reasons why the water standing in the well may not be representative of the formation or undesirable for sample analysis. They include:

- trace constituents leaching from the well casing over time (Chamness et al. 1990)
- well water mixing with stagnant water in other portions of the well or borehole (Gibs et al. 1993)
- chemical reactions associated with precipitation or adsorption to well casing materials or sampling pump (Schalla 1992; NCASI 1982)
- turbid conditions created by withdrawing water too rapidly (Kearl et al. 1992)
- gas transfer across the air-water interface of the water column causing oxygenation or the release of carbon dioxide or VOCs (Barcelona et al. 1984)
- biological reactions affecting redox conditions and metal concentrations in groundwater (NCASI 1982; Schalla 1992).

Each of these reasons and concerns regarding purging are addressed relative to specific procedures and criteria.

2.1 Procedures and Criteria for Determining Purge Volumes

The basis for determining how much water needs to be purged leads to some discussion of the alternative procedures and criteria. The history and rationale is presented to aid in understanding the milieu of approaches proposed in the literature. There are seven purge options available before samples are collected for analysis.

1. No purging
2. Specific low discharge rates (e.g., micropurging)
3. Purging based on knowledge of hydraulic properties
4. Purging of a specific number of well volumes
5. Purging of water until selected field parameters become stable or reproducible
6. Purging of water until constituents of concern are stable or reproducible
7. Fluid isolation devices and discrete interval sampling techniques.

Each of these options is discussed in the following subsections.

2.1.1 No Purging Procedure

There are circumstances or criteria that allow for not purging a well. First is the proper deployment of the pump intake opposite a highly transmissive interval with sufficiently high groundwater velocity so that the well is essentially "self purging." Second, groundwater velocity must be dominantly horizontal to prevent mixing with water in other portions of the well (Unwin and Maltby 1988; Maltby and Unwin 1992; Hall et al. 1991). Third, the pump intake must be sufficiently distant from stagnant zones (e.g., water filled casing above the top of the well screen and sediment sump) to prevent intermixing with the water in the well where constituents have been altered over time (Unwin and Maltby 1988; Maltby and Unwin 1992; Schalla 1992; Chamness et al. 1990). In addition, to further reduce turbidity of all wells at LEHR, a dedicated in situ pump was installed in each well to eliminate the disturbance of introducing a sampling device each time wells are to be sampled (Kearl et al. 1992; Schalla 1994).

2.1.2 Micropurging Procedure

To reduce the number of equivalent volumes, the concept of micropurging was introduced to the industry in 1992 (Kearl et al. 1992). Originally conceived to eliminate the need for filtering samples for metals in turbid monitoring wells and the potential errors introduced by the transport of colloids and fine particulates, the micropurge concept gained acceptance for more practical reasons. First, a smaller volume could be removed in amounts as little as 1 equivalent volume. Second, if only 1 equivalent volume was removed, purging could be conducted economically at a lower rate in wells screened in less permeable and typically more turbid formations. Third, less downgradient and chemically altered water that had flowed out of the well bore would be introduced into the sample by purging at a rate closer to and preferably less than the groundwater flow velocity. This increasingly popular concept requires the use of low (i.e., 100 to 200 ml/min) pumping rates to eliminate purging the entire water column in the screened interval. Based on laboratory and field experiments with diverse hydrogeologic conditions, it is possible to use a dedicated sampler opposite a productive interval to remove only a fraction of the water in the well (Powell and Puls 1993; Puls and Powell 1992). The experiments demonstrated that only a thin, discrete interval of the entire water-bearing zone is sampled, and no mixing with the overlying stagnant water occurs (Kearl et al. 1992). Work by other investigators have presented evidence that stagnant well water usually does mix with aquifer water at low pumping rates unless specific steps are taken to prevent mixing (Unwin and Maltby 1988; Maltby and Unwin 1992). Kearl's procedure demonstrated the importance of keeping pumping rates at rates that are similar to or lower than natural groundwater velocities, or velocities that are compatible with well developed or highly transmissive formations. This would also apply to the no purge procedure.

2.1.3 Purging Based on Knowledge of Hydraulic Properties

Purging time or volume can be based on the relation between the percent of well water from the aquifer versus its water stored in the well screen and casing and the formations hydraulic conductivity. The storage volume in the well as a contributing factor decreases in time in relation to an increasing percentage from the aquifer (Barcelona et al. 1985). The pumping time required to remove nearly 100% of the stagnant water decreases as aquifer transmissivity increases. This assumes that the depth of the screened interval, well diameter, and height of water column is the same, and hydrogeologic conditions are essentially homogeneous along the screened interval. Small variations in hydraulic conductivity can result in mixing with stagnant water in other portions of the well or borehole (Gibs et al. 1993; Unwin and Maltby 1988; Maltby and Unwin 1992). In fact, two researchers were not able to anticipate, within an order of magnitude, the purge volumes needed to achieve stable constituents and field parameters (Gibs and Imbrigiotta 1990).

2.1.4 Purging Based on a Specific Number of Well Volumes

Based on the author's own experience and other investigators' results, significant variations of measured parameters and chemical constituent concentrations can be expected as a function of purging duration and casing volumes removed (Schalla 1992; Gibs and Imbrigiotta 1990; Barcelona et al. 1994) during the purging cycle. These variations are common and result from a number of causes including: constituents reacting and lost by precipitation or adsorption to well casing materials or sampling pump (Schalla 1992; NCASI 1982; Chamness et al. 1990), gas transfer across the air-water interface of the water column, or biological reactions causing reducing conditions and depleted metal concentrations in groundwater (NCASI 1982; Schalla 1992). However, there are also conditions where the groundwater in the screened interval of the well and formation are, for practical purposes, similar for selected parameters.

Purging requirements have been based not only on variation in selected hydrochemical parameters, which will be discussed in following sections, but often on removal of a predetermined number of casing volumes (Schalla 1992; Gibs and Imbrigiotta 1990; Barcelona et al. 1994). The amount of water that is to be removed from a well casing to achieve a representative groundwater sample that is representative of the formation is usually expressed in the number of casing volumes to be removed or purged. The amount varies greatly from just over 1 to 20 volumes (Unwin 1984; Scalf et al. 1981; Schalla 1992; Barcelona et al. 1983; NCASI 1982).

The precise interpretation of the definition of casing volume varies as shown in Figure 2.1. The most commonly used term, BV, includes not only the water in the screened interval, but also the water in the well casing above the screened interval if any is present, and some volume estimate for the filter pack. The well screen diameter and length are important for determining well equivalent volumes of purge water to be removed from the screened interval (SC); purge volume in the screened interval and the filter pack (SPSC); or the purge volume in the screened interval, the filter pack, and the volume of water in the casing above the screen (BV) (Barcelona et al. 1994; Schalla 1992) (Figure 2.1).

Based on this study's test results and the results of others, the component of water above the screened interval and inside the casing should be largely ignored with respect to recommendations for purge volumes if little drawdown (i.e., less than 0.1 ft) occurs during purging. Dismissal of the casing volume above the screen in normal purge volume determinations has been demonstrated to be appropriate (Unwin and Maltby 1988; Maltby and Unwin 1992; Schalla 1992) because there is no benefit for removing the water above the screen. However, there are instances where some removal of water above the screen occurs out of necessity created by formation hydraulics. It is also important to realize that the volume issue of the filter pack is not significant if silica sands are used. These

Figure 2.1. Purge Volume Terminology

sands should not be crushed silica material that exposes a fresh reactive surface, but rather naturally rounded sand particles that have a surface that has been weathered by water previously, thereby achieving some degree of equilibrium. It is recommended practice in most text books on monitoring well design that nearly inert materials such as silica sand be used for filter pack (Nielsen 1991; Schalla and Walters 1990; Aller et al. 1991; ASTM 1990). Generally, no significant reactions have been observed using this filter pack for constituents of concern in groundwater. Some alterations have been reported in the literature for some special circumstances associated with non-aqueous phase liquids.

To explain how these largely irrelevant volume components have come into wide-spread use, some understanding of the historical logic needs to be explained. The history of purging practices and deployment of pump intakes for sampling for the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Resource Conservation and Recovery Act (RCRA) monitoring wells has been generally the following.

In the early to mid-1980s, the deployment of pump intakes in wells was determined by technical needs. For wells where the water level was always above the screened interval, the pump intake was placed usually in the screened interval at some desired depth. Fluid density effects were considered in the placement of the wells where such effects influenced the mass transport of contaminants that the investigators were trying to detect. For wells where the water level was periodically or continuously below the top of the screened interval, the pump intake was placed usually just below the

lowest anticipated water level plus a depth allowance provided for anticipated amount of drawdown during the purging and sampling cycle. The volume to be purged was typically 3 to 5 equivalent volumes; based primarily on a publication by Barcelona in 1983. The equivalent volume generally was the volume in the well screened interval and sometimes the casing above the screened interval. Regulatory agencies were still fairly lenient about discharge of contaminated water onto the ground, primarily because maximum contaminant levels had not been established and most guidance for disposal was based on acute hazard disposal concerns. Purge rates were generally less than 1 gpm because pumps available on the market could not discharge water at a rate higher than that for 2-in. wells, and sampling rates for higher discharge rate, conventional submersible pumps could not be reduced to convenient rates for sampling volatiles. Frequently, a bladder pump or bailer was used in conjunction with a submersible, that is, the submersible was used for purging and the bladder pump was used to obtain small sample volumes at rates of 100- to 300-ml/min.

In the late 1980s, following the reauthorization of the CERCLA regulations, the deployment of pump intakes in wells was determined by technical needs, but there was an increasing awareness of purging issues to obtain representative samples. For wells where the water level was always above the screened interval, the pump intake was placed usually well above the screened interval at a depth just below the water level in the well plus the amount of anticipated drawdown during the purging and sampling cycle. This was a radical departure from the more random practices earlier in the 1980s. The idea behind this method was that the stagnant water above the well screen should be removed in addition to the water in the screened interval. Water in the casing above the screened interval may be chemically different due to interaction with the casing. In any case, the stagnant water in the casing was certainly not time equivalent to the water in the screened interval that was collected months after the water in the stagnant zone was introduced into the well casing. Purging rates were higher because of the advent of piston pumps, and improved capacity and efficiency of bladder pumps and helical rotor pumps that could purge water at more than 1 gpm. Therefore, it was possible to pump out larger volumes of purge water within a reasonable time frame. When water is present above the screened interval, which occurs in a well screened in a confined aquifer, conventional practice was to purge the well at a rate and for a sufficient duration to remove virtually all of the water from above the screened interval, as shown in Figure 2.2. This approach is not efficient because it needlessly produces large amounts of purge water that has to be disposed of. This approach also runs the risk of "breaking suction" and introducing air into the discharge line and sparging volatiles from water samples. Also, recent research demonstrates that this excessive purging is unnecessary and probably not completely successful (Unwin and Maltby 1988). These recent casing volume studies suggest that with proper pump placement (just above the screened interval), only partial purging of the stagnant water above the screened interval is necessary to obtain a representative sample or measurement (Maltby and Unwin 1992). Also, regulatory agencies were sometimes still allowing discharge of contaminated water onto the ground from monitoring wells, but regulatory acceptance of this practice was changing rapidly. The removal of 3 to 5 equivalent volumes was a substantial amount of water if it had to be drummed, transported, stored, and ultimately disposed of or treated offsite. Density effects were considered in the placement of the well screened interval, but of less concern for deployment of the pump intake. For wells where the water level was periodically or continuously below the top of the screened interval, the practice remained as before, that is, the pump intake was placed usually just below the lowest anticipated water level plus a depth allowance provided for anticipated amount of drawdown during the purging and sampling cycle. The equivalent volume generally was the volume in the well screened interval and sometimes included the casing above the screened interval, and now sometimes including water in the filter pack. Purge rates were generally greater than 1 gpm because pumps available on the market could discharge water at a rate higher than that for 2-in. wells. Low discharge capacity bladder pumps or bailers in conjunction with a

Figure 2.2. Purging by Evacuation of Well Casing Above the Well Screen

submersible pump were being replaced with small diameter variable discharge (i.e., 100 to 20,000 ml/min) pumps that were commercially available. The advantages in cost savings and convenience to purge and sample with a single pump were obvious.

In the early 1990s, the deployment of pump intakes in wells was determined by technical needs, however, there was an improved understanding of purging issues to obtain representative samples. For wells where the water level was always above the screened interval, the pump intake was placed usually just above the screened interval. If the drawdown during the purging was at least a foot; then the recovery (residual drawdown) would lift the stagnant water column up above the pump intake during the sampling cycle, which was conducted at a discharge rate that was a fraction of the purge rate (Figure 2.3). However, if the drawdown during the purging was less than a foot; then the recovery (residual drawdown) would not be sufficient to lift the stagnant water column up above the pump intake during the sampling cycle. To compensate for this, the pump must be lifted initially before purging begins, and then lowered slowly just prior to the sampling cycle to prevent turbulence and mixing of the stagnant water (Maltby and Unwin 1992). This was a more rational method than the practice in the late 1980s. Purging rates were still high because of the advent of variable discharge rate, small diameter submersible pumps that varied discharge in relation to frequency. Therefore, it was possible to pump out these larger volumes of purge water rapidly. Regulatory agencies had become much more particular about discharge of contaminated water onto the ground during purging. Usually it was no longer permitted unless long-term monitoring had demonstrated that such practices were non-hazardous. Frequently, as a safety precaution, the purge water is considered a potentially hazardous waste liquid until laboratory test results prove otherwise. This necessitates delaying disposal of purge water. The time and cost savings advantage was quickly being offset by the removal of 3 to 5 equivalent volumes, a substantial amount of water that had to be drummed,

Figure 2.3. Minimal Drawdown During Purging with Reduced Discharge Rate During Sampling

transported, stored, and ultimately disposed of offsite. The time was right for the concept of micro-purging to reduce purging volumes. However, for most wells where the water level was periodically or continuously below the top of the screened interval, the pump intake was placed in the well screen, sometimes opposite the most permeable interval if data were available (Figure 2.4). The most permeable interval usually represents the zone of the greatest volume of contaminant transport, but not necessarily in all circumstances. The equivalent volume generally was the volume in the casing and well screen interval and sometimes included the water in the filter pack.

In the mid-1990s, the deployment of pumps in wells at LEHR was evaluated in light of much new information on the understanding of purging to obtain representative samples. For wells where the water level was always above the screened interval, the pump intake location is placed opposite the zone of greatest mass transport. To determine the zone of greatest mass transport, a simple borehole profile using a tracer or borehole velocity meter could be used, or a vertical profile determined by using Hydropunch at various depths or a multilevel well system. Once the vertical profile is determined as it was at LEHR (Liikala et al. 1996; Stewart et al. 1996), time series samples can be collected for constituents of interest. The pump should be placed in the well screen opposite the zone of highest concentration or at least where the contaminants are known to be consistently present. Simply placing the pump opposite the most permeable zone does not guarantee representative sampling of the constituents present. If the groundwater velocity is high, a slower purging and sampling rate should be used because the well is essentially self purging. If the zone of interest is at the top of the well screen and the drawdown during the purging is about a foot or less, then purging is done at a

Figure 2.4. Purging Opposite the Most Permeable or Contaminated Portion of Aquifer

higher rate than sampling so the recovery (residual drawdown) lifts any stagnant water column up above the pump intake during the sampling cycle. However, if the constituents to be monitored are opposite other sections of the well screen, the pump should be placed opposite them and discharge rates do not have to be as high because drawdown is not needed to lift stagnant water away from the pump intake. To minimize turbidity, it is important that the purging be conducted at a fraction of the discharge rate used during development. It is equally important that sampling be conducted at a discharge rate that is less than that of the purge rate unless the purge rate is only a few hundred ml/min.

It is desirable to purge at as high a rate as possible without creating an undesirable turbidity to reduce the time needed to remove the required amount of purge water from a well. This reduction in time also reduces effort, cost, and safety hazards. For the deeper HSU-2 wells that have at least a few feet of water in the casing above the screened interval year round, the wells should be purged (as a minimum requirement) with the pump intake located directly opposite the zone where contaminants of concern are concentrated to eliminate the need to dispose of large volumes of purge water and to reduce the amount of time required for purging. This procedure eliminates the need to purge the column of stagnant water located above the well screen.

Ideally, location of the pump intake for the shallower HSU-1 wells would be opposite the most permeable layer having the highest concentration of contaminants of concern in order to obtain consistent and representative results. The vertical distribution of permeability opposite the screened

interval can be accurately and easily determined using tracer dilution test-methods (Hall et al. 1991; Hall and Raymond 1992; Hall 1993). Setting the pump intake opposite the permeable zone or zones is not always practical because vertical variations have not been studied to the amount of detail as this site has been for chloroform concentration and distribution (Liikala et al. 1996, Stewart et al. 1996). Also, seasonal water levels may decline to such an extent that a well goes dry and the primary permeable zones are no longer saturated (Robbins and Martin-Hayden 1991; Martin-Hayden et al. 1991).

2.1.5 Purging of Water Based on Stability of Selected Field Parameters

Continuous monitoring of field indicator parameters such as pH, redox potential, specific conductance, temperature, and dissolved oxygen, are almost used ubiquitously at hazardous waste sites to determine adequacy of purging. Monitoring these parameters is used nation-wide to guide representativeness of sampling which is usually based on stabilization within approximately 10% over at least two consecutive measurements. There are significant limitations to the usefulness of these parameters, particularly if flow-through cells are not used during purging. Other criticisms pertain to their inability to determine near constant stagnant well water contribution to the formation water. These contributions might significantly alter the concentrations of contaminants of concern and in fact may bear no relation to them (Unwin and Maltby 1988; Gibs and Imbrigiotta 1990; Maltby and Unwin 1992). Turbidity has been used successfully as a field parameter as an indicator of heavy metals from colloidal particles put in suspension during installation of equipment, purging too rapidly for the relative transmissivity of the aquifer, and purging too rapidly when the filter pack/formation interface is destabilized by low water levels in the well (Puls and Powell 1992; Kearn et al. 1992; Garske and Schock 1986). Therefore, this artificial turbidity can produce significant sampling error to constituents, primarily metals in unfiltered samples.

2.1.6 Purging of Water Based on Stability of Constituents of Concern

Using contaminants of concern, or their related chemical equivalents or composites, to determine how much purge water must be removed is typically based on reproducibility of sequentially sampled water during purging (Gibs and Imbrigiotta 1990). Stabilized, or what is called reproducible measurements, for VOCs typically are difficult to obtain (Gibs and Imbrigiotta 1990). Frequently VOCs will bear little relationship to common field indicator parameters and hydraulic properties. Site-specific and well-specific characteristics such as hydrogeology (e.g., distribution of hydraulic conductivity, anisotropy, groundwater velocity, the areal extent of contamination in 3 dimensions, well construction and development) will have significant influence on the amount of purging required (Gibs et al. 1993; Schalla 1992).

Real-time measurement of contaminants of interest in the field such as VOCs, ion-specific electrodes, colorimetric reagents, or field portable analytical equipment can be very useful for determining adequate purging. Some field sensors are intrinsically more accurate than laboratory methods, though it may take some time for regulatory acceptance. There are four primary advantages of the in situ sensors: 1) sample integrity is superior by virtue of being in situ and not handled while being brought to the surface or after collection at the surface, 2) real-time monitoring capability without waiting for lab results that could be days or weeks after the fact, 3) lower costs, and 4) rapid field screening of contaminant release or mobilization (Murphy and Hostetler 1989). EPA has established strict sampling and analysis procedures for sampling and analysis of groundwater contaminants. Substitution of in situ sensors for laboratory analysis is a regulatory and legal issue, however EPA should encourage substitutions if a functional equivalent is found to reduce costs of investigative derived waste water disposal. Sensor systems for chemical characterization and monitoring could be integrated with other technologies for effective subsurface deployment.

2.1.7 Fluid Isolation Devices and Discrete Interval Sampling Techniques

The use of fluid isolation devices to limit sample collection to discrete intervals that require purging of very small volumes of stagnant water or eliminate purging entirely have been reported in literature (Barcelona et al. 1985; Robin and Gillham 1987; Keely and Boateng 1987; Schalla 1992; Maltby and Unwin 1992). Fluid isolation systems can consist of packers, isolation chambers, horizontal baffle arrays (usually with in situ samplers), or other configurations. For example, the packer is permanently inflated in the monitoring well casing. Water is purged from the screened interval without removal of water from above the packer, thus reducing the amount of water to be purged; however, studies by Maltby and Unwin (1992) indicate that it usually is impossible to purge all of the stagnant water unless the bottom of the packer has a concave surface and the pump intake is located exactly at the top of the concave surface. This placement is needed to evacuate all the water entering the well from the inside of the casing above the well screen. If there is relatively little drawdown during the purging cycle, less than one foot, or the water level is still above the top of the well screen, this technique should work. The use of packers is actually not needed as demonstrated by Maltby and Unwin (1992). They were able to show that simply elevating the pump about one or two feet before purging, then lowering the pump to its original position just as the discharge rate is reduced for sample collection, is far more successful.

3.0 Field Tests

A combined procedures approach was used for this project to ascertain purging requirements for the existing monitoring network. This approach consisted of observation of sampling procedures of the monitoring wells in February 1994, bromide tracer tests in a limited number of the wells in April 1994, time series tests and demonstration of procedural changes in May 1994, and time series samples for VOCs in December 1995.

3.1 Current Purging Procedures at LEHR

The current purging procedures at LEHR have remained unchanged since 1990 for wells with number designations 15 and higher. These wells are all 4-in. diameter wells equipped with dedicated variable discharge rate submersible pumps manufactured by Grundfos. Later in 1992, the bladder pumps or bailers previously used in other existing wells in the monitoring network were replaced with small diameter Grundfos pumps, which would fit into the older 2-in. diameter monitoring wells.

Before changes in procedure could be recommended, it was important to document current procedures. The PNNL field team leader and staff from Dames & Moore Inc. collected baseline data for purging and sampling of monitoring wells UCD2-15, 2-16, 2-17, and UCD1-20 on February 28, 1994, and March 1, 1994. Dames & Moore Inc. staff provided and collected all necessary data, and the PNNL field team leader collected data on times, volumes, and procedures. Wells UCD2-15, 2-16, 2-17, and UCD1-20 were purged at 5 gpm during the initial portion of the purging period. During the final 5 to 10 minutes, the discharge hose was fed into a flow-through cell that continuously measured temperature, specific conductance, pH, and Eh (Tables A.1 to A.4). Turbidity was measured with an instrument outside the flow-through cell. These parameters were not measured during the 5 gpm discharge phase. To use the flow-through cell, the discharge rate was lowered to 1 gpm for the final 5 to 10 minutes because the flow-through cell has a maximum discharge rate capacity of 1.5 gpm. Also, the information from the cell tends to be more accurate than other methods because the samples are not exposed to ambient air, temperatures, and pressures. The volumes discharged from monitoring wells UCD2-15, 2-16, 2-17, and UCD1-20 were 162, 170, 205, and 82 gallons, respectively. These volumes represent three times the volume of water in the casing and well screen before pumping began. Temperature, specific conductance, pH, and Eh were nearly constant as shown in Table A.1. Turbidity was less than 1 nephelometric turbidity unit (ntu) in all wells at the 1-gpm discharge rate. Drawdown was less than 0.1 ft for the HSU-2 wells when measured on February 28, 1994. During a test in the less permeable HSU-1 zone, a 15.36-ft decline occurred by the end of the 5-gpm discharge rate in UCD1-20, but by the end of purging UCD1-20 at 1-gpm, water levels had recovered to 3.51-ft below the original static water level. Actual sampling occurs at a discharge rate of 0.25 gpm (1 L/min). As a result of these decreases in discharge rates, the water levels at first decline, then recover just before and during the sampling phase as shown in Figure 3.1. Despite this large drawdown, water level remained well above the screened interval, which probably accounts for the low turbidity. If the water level is drawn down below the top of the well screen, buoyancy is lost and formation sediments and filter pack will consolidate and destabilize, thereby releasing fine sand, silt, and possibly clay into the well during pumping (Figure 3.2). This sediment-laden water will increase the turbidity observed at the surface discharge during purging, and possibly during sampling when the discharge rate is reduced.

Figure 3.1. Change in Water Levels During Purging and Sampling Monitoring Wells

Although the containerization procedure for the purge water had changed from lined 55-gal drums in 1994 to a towed storage tank, the purging field procedures had not changed in respect to purge rates and volumes for the new Grundfos pumps. For example, the wells were always purged at rates of 2.5 to 5 gal/min, except during the summer sampling quarter when water levels were low in wells screened in HSU-1. Also, the volumes removed from each well were based on the same formula as it still is today, that is, 3 equivalent volumes of the screened interval, SC, and the casing volume, CV. This volume is typically 50- to 200-gal of purge water per well depending on the level of the water in the well before purging begins and the depth of the well. Indicator parameters were not and cannot be measured in the flow-through cell instrumentation, which can handle a maximum discharge flow of 1.5 gpm. A tee could have been used to divert water into the flow-through cell while purging at a higher discharge rate. Common parameters measured are temperature, Eh, pH, and specific conductivity, but only after the purge volume has been removed. Turbidity is measured separately at the end of the discharge line, not in the flow-through cell. Parameters are measured to determine stability after 3 equivalent volumes of CV and SC have been removed. In nearly all of the research literature published on well purging and sampling, stability is measured from the beginning of discharge from the well riser, not just during the last few minutes as is done at LEHR.

Based on the field test results from February, subsequent tests should be conducted to collect data on field parameters and key constituents of concern from the start of purging through sampling of select wells at LEHR. Tracer tests should be conducted in wells that were considered uncontaminated

Figure 3.2. Excessive Drop in Water Levels During Purging Causes Formation Material to Enter Well Screen

to minimize safety and waste disposal concerns. In addition, other means to reduce the amount of purge water were considered, of which one was tested. Downhole measurements should also be conducted as well as the surface measurements at the point of discharge.

3.2 Bromide Tracers and Purge Water Minimization Device Tests

Bromide tracer tests were conducted in three LEHR wells in April 1994, which included the evaluation of a purge water minimization device known as PurgeLess.

The test objectives for the initial field demonstration of the PurgeLess device are presented below.

1. Evaluate effectiveness of the PurgeLess system for minimizing purge water volumes and obtaining representative samples during sampling:
 - evaluate agreement of surface and subsurface data obtained by use of the Hydroprobe bromide sensor
 - evaluate the relative effectiveness of the aperture PurgeLess system and the PurgeLess system with the foot valve using surface and subsurface data obtained by use of the Hydroprobe bromide sensor.

2. Evaluate field implementability of changing the purge-water volume requirements:

- determine ease of system set-up and integration with existing system
- identify system changes to improve implementability based on observations of principal investigator and field team.

The measures of success of the bromide tracer tests and the PurgeLess testing will be considered successful if the following criteria are met:

- the PurgeLess device is capable of reducing the purge-water volume requirements by at least 75%, and at least one version does not release stagnant water from inside at detectable or significant levels
- the basis for determining the appropriate minimum well purge volume for LEHR is identified following analysis of all of the data.

The bromide tracer tests were conducted with and without the PurgeLess device to determine procedures appropriate for pump placement. PurgeLess, which is illustrated in Figure 3.3, consists of an isolation cylinder, centralizers, an entry port on the bottom with a sealing mechanism, a lift system such as a bail hook, and a top piece allowing for laminar flow of fluids to avoid eddies and dead spaces during purging and sampling. Most of the volume of water that must normally be purged is isolated by the device, thus reducing the volume of the well in all or part of the screened interval. The cylinders in sections or modules provide the isolation that is the equivalent of displacement. Groundwater in the well screen interval is contained by the PurgeLess device; thus eliminating the need to purge large volumes of stagnant well water that is not representative of the formation. The water from the surrounding formation flows into the well screen, then up the annulus past the PurgeLess device (Figure 3.3). For example, the outside diameter of the cylinders used in the tests was 3.5 in., and the inside well diameter of Schedule 40 well screen is 4.0 in., the effective bore volume, and therefore the required purge volume, is reduced by 77%. In most cases, for this device to be effective the water level should be at least a few feet above the well screen to allow for placement of the pump. In those cases where the water level in a well is significantly above the top of the well screen, purge volume is reduced both by isolation and may be further reduced using a packer to separate and isolate the screened interval from the well casing above.

The device was built using hollow PVC plastic pipe to entrap the water in the well screen interval as it is submerged in the well. The aperture on the curve bottom allows flooding of the cylinder interiors. The float valve, which is the only moving part in this device, is designed to close on the filling up to the top of the device. The bottom aperture remains open, but the water inside is isolated by resting the aperture on the bottom of the well casing. Isolation is also achieved because water is highly incompressible and water in the casing cannot flow out from slight changes in water level in the well (so long as the water level is above the checkball). The only way fluids can flow out of the bottom is by diffusion, a very slow process.

The device was designed with a conical top to assure laminar flow past the top portion and avoid the issues of dead spaces. To assure laminar flow in the annulus between the well screen and casing of the device, centralizers were attached every 120° using 0.25-in. thick centralizers. However, these had to be removed to install the PurgeLess device because of either bends or ovalization of the existing PVC well casing. Even then it was difficult to install the 3.5-in. outside diameter PurgeLess device. These distortions in the well casings must have occurred after their installation and development in 1990, because submersible pumps, which are 3.75-in. in diameter, inserted and removed

Figure 3.3. PurgeLess, a Device for Reducing Purge Volume

easily during well development in 1990. During purging, fluids flow through the well screen at the same velocity as they would if the device were not there because the entrance velocity is only dependent on the rate of discharge of the pump during purging and during the first seconds or minutes well storage effects. When not pumped, the water flows around the PurgeLess device through the well screen as shown in Figure 3.4. This is a valuable feature because by maintaining the same entrance velocity, particulates are not mobilized from the formation at a greater rate than without the device. This maintains the desired low turbidity while reducing both the volume and the time of the purge cycle by at least 70% in a 4-in. diameter well.

Practical limitations accompany the accessibility and ease of deployment of the PurgeLess device and purging and sampling pumps in monitoring wells at LEHR. These limitations are related to the inside diameter of well screen, screen length, slot size, and turbidity during purging. At a minimum, the PurgeLess device must be small enough in diameter to fit inside the well screen and casing and yet allow for flow around it without increasing entrance flow velocities in the well screen. Also, the

Figure 3.4. Cross-Sectional View of Flow-Through Filter Pack, Well Screen, and Around PurgeLess Device

pump needs to allow enough clearance for water-level measurements and installation of subsurface monitoring devices such as the Temphion (a registered trademark of Instrumentation Northwest, Inc., Redmond, Washington) bromide sensor if needed.

Hydraulic conductivities in both HSUs can sustain discharge rates of 5 gpm for properly constructed monitoring wells with sufficient screen length. Wells tested are constructed of Schedule 40 PVC casing and stainless steel well screen with inside diameters of 10 cm (4.0 in.) and 11 cm (4.25 in.), respectively. The volume contained in a given length of a 4-in. well is 4 times greater than that for a 2-in. well. Also, the entrance velocities at the well screen are inverse to the square of the well diameter, and higher purge rates are allowable in larger 10-cm (4-in.) diameter wells. The well screen diameter and length are important for determining well equivalent volumes of purge water to be removed from the screened interval (SC) and the casing volume (CV), which is the volume multiplied by 3 to determine the volume to be removed from LEHR monitoring wells. The water above the screened interval will be largely ignored with respect to recommendation for standard sampling procedures, but will be evaluated and purged to remove the bromide tracer immediately following the field tests. Dismissal of the casing volume above the screen in normal purge volume determinations has been demonstrated to be appropriate (Unwin and Maltby 1988; Maltby and Unwin 1992; Schalla 1992) if the wells exhibit little drawdown during purging. The addition of filter pack in the calculation to determine purge volume is not used because there is no alteration by the filter pack. Filter

packs at LEHR are composed almost entirely of quartz. Altered or stagnant water moves out of the screened well and back into the formation in its altered state (i.e., loss of volatiles via adsorption and volatilization, precipitation of inorganics, etc.). Some of this altered fluid is recaptured during purging and possibly the sampling cycle if discharge rates are large enough. The percentage of altered water (i.e., outside the well screen in the filter pack and formation) captured varies with time and design of the well. It was anticipated that some of this effect would be seen with the bromide tracer.

The first step to installing the PurgeLess device was to determine the length necessary for each well. For fully submerged wells, the length of the device is equal to the length of the well screen interval plus the length of the open portion of the sediment trap below the well screen (Figure 3.4). For wells in the HSU-2 unit, this represents a length of 25 ft for wells UCD2-15, 2-16, and 2-17. The screened interval in UCD2-15 extends from 116- to 91-ft bgs with the pump bottom at 89.7-ft bgs. With the cone and bottom piece attached, the device was approximately 25.8-ft long. This provided 0.5 ft of clearance between the top of the device and the bottom of the pump. To achieve this, it required five 5-ft long sections (25.0 ft), a bottom cap (0.4 ft) with aperture only, and a conical top cap (0.4 ft) with support cable and anchor. The screened interval in UCD2-16 extended from 116.5- to 91.5-ft bgs with the pump bottom at 91.3-ft bgs. With the cone and bottom piece with foot valve attached, the device was approximately 24.0-ft long. This provides 1.2 ft of clearance between the top of the device and the bottom of the pump. To achieve this, it required three 5-ft long sections (15.0 ft), one 5.6-ft long section with foot valve, one 1-ft long male/female adaptor for attaching the foot valve section, one 2-ft long section (2.0 ft), and a conical top cap (0.4 ft) with support cable and anchor. Well UCD2-17 was the control well for comparing results from UCD2-15 and 2-16, and was tested conventionally without a PurgeLess device.

For partially submerged screens, the length is equal to the screened interval below the pump intake and the open portion above the bottom of the well. Well UCD2-20 falls within this category. The screened interval in UCD2-20 extends from 72.5- to 57.5-ft bgs with the pump bottom at 68.3-ft bgs. With the cone and bottom piece attached to a 5-ft long section, the device was approximately 5.8-ft long. This required that the bottom of the pump rest on the top of the device after submergence and filling with stagnant water (Figure 3.4). To achieve this, it required one 5-ft long section (5.0 ft), one bottom cap (0.4 ft) with aperture only, and a conical top cap (0.4 ft) with support cable and anchor. The required number of sections are screwed together with flush threaded couplings. The rounded cap with the aperture is screwed on flush to one end to form the bottom, and the conical section with small drainage and submergence aperture is screwed on flush to the other end to form the top as shown in Figure 3.5. The downhole bromide sensors were located immediately above and below the pump intake.

The procedure for the tracer tests generally consisted of the following. Potassium bromide was introduced into the well as a tracer solution of approximately 2 gal and diluted with the well water to approximately 100 ppm during mixing. Concentration uniformity was created by filling the hose in the well with sufficient solution to displace the water in the hose. The PurgeLess system, which includes the pump and downhole bromide and temperature sensors, was installed in the well within about 30 min after introduction of the tracer. After assembly, the PurgeLess device was slowly (i.e., approximately 5- to 10-ft/min) lowered into the well by a hook attached to a cable that is attached to the pump. With the pump reinstalled, purging proceeds as it would have without the device. The pump above the PurgeLess is started, and purging begins to remove the stagnant water between the device and the well screen and between the device and the pump intake as shown in the middle picture in Figure 3.6. Only a small amount of drawdown is desirable, preferably less than 1 ft. After the required amount of purging (and after purge parameters are stabilized), the discharge rate from the pump was reduced. This reduced discharge rate allows the water level in the well to recover to

Figure 3.5. Placement of Apparatus During Bromide Tracer Test in Well UCD2-15

above the pump (as shown in the right side picture in Figure 3.6), thereby assuring that the water collected is representative of the formation interval sampled and free of stagnant water from above.

Within about an hour, water was extracted from the well at a rate of 3.6 L/min (approximately 1 gpm). Measurements were taken every few minutes, or more often when needed, during the purging cycle. Once parameters stabilized and the bromide sensor at the surface discharge indicated the well had been purged, sampling began at a rate of 250 ml/min and continued for 5 min. After sampling, the pump was shut off and the entire PurgeLess system removed from the well. Only the pump was reinstalled and used to remove the residual bromide solution from the well. This was accomplished by pumping at 5 gpm, and moving up the well from the bottom at a rate of 10 to 20 ft/min. After "vacuuming" the well, a downhole prototype Temphion hydroprobe sensor was lowered down the well to determine the vertical concentration distribution of bromide in ppm. Because the groundwater residuals generated, exclusive of the non-hazardous bromide, may contain small amounts of contamination, the purge water, sampling water, and well cleanup water was collected in lined 55-gal drums. After "vacuuming" the entire system, the pumps and PurgeLess devices were reinstalled in the wells.

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Figure 3.6. Purging and Sampling with PurgeLess Device Installed

Test results of the bromide tracer tests for wells UCD2-16, UCD2-17, and UCD2-20 are shown in Figures 3.7, 3.8, and 3.9, respectively. Downhole bromide sensors were not functioning when the pump was turned on, therefore, only data from the surface bromide sensor could be used. These tests conducted on April 28 and 29, 1994, show the decline in bromide concentration with time as water is purged from the well at approximately 1 gal/min. In well UCD2-16, bromide concentration drops to less than 3% (i.e., 3.0 mg/L) of its original concentration in 40 min, or 40 gal, which is a far smaller volume than the usual 150 to 200 gal removed. At this point, the pump intake is receiving formation water, including some small amount of bromide that is either down gradient or in the lower portion of the screen region of the well. Well UCD2-15 had similar results. The pump intake is located 4-ft above the top of the well screen during the start of the purging cycle. After 32 min of pumping, the pump is lowered 1.5 ft to move the pump intake away from the simulated stagnant water above the pump in the well casing. This phenomenon was previously reported by Unwin and Maltby (1988) and Maltby and Unwin (1992). They demonstrated that stagnant water above the well screen could enter the pump intake almost indefinitely if there was no significant rise in water level as the discharge rate is decreased. It also assumes that there is an initial significant drawdown. Because there is no significant drawdown or recovery of water levels, as is the case with all HSU2 wells at LEHR, it was necessary to lower the pump 1.5 ft over a period of 1 min. The slow rate was necessary to avoid creating turbulence that would bring in more water rich in bromide (stagnant water). This proved to be effective as shown in Figure 3.7. In well UCD2-15, field parameters except for Eh were stable after the first gallon was removed from the well as shown in Table A.5. Similarly, parameters were

Figure 3.7. Bromide Tracer Test with PurgeLess in Well UCD2-16 on April 29, 1994

stabilized in well UCD2-16 after the first gallon was removed (Table A.6). Turbidity was higher than in the February test of these wells because of the disturbances caused by removal and installation of the PurgeLess devices.

Similar procedures were followed in well UCD2-17 but without the PurgeLess device as shown in Figure 3.8. This well is constructed nearly identical to well UCD2-16. The discharge rate was slightly higher, but the bromide concentration stabilized at less than 3% after 45 gal were discharged, that is, similar to UCD2-16 with the PurgeLess device. However, unlike UCD2-16, the discharge rate was slowed by an order of magnitude to simulate what might occur during the sampling cycle. Bromide concentrations continued to decline initially, but then began to rise steadily for about 20 min. It is suspected that the observed increase in bromide concentration was caused by a heat convection cell developing near the pump. The Rediflo2 submersible pump motor generates substantial heat as the discharge rate is lowered. If the intake rate is lowered sufficiently, the buoyant effect of the water may overcome the pump's ability to capture all of the warmed water flowing upward near the motor and past the intake. A convection cell around the pump would allow heated water from the formation to rise up and displace cooler water above; then drive down this stagnant water rich in bromide from above. Of course, the same would be true for other constituents that differed markedly from casing water to formation water. Because the downhole bromide sensors could not function because of the electromagnetic field from the pump, concentration changes above and below the

Figure 3.8. Bromide Tracer Test Without PurgeLess in Well UCD2-17 on April 28, 1994

pump could not be monitored. In well UCD2-17, field parameters except for Eh were stable after the first 3 gal were removed from the well as shown in Table A.7. This slightly longer stabilization may have been due to the absence of the PurgeLess device. Again, turbidity was higher because of the installation and removal of the pump to install the bromide tracer.

Again, similar procedures were followed in well UCD1-20 without the PurgeLess device as shown in Figure 3.9. This well is constructed in the less permeable zone of HSU-1. The discharge rate was 1 gpm, and the bromide concentration stabilized at less than 3% after slightly less than 40 gal were discharged, that is, similar to UCD2-16 with the PurgeLess device. Also, the concentration of bromide dropped precipitously in the first 5 min of purging just like the other wells. In well UCD1-20, field parameters except for Eh were stable after the first 7 gal were removed from the well as shown in Table A.8. Again, turbidity was higher than in February because of the installation and removal of the pump and an attempt to install the PurgeLess device in the ovalized casing before introducing the bromide tracer.

Based on the field test results from the tracer tests, the effectiveness of the PurgeLess system for conditions at LEHR is limited. Reduction in concentrations was not significantly better than without using the modified sampling procedure. The failure of the downhole bromide sensors prevented collection of data that might determine the presence of a heat convection cell around the pump. Displacement of bromide tracer volume into the formation during installation of the PurgeLess device may have exaggerated the true time it would take to purge the tracer. Surface and downhole temperature sensors were recommended for subsequent tests in May. Field parameters indicate that

Figure 3.9. Bromide Tracer Test Without PurgeLess in Well UCD1-20 on April 29, 1994

parameters stabilize quickly after the first few gallons are removed, but little advantage is gained using the PurgeLess device. The system was fairly easy to install once the centralizers were removed, and easy to remove because the aperture or valve allowed them to drain quickly. The success of these tests showed that with or without the PurgeLess device, current purging could be reduced by about 75%. To have pumps above the well screen was not possible for HSU-1 wells because of seasonal decline of water levels to the bottom of the screened intervals. To keep them above the well screen would require raising them a couple of feet during the purging cycle then lowering them just before the sampling cycle begins. This is not practical. Final determination of proper pump intake placement and appropriate discharge volumes would have to be accomplished using time-series tests for contaminants of concern. The first part of the time-series of analysis was conducted in the following month. To allow use of the flow-through cell for measuring field parameters, the discharge rate was kept at less than 1.5 gpm. The PurgeLess device was removed from well UCD2-15 following the tracer test because of constrictions in the well casing noticed during installation of the device. The device was installed with great difficulty in UCD1-20. Because of the constrictions in the well casing, it was decided to remove the device before conducting the tracer test in UCD1-20. The PurgeLess device in well UCD2-16 was not removed until a new pump was installed in the well in October 1995.

3.3 Time Series Tests of Inorganics and Procedural Changes

Time series analysis of inorganics were conducted in tests in three LEHR wells on May 23 and 24, 1994. These tests included procedural changes that would likely be recommended in this report.

In well UCD2-15, field parameters were relatively stable after the first 3 gal were removed from the well as shown in Table A.9. Turbidity was lower than in the April test of this well because the wells were not disturbed by removal and reinstallation of pumps or the PurgeLess devices. NTU had declined to about 1 or near the values in February by the end of sampling. Thermistors were used instead of thermocouples because of the more rapid response time (4ms, compared with 60ms). They were located similarly to the bromide sensors shown in Figure 3.5, that is immediately above and below the pump. Because of the somewhat erratic response, the temperature data from the downhole temperature probes P1 and P2 was not considered reliable. Interference from the pump motor caused the readings to fluctuate radically at times during the purging and sampling cycle. These temperature probes created artificial data when the pump was on resulting in the data as shown in Figure A.10. P1 probe was raised during the test as a check against probe P2. Results only indicate that the downhole temperature data is not reliable. The purge rate was approximately 1 gpm. Chemical parameters shown in Table A.10 indicate that inorganic constituents were stable during the period of measurement. Hexavalent chromium was constant during the purging cycle after the first 3 gal were discharged, and dropped slightly during the middle of the sampling cycle. Dames & Moore Inc. samples were analyzed by standard laboratory methods by Lockheed Analytical Services. PNNL used a less sensitive Hach kit. This decline may be due to heat convection effects during low discharge, but because the data from the downhole temperature probes was unreliable, this assumption could not be confirmed.

Figure 3.10. Purging and Sampling Test with PurgeLess in Well UCD2-15 on May 23, 1994

In well UCD2-17, temperature measured in the flow-through cell was relatively stable after the first 2 gal were removed at a discharge rate of 1 gpm from the well as shown in Table A.11. Other parameters were less stable and continued to fluctuate nearly 10% during the purging cycle, and more relative to the sampling cycle. Like UCD2-15, turbidity was lower than in the April test of this well because the wells were not disturbed. NTU had declined to less than 1, or near the values in February, by the end of purging. Again, because of the very erratic response, the temperature data from the downhole temperature probes P1 and P2 were not considered reliable. Chemical parameters shown in Table A.12 indicate that inorganic constituents were stable during the period of measurement. Hexavalent chromium was fairly constant during the purging and sampling cycle after the first few gallons were discharged.

In well UCD1-20 only, temperature from the two downhole temperature probes could be measured during the discharge of the first 40 gal because the discharge rate was at 5 gpm. Temperature measured in the flow-through cell was relatively stable in Table A.13. Surface discharge water temperature values were not consistent with subsurface values measured in probes P1 and P2. For example, as surface temperature discharge water declined slightly in value, temperature in P2 rose 3.3°C. Also, the rapid drop of 4.2°C in 15 sec seems improbable (Table A.13). Other parameters were less stable and continued to fluctuate more than 10% during the purging cycle, and more relative to the sampling cycle. Turbidity was lower than in the April test of this well because the wells were not disturbed. NTU had declined to less than 1 or near the values in February by the end of purging. Again, because of the very erratic response, the temperature data from the downhole temperature probes P1 and P2 was not considered reliable. Chemical parameters were not measured in this well, this is unfortunate because concentrations would be above detection limits.

3.4 Time Series Tests of VOCs

Time series analysis of VOCs were conducted in tests in two LEHR wells on December 4, 1995. Two wells, UCD2-26 and UCD1-12, with the highest concentrations of chloroform in HSU-2 and HSU-1, respectively, were selected for time-series analysis of chloroform and other VOCs. The analyses were conducted onsite by PNNL staff using a GC/MS, such that the selection of subsequent Hydropunch locations was based on analytical results from initial locations. PNNL Procedure NHFP-FA-6, "Sample Collection and Analysis of Hydropunch Water Samples for Volatile Organic Compounds" was used. Duplicate chloroform and some additional chloroform samples were analyzed by Lockheed Analytical Services.

Chloroform concentrations for well UCD2-26 declined initially, but remained fairly constant during the purging cycle, then rose during the sampling portion as shown in Figure 3.11. Discharge water temperature rose during purging and peaked at the end of the sampling cycle. The discharge rate during purging was 3.3 gal/min for a total purge volume of 120 gal. Time-series results for chloroform are shown in Table A.14. Field parameters were relatively stable after the first few gallons were removed from the well as shown in Table A.15. Eh instrument was not functional. Turbidity was lower than in the April and May field tests, and had declined to near 1 NTU, or near the values observed in February tests, by the end of sampling.

Chloroform concentrations for well UCD1-12 were highly variable during the first two measurements while 3 gal were removed. After the 3 gal were removed, these two initial chloroform concentration results remained fairly constant during the purging cycle, then rose during the sampling portion as shown in Figure A.12. The discharge rate during purging was 2.7 gal/min for a total purge volume of 105 gal. Unlike the steady rise observed in UCD2-26, discharge water temperature from

Figure 3.11. Concentration of Chloroform and Water Temperature During Purging and Sampling Well UCD2-26

UCD1-12 remained fairly constant during both the purging and the sampling cycle. Time-series results for chloroform are shown in Table A.16. Although other VOCs were detected in extremely low concentrations, they are not relevant to this particular report. The concentrations of other VOC constituents found have been previously noted by Liikala et al. (1996) and Stewart et al. (1996). Field parameters were relatively stable after the first few gallons were removed from the well as shown in Table A.17. Eh instrument was not functional. Turbidity was lower than in the April and May field tests, and had declined to near 1 NTU, or near the values observed in February tests, by the end of the sampling cycle.

- = Concentration of chloroform in µg/L
- = Temperature °F
- BV = Borehole volume (water in casing, screen, and sandpack), 78 gallons
- SC = Screened interval, 22 gallons
- SP/SC = Screened interval and sandpack, 44 gallons
- Pv = Purge volume required at LEHR, 105 gallons
- Rv = Volume in riser tube, 1 gallon

Figure 3.12. Concentration of Chloroform and Water Temperature During Purging and Sampling of Well UCD1-12

4.0 Conclusions

The basis for determining how much water needs to be purged is field data presented herein, existing scientific literature, and reports by Liikala et al. (1996), Stewart et al. (1996), and Schalla (1994). There are several general conclusions regarding purging for LEHR monitoring wells that can be reached based on this information. The conclusions pertain to: well design and materials used in construction; vertical location of the well screen relative to HSUs and permeable zones within each unit; vertical distribution of contaminants of concern; sampling pump suitability, performance, and deployment in the well; discharge rate impact on obtaining representative samples; usefulness of field parameters and constituents of concern to determine purge water volumes; and use of isolation devices to reduce purge water. The primary conclusions are summarized in the following list and a more detailed description and basis are provided in the following subsections. The summary conclusions are listed below.

- The construction and materials used in the 4-in. diameter monitoring wells at LEHR have not influenced the water chemistry results at LEHR.
- Some 4-in., Schedule 40 PVC casing has bent and ovalized below the groundwater table in some wells, but it is not known how common casing deformation is.
- The vertical location of well screens in nearly all monitoring wells is suitable for deploying sampling pump intakes at optimal locations for intercepting and sampling contaminants of concern.
- The suitability and performance of the Rediflo2 submersible pump to obtain representative samples was confirmed by time-series tests and previous information (Schalla 1994).
- The discharge rates during purging and sampling can be selected to minimize turbidity and obtain representative samples by avoiding excessive drawdowns.
- Less than 10 gal, rather than the current large volumes (100 gal or more), in the purge cycle need to be removed to obtain representative samples of groundwater.
- Fluid isolation systems are not needed because wells are essentially automatically purged by the groundwater flowing through the well screen.

4.1 Well Construction and Materials

The 4-in. diameter wells constructed since 1989 were designed and developed successfully to allow for the free flow of fluids into and out of the well screen with negligible amounts of turbidity. All chemical and hydrologic test data suggests the vertical seals have been properly placed to achieve isolation of HSUs and permeable zones. Materials used for casing, well screen, filter pack, bentonite, and cement seals have not altered the ability to obtain representative samples of groundwater from the monitoring wells as evidenced by 6 years of water chemistry data. Some 4-in. diameter well casing at depths below 50 ft had begun to deform because of pressures probably caused by differential settlement and consolidation of formation sediment. This was observed in wells UCD1-20 and UCD2-15, but may have occurred in other monitoring wells.

4.2 Vertical Location of Well Screens and Contaminants of Concern

The vertical location of well screens varies relative to the aquifer, but in most cases the variations are relatively small, particularly in the 4-in. diameter wells. The screen intervals are typically 15 ft in the bottom portion of HSU-1 or in the top 15 to 25 ft of HSU-2. A few exceptions exist as can be seen in Table 1.1. Because of the 15-ft length of screen in HSU-1, thin, permeable layers that carry contaminants have been consistently intercepted as determined by hydraulic test results (Liikala et al. 1996). Also, more permeable sands and gravels are present in the upper portion of the aquifer known as HSU-2 (Liikala et al. 1996). Therefore, it should be possible to deploy sampling pump intakes at optimal locations for intercepting constituents of concern.

4.3 Sampling Pump Suitability, Performance, and Deployment

The suitability and performance of the Rediflo2 submersible pump was covered in a previous report by Schalla (1994). The only issue of potential impact was the heating by the pump motor, that is, would it have an impact on sample representativeness when discharge rates were reduced? This issue was not conclusively resolved for LEHR monitoring wells until the time series data was collected, particularly for chloroform. There is evidence that the rise in temperature during the sampling period following purging does not result in loss of volatiles. Both a well that had low chloroform concentrations (i.e., UCD2-26) and a well with high chloroform concentrations (i.e., UCD1-12) showed that representative results were obtained for chloroform.

Except where immediately adjacent to the contaminant source area, contaminants of concern are concentrated in the lower portion of HSU-1 and the upper portion of HSU-2 (Liikala et al. 1996). Because the screen intervals almost always span these intervals, it is possible to deploy pump intakes opposite the interval of concern, which commonly contains the more permeable zones in each HSU. Older methods of deployment of pumps such as above the well screen are possible, however, they require larger volumes of purge water to be removed and are often less representative of current groundwater constituents measured.

4.4 Discharge Rate and Representative Samples

The discharge rates during the purging cycle using the Rediflo2 submersible pump could be at rates as high as 5 gpm. There is no conclusive adverse effect from such high discharge rates for HSU-2 wells because they cannot be drawn down significantly at that discharge rate. However, there is a potential adverse impact on HSU-1 wells. During most sampling periods when water levels before purging are only several feet above or below the top of the screened interval, a rapid decline of more than 10 ft in 20 min could have potential impact on the values obtained for unfiltered metal samples and possibly other constituents. Excessive drawdowns may alter which zones are contributing to the sample collected for analysis resulting in artificially high or low values.

There has been much discussion in the literature regarding appropriate discharge rates for purging and sampling. One item where there is general agreement is that the discharge rate during sampling should be less than the purge rate unless the purging is already being done at the low sampling rate. There is an additional argument for purging at a discharge rate several times that of the sampling cycle discharge rate. The higher discharge rate removes particulates that have accumulated during the period between samplings or servicing the well. The higher velocity discharge rate can quickly remove these sediments because of high entrance velocities through the well screen.

Turbidity data collected supports this conclusion. It has also been the experience by sampling staff at LEHR to reduce discharge rates during sampling to less than 1 L/min to prevent loss of bottle preservatives (e.g., sulfuric acid) by washing them out and to minimize the potential for air bubbles in volatile organic analyte vials.

4.5 Field Parameters and Contaminants of Concern to Determine Purge Volumes

The volume required to be removed during the purging cycle to obtain a representative sample is the primary concern of this report. The tracer test results helped with deployment issues, but that was primarily to confirm what other researchers had already determined, that is, the pump intake should be deployed opposite the zone of interest. Volume to be removed had relatively little to do with the well volume. For example, the casing volume above the screen is never really removed during purging cycle, nor does it need to be. This volume above the well screen merely needs to be avoided. Volume in the filter pack is irrelevant unless some reactive material was in the filter pack. There is no reactive material in the filter pack, so sand or filter pack volume is irrelevant to any volume calculation. The data indicates that there is no significant variation in the screened interval because groundwater velocities are so high in most of the HSU-1 wells and all of the HSU-2 wells. Bromide tracers quickly began moving from inside the well with velocities of a few feet per day. Volume to be removed was most effectively determined by the time-series analysis of the contaminants of concern. Collectively, field parameters appear to give indications of stable values for constituents of concern, but not consistently or directly comparable to actual measured values of the contaminants measured. It is evident from the time-series data that the gallon or so in the riser and pump chamber is often not representative of the formation for constituents of concern. At a minimum, a multiple of this volume should be removed. It is evident that large volumes currently being purged are not necessary to obtain representative samples from 4-in. diameter monitoring wells at LEHR. Although it may apply, there is no data to confirm if these conclusions can be applied to the older 2-in. diameter wells with a construction history and reliability that is less certain than the 4-in. wells.

4.6 Isolation Devices to Reduce Purge Volumes

The volume required to be removed during the purging cycle based on the tracer test results was not reduced significantly by the fluid isolation system called PurgeLess. Also, time-series tests of contaminants of concern indicated there was no need for this device at LEHR, although benefits might be derived at other sites where hydrogeologic and water chemistry conditions differ.

5.0 Recommendations

The recommendations presented are based on the data presented and the desire to remove the minimum amount of purge volume at as high a rate as possible without an undesirable turbidity and potential impacts on water chemistry during sampling of groundwater from monitoring wells at LEHR. This reduction in time and volume is part of a waste minimization effort to also reduce cost and the safety hazards associated with handling the waste water. There are several recommendations regarding purging for LEHR monitoring wells. The recommendations pertain to: well design and materials used in construction; vertical location of the well screen relative to HSUs and permeable zones within each unit; vertical distribution of contaminants of concern; sampling pump suitability, performance, and deployment in the well; discharge rate impact on obtaining representative samples; usefulness of field parameters and constituents of concern to determine purge water volumes; and use of isolation devices to reduce purge water. The recommendations are listed below.

- Continue construction using all stainless steel well casing with sufficient collapse strength to minimize the potential of casing deformation and ovalization.
- Well screens for HSU-1 wells should be screened from 5-ft above the contact with the top of HSU-1 extending 15-ft upward, thereby spanning the lower portion of HSU-1.
- Well screens for HSU-2 wells should be screened from 5-ft below the contact with the top of HSU-2 extending downward 15 ft, thereby spanning the upper portion of HSU-2.
- Pump intakes in HSU-1 wells should be 2 to 5 ft from the bottom of the 15-ft-long well screens to intercept constituents and allow for periods of low water level.
- For HSU-2 wells, pump intake should be in the upper portion of the screened interval approximately 10- to 15-ft below the top of HSU-2.
- Continue using the Rediflo2 submersible pumps for both purging and sampling to obtain representative samples of groundwater.
- Reduce discharge rates during purging to 0.5 to 1.0 gpm (2 to 4 L/min) to avoid excessive drawdowns, reduce turbidity, and obtain continuous results of field parameters.
- Reduce discharge rates during sampling to 0.25 gpm (1 L/min) or less to prevent loss of bottle preservatives and to minimize air bubbles in volatile organic analyte vials.
- Purge volumes can be reduced to approximately 2 to 3 gal per well, but to assure representative samples, twice that amount (6 gal) should be purged.
- Do not use fluid isolation systems in the monitoring wells.

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Appendix A

Appendix A

Table A.1. Field Parameters for Well UCD2-15, February 28, 1994

Time	Temperature (°C)	Specific Conductivity (μmhos/cm)	pH	Turbidity (NTU)	Eh (mV)	Approx. Gallons Removed	Comments (appearance of water, odor, etc.)
1348	-	-	-	-	-	0	Pump on
1423	18.5	610	7.46	0.39	92	155	Clear, no odor
1427	18.5	563	7.48	0.20	88	159	Clear, no odor
1428	18.5	550	7.48	0.13	88	160	Clear, no odor
1430	18.5	584	7.49	0.31	88	162	Parameters stable

Table A.2. Field Parameters for Well UCD2-16, February 28, 1994

Time	Temperature (°C)	Specific Conductivity (μmhos/cm)	pH	Turbidity (NTU)	Eh (mV)	Approx. Gallons Removed	Comments (appearance of water, odor, etc.)
1600	18.8	640	7.52	0.36	063	165	Clear, no odor
1602	19.2	648	7.45	0.12	070	167	Clear, no odor
1603	19.2	648	7.43	0.35	073	168	Clear, no odor
1605	19.2	650	7.44	0.07	074	170	Parameters stable

Table A.3. Field Parameters for Well UCD2-17, February 28, 1994

Time	Temperature (°C)	Specific Conductivity (μmhos/cm)	pH	Turbidity (NTU)	Eh (mV)	Approx. Gallons Removed	Comments (appearance of water, odor, etc.)
1049	18.6	593	7.52	0.31	87	195	Clear, no odor
1052	18.6	574	7.40	0.27	094	198	Clear, no odor
1055	18.6	522	7.36	0.20	096	201	Clear, no odor
1058	18.6	462	7.37	0.19	097	204	Clear, no odor
1059	18.6	449	7.37	0.24	098	205	Parameters stable

Table A.4. Field Parameters for Well UCD1-20, February 28, 1994

Time	Temperature (°C)	Specific Conductivity (μmhos/cm)	pH	Turbidity (NTU)	Eh (mV)	Approx. Gallons Removed	Comments (appearance of water, odor, etc.)
0912	19.8	684	7.41	0.11	132	75	Clear, no odor
0914	20.0	719	7.42	0.69	134	77	Clear, no odor
0916	20.0	721	7.41	0.07	133	79	Clear, no odor
0919	20.0	717	7.40	0.05	137	82	Parameters stable

Table A.5. Field Parameters for Well UCD2-15, April 28, 1994

Time (hr-min:sec)	Temperature (°C)	Specific Conductivity (μmhos/cm)	pH	Turbidity (NTU)	Eh (mV)	Approx. Gallons Removed	Comments (appearance of water, odor, etc.)
1131:30	-	-	-	-	-	0	Pump on
1132:00	21.3	618	8.04	-	136	0.3	
1132:15	18.9	620	7.86	-	137	0.4	
1132:30	18.6	617	7.85	-	135	0.6	
1132:45	18.6	613	7.83	-	133	0.7	
1133	18.6	596	7.82	-	130	0.8	
1133:30	18.6	587	7.81	-	130	1.1	
1133:45	18.7	561	7.81	-	135	1.3	
1134	18.7	530	7.80	-	124	1.4	
1135	18.8	518	7.78	-	116	2.0	
1136	18.8	513	7.76	-	110	2.5	
1137	18.8	511	7.76	-	104	3.1	
1138	18.9	504	7.73	-	93	3.6	
1139:30	18.9	502	7.72	-	79	4.5	
1140	18.8	501	7.73	-	77	4.8	
1141:30	18.8	502	7.73	-	69	5.6	
1142	18.8	500	7.73	-	67	5.9	
1143	18.8	502	7.73	159.3	61	6.4	
1144	18.8	500	7.73	-	57	7.0	
1145	18.8	495	7.73	-	54	7.6	
1146:15	18.9	500	7.73	-	50	8.3	
1147	18.8	494	7.73	118.2	48	8.7	
1149	18.8	495	7.74	-	45	9.8	
1150	18.8	498	7.74	-	45	10.4	
1152	18.9	500	7.75	-	45	11.5	
1155	18.9	493	7.76	92.5	46	13.2	
1159:15	18.9	477	7.77	-	47	15.5	
1203	18.8	491	7.77	74.6	50	17.6	
1207	18.9	533	7.78	-	52	19.9	
1217	18.9	525	7.79	-	59	25.5	Pump off

Table A.6. Field Parameters for Well UCD2-16, April 29, 1994

Time (hr-min:sec)	Temperature (°C)	Specific Conductivity (μmhos/cm)	pH	Turbidity (NTU)	Eh (mV)	Approx. Gallons Removed	Comments (appearance of water, odor, etc.)
1018						0	Pump on (0.9 gpm)
1018:30	17.9	781	7.48	-	125	0.45	
1019	18.1	777	7.47	-	126	0.90	
1019:30	18.1	777	7.47	-	125	1.35	
1020	18.1	776	7.47	-	123	1.80	
1020:30	18.3	785	7.47	-	121	2.25	
1021	18.3	792	7.47	-	119	2.70	
1021:30	18.4	791	7.48	-	116	3.15	
1022	18.5	784	7.47	-	110	3.60	
1022:30	18.5	776	7.48	-	106	4.05	
1023	18.5	770	7.48	-	103	4.50	
1023:30	18.5	766	7.49	-	101	4.95	
1024	18.5	762	7.48	-	99	5.40	
1024:30	18.5	758	7.48	-	97	5.85	
1025	18.5	753	7.49	-	95	6.30	
1026	18.5	750	7.48	53.5	93	7.20	
1027	18.5	746	7.49	-	91	8.10	
1028	18.5	743	7.48	-	89	9.00	
1029	18.5	740	7.49	-	89	9.90	
1030	18.5	740	7.49	31.5	88	10.80	
1032	18.5	737	7.49	-	87	12.60	
1034	18.5	734	7.48	-	87	14.40	
1037	18.5	733	7.49	-	88	17.10	
1040	18.5	732	7.49	13.77	88	19.80	
1042	18.5	729	7.49	-	89	21.60	
1045	18.5	732	7.49	9.53	90	24.30	
1048	18.5	732	7.49	8.50	91	27.00	
1049	18.5	732	7.49	-	91	27.90	
1050	18.5	729	7.49	-	91	28.80	
1051	18.4	728	7.49	4.15	92	29.70	
1053	18.5	726	7.49	-	92	31.50	
1055	18.5	729	7.49	6.22	92	33.30	
1057	18.5	730	7.48	6.51	92	35.10	
1100	18.5	732	7.48	5.71	92	37.80	
1105	18.6	734	7.48	7.43	92	42.30	
1107	-	-	-	-	-	44.10	Pump off

Table A.7. Field Parameters for Well UCD2-17, April 28, 1994

Time (hr-min:sec)	Temperature (°C)	Specific Conductivity (μmhos/cm)	pH	Turbidity (NTU)	Eh (mV)	Approx. Gallons Removed	Comments (appearance of water, odor, etc.)
1627							Pump on (1.5 gpm)
1628:30	20.2	693	7.59	-	135	2.25	
1629	18.7	682	7.62	-	134	3.00	
1629:30	18.5	679	7.61	-	135	3.75	
1630	18.5	677	7.48	-	139	4.50	
1630:30	18.5	675	7.42	-	143	5.25	
1631	18.5	671	7.40	-	142	6.00	
1631:30	18.4	631	7.43	-	140	6.75	
1632	18.4	622	7.43	-	139	7.50	
1632:30	18.4	617	7.45	-	137	8.25	
1633	18.4	612	7.46	-	134	9.00	
1634	18.3	607	7.47	-	131	10.50	
1635	18.3	602	7.48	-	130	12.00	
1636	18.3	600	7.49	-	129	13.50	
1637	18.3	599	7.50	-	128	15.00	
1638	18.3	598	7.51	-	126	16.50	
1639	18.2	596	7.51	83.8	127	18.00	
1640	18.2	597	7.54	-	126	19.50	
1642	18.2	597	7.56	-	125	22.50	
1644	18.2	597	7.57	-	124	25.50	
1646	18.2	596	7.59	-	126	28.50	
1648	18.2	595	7.61	-	124	31.50	
1651	18.2	595	7.62	18.33	123	34.50	
1655	18.2	595	7.64	-	124	40.50	
1657				-			Flow rate reduced to 0.14 gpm
1657:30	18.2	594	7.65	-	124	43.57	
1657:45	18.4	602	7.66	-	126	43.60	
1659:10	18.6	602	7.66	-	125	44.0	
1659:40	18.7	601	7.66	-	126	44.4	
1700	18.7	602	7.66	-	125	45.6	
1702	19.1	609	7.67	9.81	125	45.9	
1705	19.6	549	7.68	-	122	46.3	
1710	20.4	634	7.70	-	116	47.0	
1715	20.6	642	7.70	-	113	47.7	
1720	20.6	638	7.69	-	111	48.4	
1725	20.9	643	7.68	7.76	109	49.1	

Table A.8. Field Parameters for Well UCD1-20, April 29, 1994

Time	Temperature (°C)	Specific Conductivity (µmhos/cm)	pH	Turbidity (NTU)	Eh (mV)	Approx. Gallons Removed	Comments (appearance of water, odor, etc.)
1411	19.9	668	7.55	-	130	7.2	
1412	19.9	668	7.56	102.1	128	8.1	
1413	19.9	668	7.56	-	125	9.0	
1414	19.9	668	7.57	-	123	9.9	
1415	19.9	682	7.56	-	122	10.8	
1417	19.9	688	7.57	93.5	119	12.6	
1419	19.9	691	7.56	-	114	14.4	
1421	19.9	689	7.55	76.8	112	16.2	
1423	19.9	684	7.56	-	109	18.0	
1425	19.9	687	7.55	-	106	19.8	
1427	19.9	686	7.55	71.5	104	21.6	
1429	19.9	688	7.54	-	103	23.4	
1433	19.9	687	7.54	95.2	101	27.0	
1438	19.8	684	7.54	130.8	100	31.5	
1444	19.9	683	7.53	132.6	102	36.9	Pump off
1459	19.9	690	7.52	-	112	38.7	Pump back on
1500	19.9	691	7.52	-	108	39.6	
1502	20.1	690	7.53	-	108	41.4	

Table A.9. Field Parameters for Well UCD2-15, May 23, 1994

Time	Surface Temperature (°C)	Probe P1 Temperature (°C)	Probe P2 Temperature (°C)	Specific Conductivity (µmhos/cm)	pH	Turbidity (NTU)	Eh (mV)	Approx. Gallons Removed	Comments (appearance of water, odor, etc.)
1049	-	-	-	-	-	-	-	0	Pump on (1.0 gpm) P1 at 90 ft. bgs
1052	18.6	17.4	19.4	633	7.26	39.9	2	3.0	
1053	18.6	17.3	19.5	631	7.26	39.2	3	4.0	
1056	18.4	17.0	19.5	639	7.28	35.0	3	7.0	
1059	18.5	-	19.5	640	7.29	8.41	4	10.0	
1102	18.5	16.9	19.5	642	7.30	5.23	4	13.0	
1106	18.5	16.4	19.5	640	7.32	6.88	5	17.0	P1 raised to 86 ft bgs
1111	18.5	16.5	20.1	640	7.36	3.59	4	22.0	
1117	18.6	16.5	20.1	643	7.38	2.86	5	27.0	
1118	18.6	16.5	20.1	640	7.35	2.86	5	30.0	
1121	18.5	16.6	20.0	640	7.36	1.91	5	35.0	
1122	18.5	-	-	640	7.36	1.87	5	36.0	
1128	18.5	16.6	20.3	645	7.36	2.12	5	40.0	
1141	-	-	-	-	-	-	-	52.0	Flow rate reduced to 0.2 gpm
1143	19.7	-	-	460	7.41	1.91	5	52.4	
1146	20.2	16.9	20.3	223	7.42	1.71	4	53.0	
1152	20.5	17.2	20.2	159	7.42	1.21	4	54.2	
1200	20.7	18.1	20.1	227	7.42	1.33	5	55.8	
1208	20.9	18.9	20.2	663	7.43	1.21	4	57.4	
1210	20.8	19.0	20.3	664	7.43	1.17	4	57.8	
1218	21.2	19.4	20.4	667	7.42	1.29	3	59.4	
1226	-	-	-	-	-	-	-	61.0	Pump Off

Table A.10. Chemical Parameters for Well UCD2-15, May 23, 1994

Time	Chromium		Barium ($\mu\text{g/L}$)	Chloride ($\mu\text{g/L}$)	Nitrate ($\mu\text{g/L}$)	Sulfate ($\mu\text{g/L}$)
	Dames & Moore	PNL				
1051	6.8	-	-	-	-	-
1054	9.3	-	-	-	-	-
1104	9.3	-	-	-	-	-
1109	-	<10	143	22,000	2100	36,000
1114	-	<10	140	22,000	2100	36,000
1118	9.8	<10	138	22,000	2100	36,000
1121	-	<10	141	22,000	2100	36,000
1156	7.4	-	-	-	-	-

Table A.11. Field Parameters for Well UCD2-17, May 23, 1994

Time	Surface Temperature (°C)	Probe P1 Temperature (°C)	Probe P2 Temperature (°C)	Specific Conductivity (µmhos/cm)	pH	Turbidity (NTU)	Eh (mV)	Approx. Gallons Removed	Comments (appearance of water, odor, etc.)
1445	-	-	-	-	-	-	-	0	Pump on (1.0 gpm P2 at 92 ft. bgs)
1447	18.4	-	-	594	7.73	10.68	-	2	
1448	18.7	19.4	22.4	-	-	-	-	3	
1449	18.7	-	-	596	7.77	7.32	-	4	
1453	18.5	19.5	22.5	-	-	-	-	8	
1455	18.6	19-20	22.3	595	7.77	5.12	-	10	P2 raised to 86 ft. bgs
1459	18.5	20.0	19.4	-	-	-	-	14	
1500	18.5	-	-	596	8.14	3.12	-	15	
1505	18.5	20.2	19.4	554	8.09	3.97	-	20	
1507									P2 lowered to 92 ft. bgs
1510	18.5	19.8	23.0	531	8.01	7.44	-	25	
1515	18.5	18.8	23.0	596	7.96	1.94	-	30	
1520	18.5	18.8	22.8	558	7.93	2.44	-	35	
1522	18.5	18.8	22.8	562	7.91	1.79	-	37	
1525	18.5	19.0	22.8	554	7.91	1.19	-	40	
1530	18.5	19.6	22.6	556	7.89	0.70	-	45	
1542									Flow rate reduced to 0.2 gpm
1550	20.2	19-20	22.4	454	7.74	3.50	NM	57.6	
- = not measured.									

Table A.12. Chemical Parameters for Well UCD2-17, May 23, 1994

Sample Number	Chromium (µg/L)		Barium (µg/L)	Chloride (µg/L)	Nitrate (µg/L)	Sulfate (µg/L)
	Dames & Moore	PNL				
UCD-17-1	8.70	<10	121	19,000	1500	3300
UCD-17-2	9.20	<10	124	18,000	1500	3300
UCD-17-3	8.70	<10	118	18,000	1500	3300
UCD-17-4	9.30	<10	121	18,000	1500	3300
UCD-17-5	8.70	<10	120	19,000	1500	3300

Table A.13. Field Parameters for Well UCD1-20, May 24, 1994

Time (hr-min:sec)	Surface Temperature (°C)	Probe P1 Temperature (°C)	Probe P2 Temperature (°C)	Specific Conductivity (μmhos/cm)	pH	Turbidity (NTU)	Eh (mV)	Approx. Gallons Removed	Comments (appearance of water, odor, etc.)
0930		18.6	19.0					0	Pump on (5 gpm)
0932		18.6	19.0					10	
0933		18.6	19.0					15	
0934		18.6	18.9					20	
0934:30		18.6	18.8					22.5	
0935		18.6	18.7					25	
0936		18.6	18.7					30	
0936:30		18.7	18.8					32.5	
0937		18.7	18.8					35	
0937:30		18.7	18.8					37.5	
0938		18.6	18.7					40	Flow reduced to 1 gpm
0939	20.6	18.5	19.7	605	7.53	11.88	210	41	
0939:30		18.5	20.4					41.5	
0940		18.6	21.8					42	
0940:30		18.5	22.4					42.5	
0941	19.9	18.6	22.7	654	7.46	7.63	168	43	
0941:30		18.5	22.7					43.5	
0942		18.5	22.8					44	
0942:30		18.5	22.9					44.5	
0943	19.8	18.5	23.0	710	7.43	6.27	158	45	
0943:30		18.4	23.0					45.5	
0944	19.8	18.4	23.0	713	7.43	4.27	154	46	
0944:30		18.3	23.1					46.5	
0945		18.2	23.1					47	
0945:30		18.2	23.2					47.5	
0948		18.2	23.2					50	
0949		18.1	23.2					51	
0950		18.1	23.2					52	
0951		18.1	23.2					53	
0952:45		18.1	23.2					54.8	
0953								55.0	Flow reduced to 0.3 gpm
0953:30		18.1	23.2					55.15	
0954		18.1	23.2					55.3	
0954:15								-	Pump off
0954:30		18.7	19.0					-	
0959		18.7	19.0					-	
1001		18.7	19.0					-	
1010		18.7	19.0					-	

Table A.14. Chloroform Time Series Data for Well UCD2-26 (ug/L)

Sample ID	Sample Date	Sample Time	Conc	Detection Limit	Dilution	Date Tested	Method
TSGW2262	12/04/95	13:26	9.800	.30		12/04/95	HEADSP
TSGW2263	12/04/95	13:29	8.600	.30		12/04/95	HEADSP
TSGW2264	12/04/95	13:32	7.600	.30		12/04/95	HEADSP
TSGW2265	12/04/95	13:35	8.500	.30		12/04/95	HEADSP
TSGW2266	12/04/95	13:38	7.500	.30		12/04/95	HEADSP
TSGW2267	12/04/95	13:42	8.400	.30		12/04/95	HEADSP
TSGW2268	12/04/95	13:46	8.500	.30		12/04/95	HEADSP
TSGW2269	12/04/95	13:50	7.400	.30		12/04/95	HEADSP
TSGW22610	12/04/95	13:54	8.300	.30		12/04/95	HEADSP
TSGW22611	12/04/95	13:57	8.000	.30		12/04/95	HEADSP
TSGW2261	12/04/95	13:26	10.300	.30		12/04/95	HEADSP
TSGW22612	12/04/95	14:01	7.200	.30		12/04/95	HEADSP
GWGW0254	12/04/95	14:10	11.000	1.00	1.00	12/08/95	CLPVOA

Table A.15. Field Parameters for Well UCD2-26, December 4, 1995

Time	Temperature (°C)	Specific Conductivity (µmhos/cm)	pH	Turbidity (NTU)	Approx. Gallons Removed	Comments (appearance of water, odor, etc.)
1327	66.1	6.41	8.0	23.2	7.5	
1335	66.6	5.82	7.7	6.5	37	
1345	66.9	5.75	7.8	3.2	74	
1400	68.4	5.83	7.8	1.3	130	
1411	70.0	5.89	7.8	3.1	133	
1417	69.8	5.91	7.8	1.5	135	
1425	71.9	6.01	7.7	1.3	136	

Table A.16. Chloroform Time Series Data for Well UCD1-12 (ug/L)

Sample ID	Sample Date	Sample Time	Conc	Detection Limit	Dilution	Date Tested	Method
TSGW1121	12/04/95	10:36	7261.000	.30		12/04/95	HEADSP
TSGW1122	12/04/95	10:37	2815.000	.30		12/04/95	HEADSP
TSGW1123	12/04/95	10:43	5828.000	.30		12/04/95	HEADSP
TSGW1124	12/04/95	10:46	5205.000	.30		12/04/95	HEADSP
TSGW1125	12/04/95	10:49	5074.000	.30		12/04/95	HEADSP
TSGW1126	12/04/95	10:52	5035.000	.30		12/04/95	HEADSP
TSGW1127	12/04/95	10:55	5521.000	.30		12/04/95	HEADSP
TSGW1128	12/04/95	10:58	4994.000	.30		12/04/95	HEADSP
TSGW1129	12/04/95	11:01	4836.000	.30		12/04/95	HEADSP
TSGW11210	12/04/95	11:04	4661.000	.30		12/04/95	HEADSP
TSGW11211	12/04/95	11:07	4742.000	.30		12/04/95	HEADSP
TSGW11213	12/04/95	11:14	5053.000	.30		12/04/95	HEADSP
TSGW11212	12/04/95	11:10	4706.000	.30		12/04/95	HEADSP
GWGW0260	12/04/95	11:20	5800.000	500.00	500	12/07/95	CLPVOA
GWGW0261	12/04/95	11:25	6400.000	500.00	500	12/09/95	CLPVOA

Table A.17. Field Parameters for Well UCD1-12, December 4, 1995

Time	Temperature (°C)	Specific Conductivity (µmhos/cm)	pH	Turbidity (NTU)	Approx. Gallons Removed	Comments (appearance of water, odor, etc.)
1046	65.3	14.30	7.6	1.82	33	
1055	65.9	16.51	7.4	0.57	60	
1105	65.1	16.93	7.4	0.75	90	
1110	64.9	16.94	7.4	0.26	105	
1122	65.3	18.60	7.2	0.20	108	
1131	64.0	18.15	7.2	0.14	110	
1133	65.7	18.10	7.4	0.18	111	
1135	65.2	18.60	7.3	0.16	111.5	

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