1226723

SGW-38757

DRAFT A

[0084844]

Investigation of Hexavalent Chromium Source in the Southwest 100-D Area

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Project Hanford Management Contractor for the
U.S. Department of Energy under Contract DE-AC06-96RL13200

FLUOR

P.O. Box 1000
Richland, Washington

RECEIVED
AUG 22 2014
EDMC

Approved for Public Release
Further Dissemination Unlimited

118

Investigation of Hexavalent Chromium Source in the Southwest 100-D Area

Document Type: TR Program/Project: SGW

S. W. Petersen
Fluor Hanford, Inc.

S. H. Hall
Freestone Environmental Services, Inc.

Date Published
September 2008

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Project Hanford Management Contractor for the
U.S. Department of Energy under Contract DE-AC06-96RL13200

FLUOR
P.O. Box 1000
Richland, Washington

S. D. Aardal 09/17/2008
Release Approval Date

Approved for Public Release.
Further Dissemination Unlimited

TRADEMARK DISCLAIMER

Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors.

This report has been reproduced from the best available copy.

Printed in the United States of America

CONTENTS

1.0 INTRODUCTION 1-1

1.1 BACKGROUND AND SCOPE 1-1

2.0 FIELD ACTIVITIES AND ASSOCIATED DATA COLLECTION 2-1

2.1 DRILLING 2-1

2.2 SAMPLING AND ANALYSIS 2-1

2.2.1 Sediment Samples 2-1

2.2.2 Periodic Groundwater Sampling 2-5

2.2.3 Depth-Discrete Groundwater Sampling 2-5

2.3 WELL TESTING 2-7

2.4 WATER LEVEL MEASUREMENTS 2-7

3.0 DATA INTERPRETATION 3-1

3.1 HEXAVALENT CHROMIUM DISTRIBUTION 3-1

3.1.1 Groundwater Sampling and Analysis 3-1

3.1.2 Depth-Discrete Sampling 3-5

3.1.3 Statistical Method for Chrome Source Location 3-7

3.2 QUALITY ASSURANCE/QUALITY CONTROL 3-7

3.2.1 Soil Analyses 3-7

3.2.2 Groundwater Analyses 3-8

3.3 HYDROGEOLOGY 3-8

3.3.1 Hydraulic Conductivity 3-8

3.3.2 Hydraulic Gradients 3-9

3.3.3 Groundwater Flow 3-12

3.4 GEOLOGY 3-12

4.0 CONCLUSIONS 4-1

5.0 REFERENCES 5-1

APPENDICES

A WELL SUMMARY SHEETS ..... A-i

B SUMMARY OF GROUNDWATER AND SEDIMENT ANALYSIS ..... B-i

C DEPTH-DISCRETE GROUNDWATER SAMPLING ..... C-i

D FLOW MODELING REPORT ..... D-i

FIGURES

Figure 1-1. Hexavalent Chromium in Groundwater in the 100-D Area (2005 data after PNNL-015670). 1-1
Figure 2-1. Location Map for Chromium Source Investigation Well Sites. 2-2
Figure 2-2. Well Completion Design for the 100-D Area Chromium Source Investigation Wells. 2-4
Figure 3-1. Hexavalent Chromium in High-Concentration Wells. 3-2
Figure 3-2. Hexavalent Chromium in Low-Concentration Wells. 3-3
Figure 3-3. Hexavalent Chromium Concentrations (May 16, 2008). 3-4
Figure 3-4. Wireframe Version of Figure 3-3. 3-4
Figure 3-5. Concentration Profiles of Hexavalent Chromium for Wells Sampled in March 2008. 3-6
Figure 3-6. Concentration Profiles of Hexavalent Chromium for Wells Sampled in June 2008. 3-6
Figure 3-7. River Stage Versus Water Table Elevation for Three Wells. 3-11
Figure 3-8. Location Map for Fence Diagrams. 3-13
Figure 3-9. Cross-section A-A'. 3-14
Figure 3-10. Cross-section B-B'. 3-15
Figure 3-11. Cross-section C-C'. 3-17

TABLES

Table 2-1. Well Identification Numbers and Purpose. 2-3
Table 2-2. Sampling and Analysis Requirements. 2-6
Table 2-3. Wells on the Automated Water Level Network. 2-7
Table 3-1. Single-Well Estimates of Hydraulic Conductivity. 3-10

TERMS

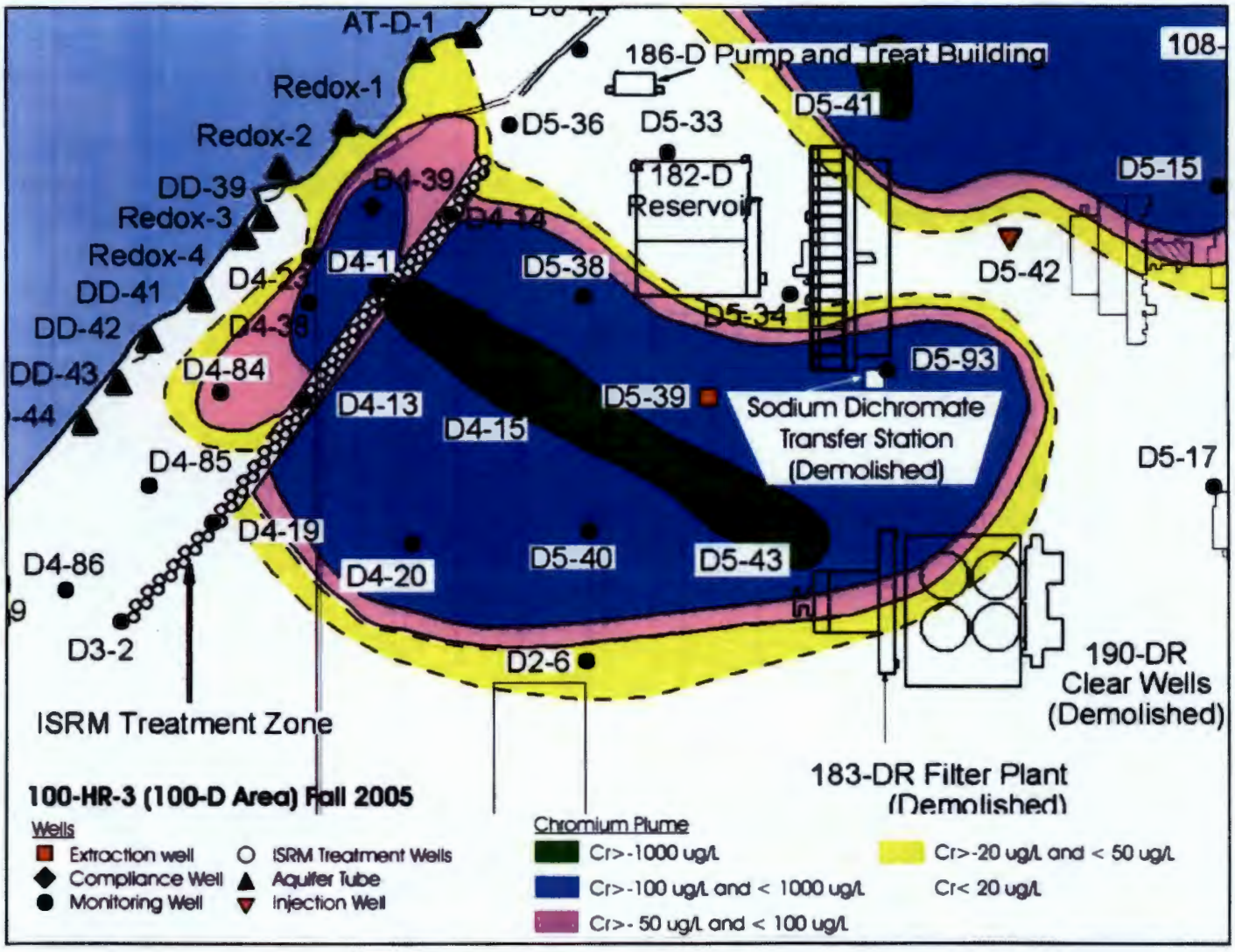
FY	fiscal year
ISRM	In Situ Redox Manipulation
PNNL	Pacific Northwest National Laboratory

This page intentionally left blank.

1.0 INTRODUCTION

This report presents the results of a field investigation to characterize hexavalent chromium contamination in the southwestern plume of the 100-D Area, shown in Figure 1-1 as it was understood at the onset of the project (PNNL-15670, *Hanford Site Groundwater Monitoring for Fiscal Year 2005*). The main objective of the investigation has been to locate or significantly narrow the probable location of the source of chromium to within a one-hectare area (DOE/RL-2006-74, *Field Investigation Plan for the Southwestern Chromium Plume in the 100-D Area*). The results of the investigation are intended to facilitate evaluation of remedial alternatives.

Figure 1-1. Hexavalent Chromium in Groundwater in the 100-D Area (2005 data after PNNL-015670).



1.1 BACKGROUND AND SCOPE

In fiscal year (FY) 2005, Congress allocated funding to the U. S. Department of Energy to analyze groundwater contamination sources at the Hanford Site, interject new technologies, and

accelerate active cleanup. A portion of this funding is being used to implement a "systems approach" for cleaning up chromium in the 100-D Area aquifer which will accelerate the current remediation efforts. The work involved with this new approach has included mending the In Situ Redox Manipulation (ISRM) Barrier, testing a new technology for removing chromium from groundwater, and refining the source area of the southwestern chromium plume.

Hexavalent chromium as sodium dichromate was added to the cooling water in the Hanford Site 100-D Area nuclear reactors to retard corrosion in the metal pipes of the reactor cooling system. The chemical feed stock was delivered to the reactor areas in bags, barrels or rail cars, and transferred to points of use through local underground pipelines in a stock solution that was up to 25 wt. % hexavalent chromium. The solution was diluted so that the reactor coolant contained approximately 700 μg/L hexavalent chromium.

Multiple sources of hexavalent chromium were present in the 100-D Area during the reactor operations period of 1950 to 1964. Possible releases of sodium dichromate include spills during handling and/or leaks from pipelines used to deliver the chemical to water treatment plants in the area. The spilled or leaked sodium dichromate has migrated through the vadose zone to the groundwater. The resulting plume is currently being treated by the ISRM permeable reactive barrier which intercepts chromium before it reaches the river (Figure 1-1). However, chromium concentrations in the plume have not significantly diminished in wells upgradient of the ISRM barrier since the plume was discovered in 1999, and the source of the hexavalent chromium is assumed to be currently active. Hexavalent chromium is the only contaminant of concern in the local unconfined aquifer (DOE/RL-2006-74).

Several likely source locations have been identified and investigated since 1999. The most intensely characterized area before the onset of the present project was the site of the 183-DR Head House, where water-conditioning chemicals including sodium dichromate were handled. This facility was part of the 183-DR Water Treatment Facility, which was demolished in 1978. In an attempt to find chromium in the vadose zone, two boreholes were drilled and sampled and several deep trenches were excavated and sampled in 2000. Samples were also obtained from surface soils and test pits excavated in 2004 near the suspected source. These efforts were not successful in finding elevated chromium in the vadose zone, although low levels (< 4 mg/kg) were found in a few areas near the surface (BHI-01747, *Results of Hexavalent Chromium Sampling Near 100-D Area Sodium Dichromate Transfer Station Railroad Tracks*).

The earlier drilling campaigns and reconnaissance sampling of surface and near-surface sediments did not lead to the discovery of the hexavalent chromium source. This is strongly suggestive of a localized source or sources within the vadose zone and/or the aquifer.

The plume configuration shown in Figure 1-1 is based on groundwater data available in 2005, which suggest that the most likely location of the chromium source would be near the 183-DR Head House. This in turn indicated that a likely source of the hexavalent chromium was the highly concentrated solution of sodium dichromate delivered to the water treatment plant.

Recognizing the small probability of directly intercepting a chromium source in the vadose zone by drilling, the project team designed the present project to focus on hydrogeologic and geochemical evidence from the aquifer in an attempt to backtrack the contamination to where it enters the aquifer from the vadose zone. Evidence from the saturated zone was supplemented by

examination and chemical analysis of drill cuttings collected during construction of new groundwater monitoring wells.

The program of data collection comprised the following activities, each of which is summarized in Section 2.0:

- Seven new groundwater monitoring wells drilled in FY2007, and four additional wells in FY2008, all completed in and fully penetrating the uppermost unconfined aquifer.
- Measurement of hexavalent chromium in vadose zone sediment samples collected during drilling.
- Hourly water level measurements in the new wells (with additional data from other wells in the Hanford Site automated water level measurement network).
- Twice-monthly collection of water samples from the new wells for determination of hexavalent chromium.
- Depth-discrete groundwater sampling and hexavalent chromium measurement for selected wells to determine if the contaminant plume is stratified.

This page intentionally left blank.

2.0 FIELD ACTIVITIES AND ASSOCIATED DATA COLLECTION

This section describes the program of well construction and of field and laboratory measurements performed for the purpose of characterizing the contaminant distribution and the local hydrogeology.

2.1 DRILLING

This field investigation was designed to characterize and define the magnitude and extent of the 100-D Area southwestern contaminant plume upgradient of the ISRM barrier and to refine the location of the source of the chromium groundwater contamination. Seven new monitoring wells were constructed in FY2007 and a program of intensive groundwater sampling and analysis and automated hourly water level monitoring was initiated at the new wells (DOE/RL-2006-74).

Four additional groundwater monitoring wells were constructed in FY2008 to supplement the data gathered from the first seven wells and to further focus the search for the chromium source by increasing sampling density in the vicinity of wells that have shown the highest chromium concentration (DOE/RL-2008-28, *Drilling Four New chromium Source Investigation Wells in the 100-D Area*).

A site map with the locations of the 11 new wells is shown in Figure 2-1. Table 2-1 lists the wells along with the completion date and the rationale for their locations.

The 11 wells were drilled using a cable-tool drill rig and drive barrel methods. The wells were constructed with 4-in. diameter polyvinyl chloride (PVC) casing and a 0.020-in. (20-slot) screen that fully penetrated the unconfined aquifer. Figure 2-2 shows the general well design and illustrates the construction details for the monitoring wells. The well summary sheets showing well completion information and lithologic descriptions for the new monitoring wells are presented in Appendix A.

2.2 SAMPLING AND ANALYSIS

2.2.1 Sediment Samples

For the seven wells drilled in FY2007, sediment samples (drill cuttings) were collected at 5-ft intervals beginning 5 ft below ground surface, and at changes in lithology (SGW-33472, *Borehole Summary Report for the Installation of Chromium Source Investigation Wells in the 100-D Area, FY2007*). Each sediment sample was photographed and described, two representative one-pint samples were taken, and a smaller chip tray sample was collected. One of the one-pint samples from each sampled depth was submitted to the Washington State Department of Ecology for analysis of hexavalent chromium content. The remaining one-pint samples and the chip trays were retained by Fluor Hanford as archive samples.

Figure 2-1. Location Map for Chromium Source Investigation Well Sites.

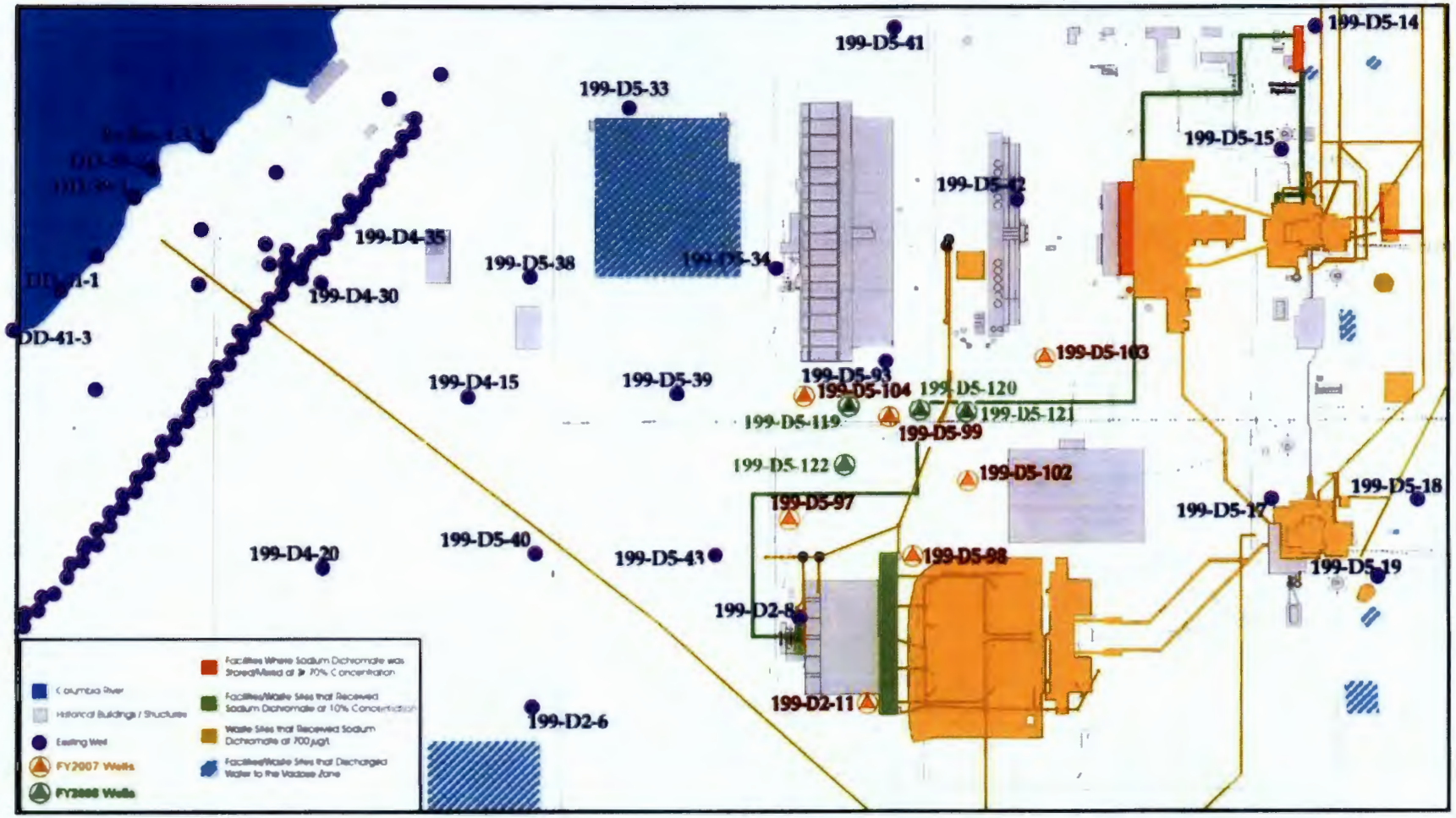
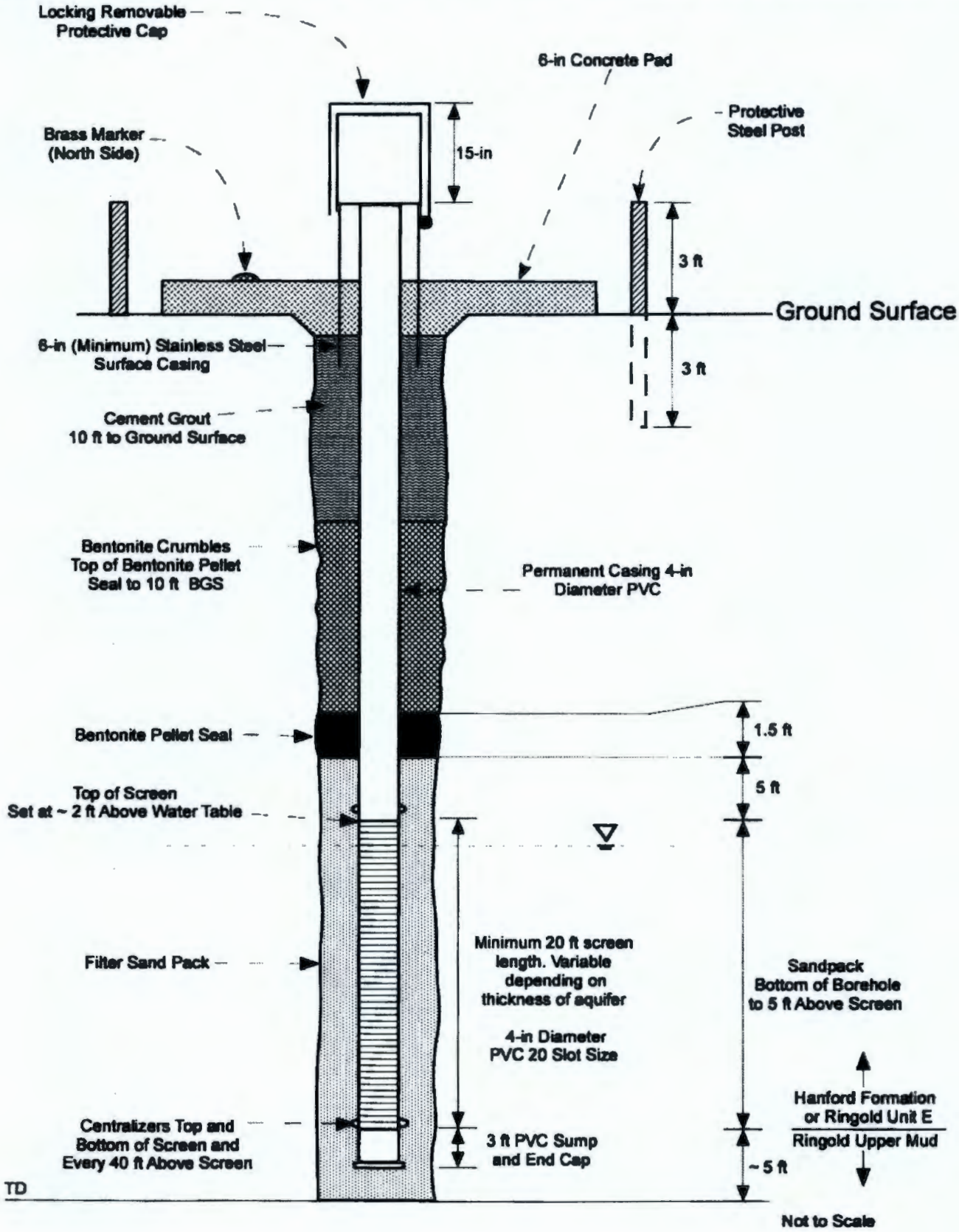


Table 2-1. Well Identification Numbers and Purpose.

Well Construction ID Number	Well Name	Well Completion Date	Rationale for Location
C5390	199-D5-97	2/21/2007	This well was placed in an area of high historic Cr(VI) concentration, downgradient of the railroad spur and upgradient of pipeline.
C5391	199-D5-98	2/27/2007	This well location was intended to define the upgradient extent of the chromium plume.
C5392	199-D5-99	2/28/2007	This well was placed in an area of high historic Cr(VI) concentration and to investigate the transfer station and nearby segment of pipeline.
C5394	199-D2-11	3/08/2007	This location was intended to define the southern extent of the plume near its apparent head.
C5398	199-D5-102	3/12/2007	This well was placed to constrain the upgradient extent of the plume.
C5399	199-D5-103	3/23/2007	This well is located to help constrain the upgradient extent of the plume.
C5400	199-D5-104	3/22/2007	This well was placed in an area of assumed high concentration, downgradient of transfer station and pipeline.
C5933	199-D-119	4/21/2008	This well location was selected to further define chromium concentrations along the principal plume axis.
C5934	199-D-120	3/25/2008	This location was intended to confirm or eliminate Cr(VI) in the vicinity of the "stained valve" as the primary source of chromium contamination. The choice of this location was predicated on the assumption that well 199-D5-99 is very near to the chromium source.
C5935	199-D-121	5/23/2008	This location was intended to eliminate (or confirm) a source further upgradient of the pipelines.
C5936	199-D-122	5/16/2008	This location is roughly equidistant from four existing wells and is over the railroad tracks that carried the sodium dichromate feed stock to the 100-D Area. The well will further define the southern extent of the plume and contribute needed water level data. It will also help to eliminate the southern length of the pipeline as a major primary source.

Cr(VI) = hexavalent chromium

Figure 2-2. Well Completion Design for the 100-D Area Chromium Source Investigation Wells.



The yellow to greenish-yellow staining that can be caused by hexavalent chromium contamination is distinctive and intense. Therefore, it was decided that if stained sediments were observed during drilling, cuttings from the entire stained interval would, if possible, be collected and submitted to Pacific Northwest National Laboratory (PNNL) for analysis of hexavalent chromium and additional characterization in conjunction with an ongoing PNNL project. However, no stained sediments were encountered during the drilling of any of the wells.

For the four wells drilled during FY2008, the sediment analysis program was significantly expanded (SGW-xxxxx, *Borehole Summary Report for the Installation of Chromium Source Investigation Wells in the 100-D Area, FY2008*). At all four wells, two one-pint samples were collected at 5-ft intervals, and one of each sample pair was submitted to a laboratory for determination of hexavalent chromium, total chromium, and heavy metals. One of the FY2008 wells, 199-D5-120, was drilled near a valve that exhibited external staining believed to be hexavalent chromium. The well was placed at this location to help confirm or eliminate the valve as the original source of the chromium contamination, and the sampling plan was further expanded to include several split-spoon samples in the both the vadose and saturated zones. Small amounts of hexavalent chromium (≤1.5 mg/kg) were detected in some sediment samples (see Section 3.1 and Appendix B), including samples from 199-D5-120, but there was no evidence of significant leakage from the suspect valve. The results of analysis of sediment samples are included in Appendix B.

2.2.2 Periodic Groundwater Sampling

Each of the 11 new wells was sampled upon successful well development. Subsequent purging and sampling was initially scheduled twice monthly. This schedule was relaxed to a schedule of monthly sampling in November 2007 to accommodate depth-discrete groundwater sampling of selected FY2007 wells, and in spring 2008 for depth-discrete sampling of FY2008 wells. For well 199-D5-120 additional groundwater samples were collected at 5-ft intervals during penetration of the saturated zone in a drill and test sequence. This was accomplished by installing a temporary well screen and purging at least three bore volumes of water at each sampling depth. Results of sample analysis are provided in Appendix B and discussed in Section 3.0.

2.2.3 Depth-Discrete Groundwater Sampling

In addition to the collection of pumped groundwater samples discussed above, nine of the wells in the project area were sampled at multiple depths to develop vertical profiles of hexavalent chromium concentrations. The results of analysis are included in Appendix B and are discussed in Section 3.0. The precautions and procedures for depth-discrete sampling can be found in Appendix C. Also, during drilling of well 199-D5-120, groundwater samples were collected at 5-ft intervals in a drill-and-test sequence. Results are also included in Appendix B and discussed in Section 3.0.

Table 2-2 has been included to summarize the details of the sediment and periodic groundwater sampling program.

Table 2-2. Sampling and Analysis Requirements.

Sample Interval	Sample Volume	Sample Container	Analytical Measurements	Organization Responsible for Analysis
Drill Cutting Samples				
Every 5 ft through the vadose and saturated zones, and at change in lithology, except where split spoon samples are collected.	Two pints per sample.	2 ea. one-pint jars, one jar to archive FY07 wells-one jar to Ecology FY08 wells – one jar to WCH	Cr(VI), Cr-total	FY07 wells – Ecology FY08 wells - WCH
Chromium-stained sediments.	Entire stained interval.	Not specified.	Not specified.	PNNL
Split-Spoon Samples				
For well 199-D5-120: Single 2-ft segment immediately above water table (i.e., in the capillary fringe).	As recovered using 2-ft split-spoon sampler.	Lexan® split-spoon liners, capped and sealed.	Cr(VI), Cr-total, ICP Metals, Hg, soil moisture	FH
For well 199-D5-120: Top 2 ft of the saturated zone.	As recovered using 2-ft split-spoon sampler.	Lexan® split-spoon liners, capped and sealed.	Cr(VI), Cr-total	FH
For well 199-D5-120: Vadose zone samples at 15-17, 20-22, 25-27, 40-42, 55-57, 65-67, 67-69, 69-71, and 71-73 ft bgs.	As recovered using 2-ft split-spoon sampler.	Lexan® split-spoon liners, capped and sealed.	Cr(VI), Cr-total, ICP Metals, Hg, soil moisture	Metals: WCH Soil Moisture: WCH
Additional saturated zone samples, to be collected at 5-ft intervals.	As recovered using 2-ft split-spoon sampler.	Lexan® split-spoon liners, capped and sealed.	Cr(VI), Cr-total	FH
Groundwater Samples				
(a) For well 199-D5-120: During well construction, collect water samples at 5-ft intervals through the saturated zone (drill and test). (b) Bi-weekly samples from completed wells.	Minimum 1.0 L.	Polyethylene or glass.	Field parameters plus analysis for hexavalent chromium	FH

bgs = below ground surface
Cr(VI) = hexavalent chromium
Cr-total = total chromium
Ecology = Washington State Department of Ecology
FH = Fluor Hanford
FY = fiscal year
ICP = inductively coupled plasma
Lexan® is a registered trademark of General Electric, Fairfield, Connecticut.
PNNL = Pacific Northwest National Laboratory
WCH = Washington Closure Hanford

2.3 WELL TESTING

Drawdown data collected during development were used to estimate the aquifer hydraulic conductivity for each of the 11 new wells. Results are presented in Section 3.2.

The seven FY2007 wells were developed using up to three cycles of pumping and recovery for a total pumping duration of approximately two hours. Surging the well in three cycles enhances well development, however, the use of short pumping periods hampers hydrologic interpretation of drawdown data. Therefore, well development of the FY2008 wells was done using a modified procedure. The modified development practice comprised two 10-minute pumping periods, each followed by a minimum of a 10-minute recovery period. These cycles were then followed by development pumping until (a) pumping was sustained for a minimum of two hours, and (b) the turbidity of the effluent was <5 nephelometric turbidity units in accordance with WAC 173-303 ("Dangerous Waste Regulations"). This procedure effectively removes fines from the upper part of the aquifer and increases the reliability of hydraulic conductivity estimates based on drawdown data, but it does not substantially increase the amount of groundwater to be removed from the well and collected as waste. In all cases, the pump was placed as deep as practical in the well.

2.4 WATER LEVEL MEASUREMENTS

Pressure transducers were installed in each of the seven FY2007 wells to monitor the fluctuation of water level on an hourly basis as part of the Hanford automated water level monitoring network. Water level monitoring of these wells was initiated in April 2007, and continues to the present day. The FY2008 wells were added to the automated network in summer 2008. Additional water level data are available from pre-existing wells in the project area that were already on the automated network. A list of these wells is presented in Table 2-3. The hydraulic head measurements were used for groundwater flow interpretation as discussed in Section 3.2.3. The 100-D Area river stage recorder supplied additional hydrologic information.

Transducer data obtained from the automated water level network the D River Gauge are maintained in the project file.

Table 2-3. Wells on the Automated Water Level Network. (2 sheets)

FY2007 Chromium Source Investigation Wells		
C5390 (199-D5-97)	C5394 (199-D2-11)	C5399 (199-D5-103)
C5391 (199-D5-98)	C5398 (199-D5-102)	C5400 (199-D5-104)
C5392 (199-D5-99)	--	--
FY2008 Chromium Source Investigation Wells*		
C5933 (199-D5-119)	C5934 (199-D5-120)	C5935 (199-D5-121)
C5936 (199-D5-122)	--	--

Table 2-3. Wells on the Automated Water Level Network. (2 sheets)

Pre-Existing Wells in the Automated Network		
199-D4-13	199-D4-38	199-D5-34
199-D4-19	199-D4-84	199-D5-36
199-D4-20	199-D4-85	199-D5-38
199-D4-21	199-D5-33	199-D5-43

*To be included in network summer 2008.
FY = fiscal year

3.0 DATA INTERPRETATION

The field program described in the previous section has provided a wealth of geochemical, geologic, and hydrologic data. As these data were acquired, it became increasingly clear that the distribution of hexavalent chromium in the groundwater is distinctly bimodal, where a high concentration zone is surrounded by a much larger low concentration zone. The difference in concentration between the two zones is more than an order of magnitude, and the concentration gradient between the zones is quite steep. In this section, the technical approaches used for data interpretation are described and are presented in a manner designed to support and illustrate the bimodal distribution of hexavalent chromium in the groundwater. In addition, an analysis of water level measurements suggests that the high concentration zone is virtually stagnant, which helps to explain the hydraulic persistence of the high concentration zone.

3.1 HEXAVALENT CHROMIUM DISTRIBUTION

The investigation of the distribution of hexavalent chromium contamination within the project area has involved surface and near-surface observation and sampling, analysis of drill cuttings and split-spoon samples collected during the construction of groundwater monitoring wells, and collection and analysis of groundwater samples.

Surface and near surface soil sampling has revealed localized spots of residual hexavalent chromium contamination but there has been no such contamination that appears to indicate an extensive spill of sodium dichromate. Recent excavations for environmental restoration by Washington Closure Hanford in the 100-D Area have revealed that a concentrated solution of sodium dichromate remained in some sections of buried pipeline (the pipeline has since been removed) and that a valve elsewhere in the line apparently leaked into the surrounding fill.

As discussed earlier, drill cuttings and split-spoon samples from wells constructed in FY2008 were analyzed for total and hexavalent chromium as well as for other metals that may be indicative of contamination. The total chromium concentrations were consistent with the Hanford background mineralogy range of 2.9 to 30.6 mg/kg based on 104 random samples collected from typical geologic media. However, additional samples from less common media contained as much as 320 mg/kg (DOE/RL-92-24, *Hanford Site Background: Part 1, Soil Background for Nonradioactive Analytes*). One sample from well 199-D5-120 (55 to 57 ft bgs) contained 54.4 mg/kg total chromium, but this occurrence may be natural. In most of the samples, hexavalent chromium concentrations were below the 0.2 mg/kg detection limit, although a total of twelve samples (from wells 199-D5-120, 199-D5-121, and 199-D5-122) exhibited traces of hexavalent chromium in concentrations ranging from 0.3 to 1.5 mg/kg. These three wells are within or near the area of greatest hexavalent chromium groundwater contamination, but the traces of hexavalent chromium found in overlying sediments clearly do not represent a significant reservoir of vadose zone contamination. Chemical data from the vadose zone samples are presented in Appendix B.

3.1.1 Groundwater Sampling and Analysis

In the year before this project began, the highest concentrations of hexavalent chromium measured in the project area groundwater were slightly less than 2 mg/L (e.g., see Figure 1-1).

However, results from the analysis of groundwater samples collected in March 2007, from newly constructed wells 199-D5-99 and 199-D5-104 showed concentrations of 12.56 and 6.84 mg/L, respectively. Groundwater samples from two wells constructed in FY2008, 199-D5-119 and 199-D5-122, showed similarly elevated concentrations of 5.01 and 22.4 mg/L, respectively. Hexavalent chromium concentrations in these four wells have remained significantly higher than in any other wells in this area.

Figure 3-1 depicts chromium concentrations measured in groundwater samples collected from the four high concentration wells since sampling began in February 2007. Note that the highest concentration measured to date is 39.9 mg/L from well 199-D5-99, but seven months earlier in that well, the concentration was less than 1 mg/L. Comparing Figure 3-1 to Figure 2-1, it is seen that during the calendar year June 2007 to June 2008, the peak observed concentration appears to have migrated from 199-D5-104 to 199-D5-99 to 199-D5-122.

Figure 3-1. Hexavalent Chromium in High-Concentration Wells.

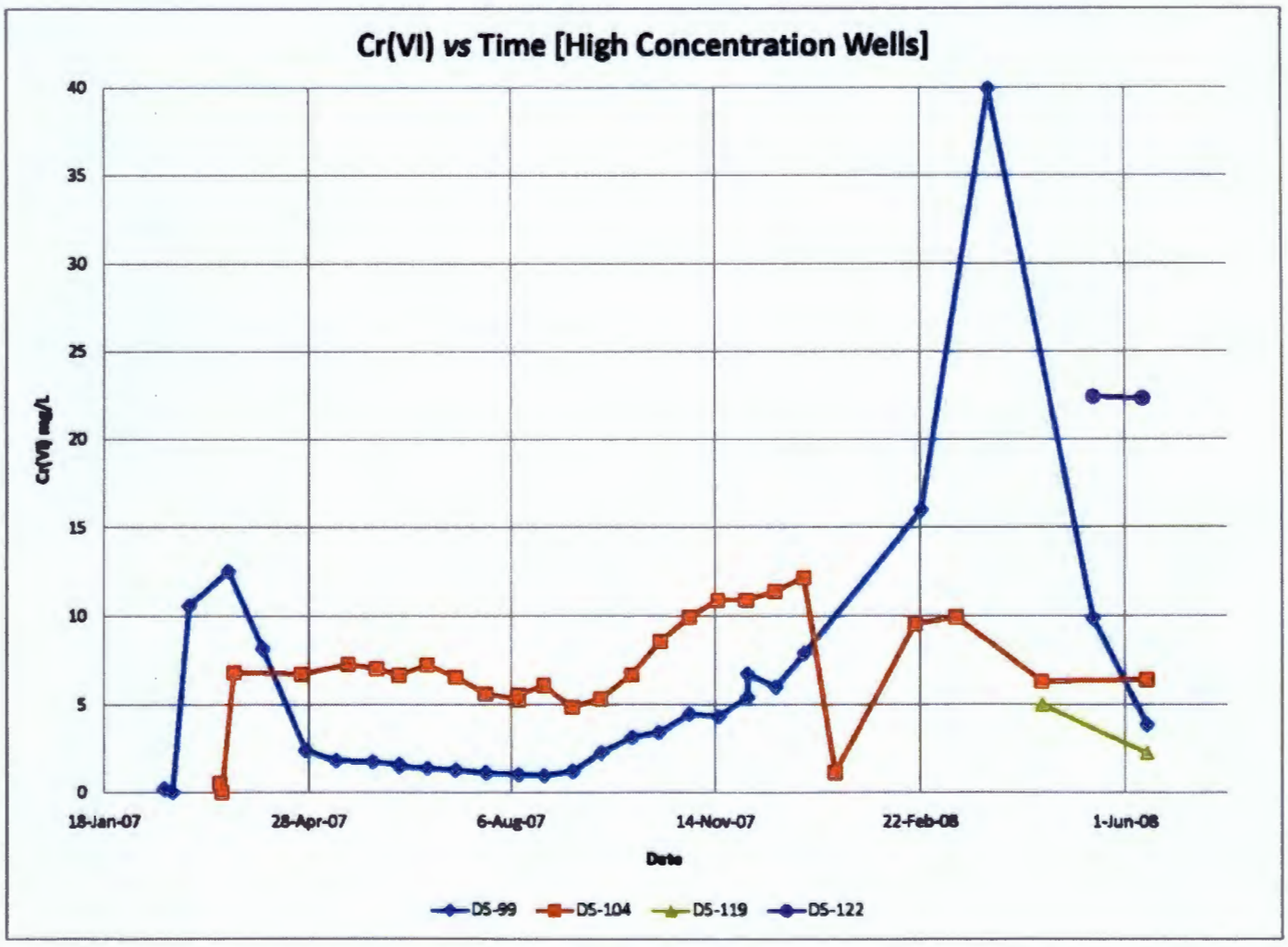


Figure 3-2 illustrates chromium concentrations measured in the seven low concentration wells not included in Figure 3-1.

Figure 3-2. Hexavalent Chromium in Low-Concentration Wells.

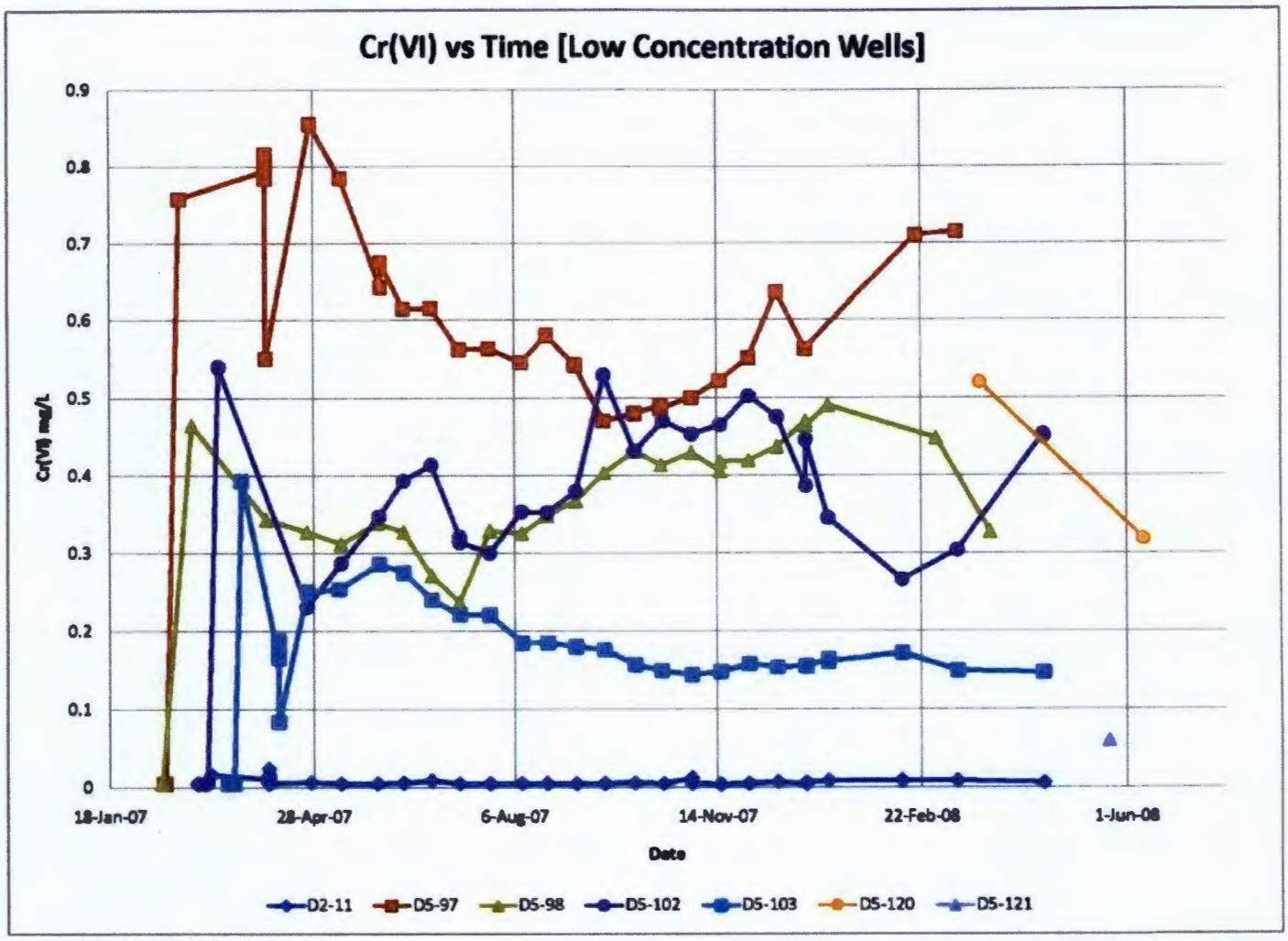


Figure 3-3 illustrates contoured hexavalent chromium concentrations for groundwater in mid-May, 2008. For added perspective, Figure 3-4 is a wireframe diagram representing the same mid-May chromium data. The contours and wireframe were created by kriging using an isotropic, linear variogram. Figures 3-3 and 3-4 clearly indicate a distinct bimodal distribution of hexavalent chromium, where a high concentration zone of contamination is differentiated from a widespread, surrounding zone of much lower concentration extending from the high concentration zone to the river.

Figure 3-3. Hexavalent Chromium Concentrations (May 16, 2008).

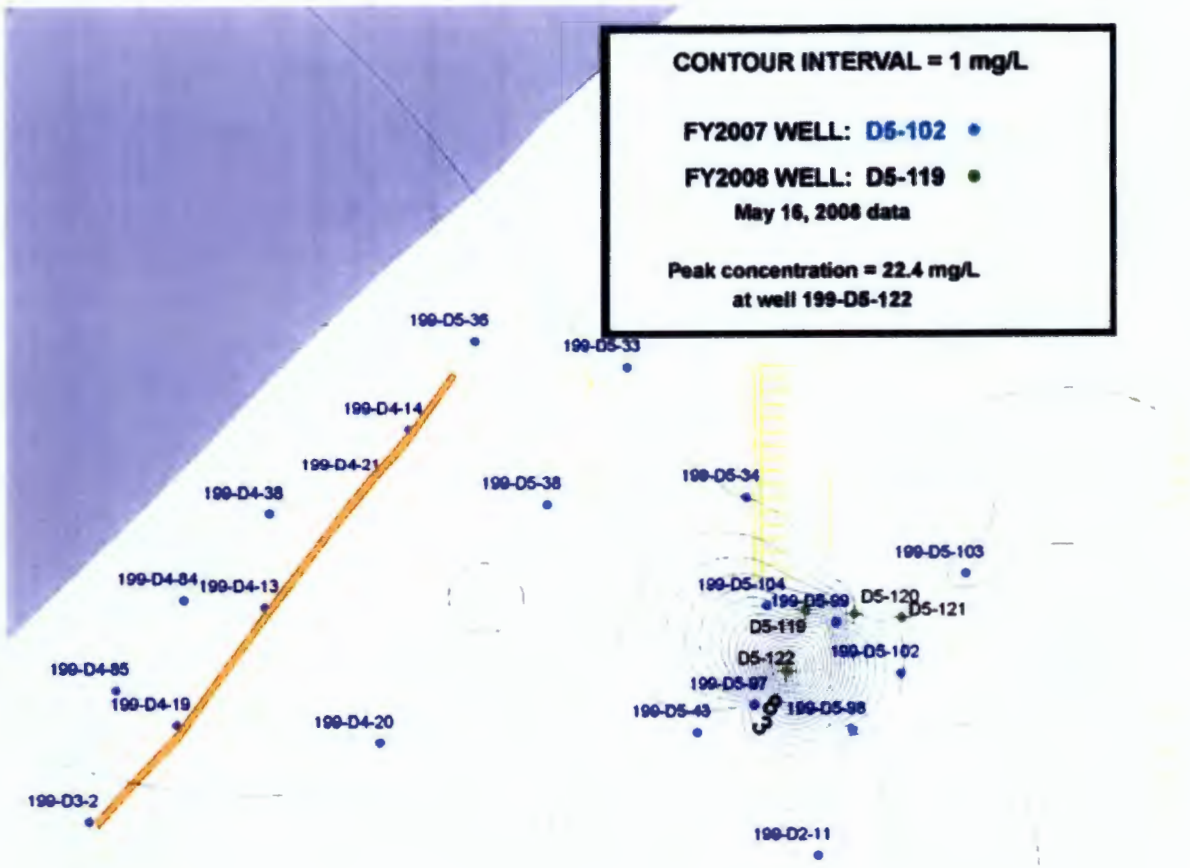
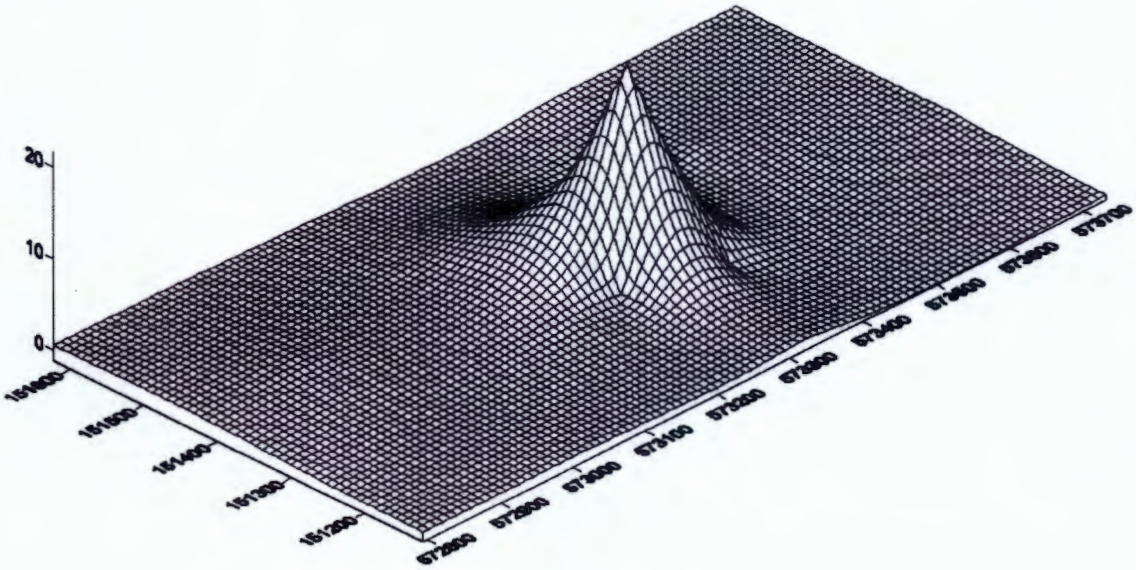


Figure 3-4. Wireframe Version of Figure 3-3.



3.1.2 Depth-Discrete Sampling

The qualitative hydrogeologic site model that was initially developed as a working hypothesis for the chromium source investigation was based on the facts that highly concentrated sodium dichromate solutions were routinely transported and handled within the project area, that the hexavalent chromium groundwater contaminant plume has been persistent since its discovery in 1999, and that an ensuing program of drilling and surface sampling has been unable to discover the source of the contamination.

The basis of the qualitative model that evolved is described as follows:

- The hexavalent chromium comes from a continuing vadose zone source.
- The source is highly concentrated.
- The source is localized, with a narrow wetted path from the surface to the water table, thus making it difficult to locate.
- It enters the aquifer at the top of the water column, is continually flushed downgradient by horizontal advection, and disperses horizontally and vertically.

With this simplified model, it was envisioned that near the point where the contamination enters the aquifer, the chromium would be found near the top of the water column. As the contamination migrates downgradient, vertical dispersion would spread the chromium downward, which would eventually become evenly distributed vertically.

Thus, a limited program of depth-discrete groundwater sampling and analysis was designed and executed to test the model and to determine if the vertical distribution of hexavalent chromium might be used to estimate how near the wells might be to the assumed vadose zone source. Depth-discrete sampling was conducted in April 2007 and March and June 2008.

The April 2007 sampling was performed at 2-ft intervals using a Kabis sampler. The results of hexavalent chromium analysis revealed even vertical contaminant distribution. However, the representativeness of results was questioned because the volume of water displaced by the sampler and the volume of water collected from each depth interval was deemed significant in a four-inch diameter well bore.

The sampling performed in 2008 used a low-volume sampler designed to minimize errors caused by water volume displacement and removal. Results of the 2008 depth-discrete sampling events are presented in Figures 3-5 and 3-6. Appendix C describes the low-volume apparatus and procedures used for the 2008 sampling campaign and presents the field logs.

During the construction of well 199-D5-120 in March 2008, groundwater samples were collected in a drill-and-test sequence as drilling progressed through the saturated zone (SGW-xxxxx). Results were similar to those obtained for this well in June 2008 (Figure 3-6).

Analytical results for depth-discrete groundwater sampling in both 2007 and 2008 are included in Appendix B.

Figure 3-5. Concentration Profiles of Hexavalent Chromium for Wells Sampled in March 2008.

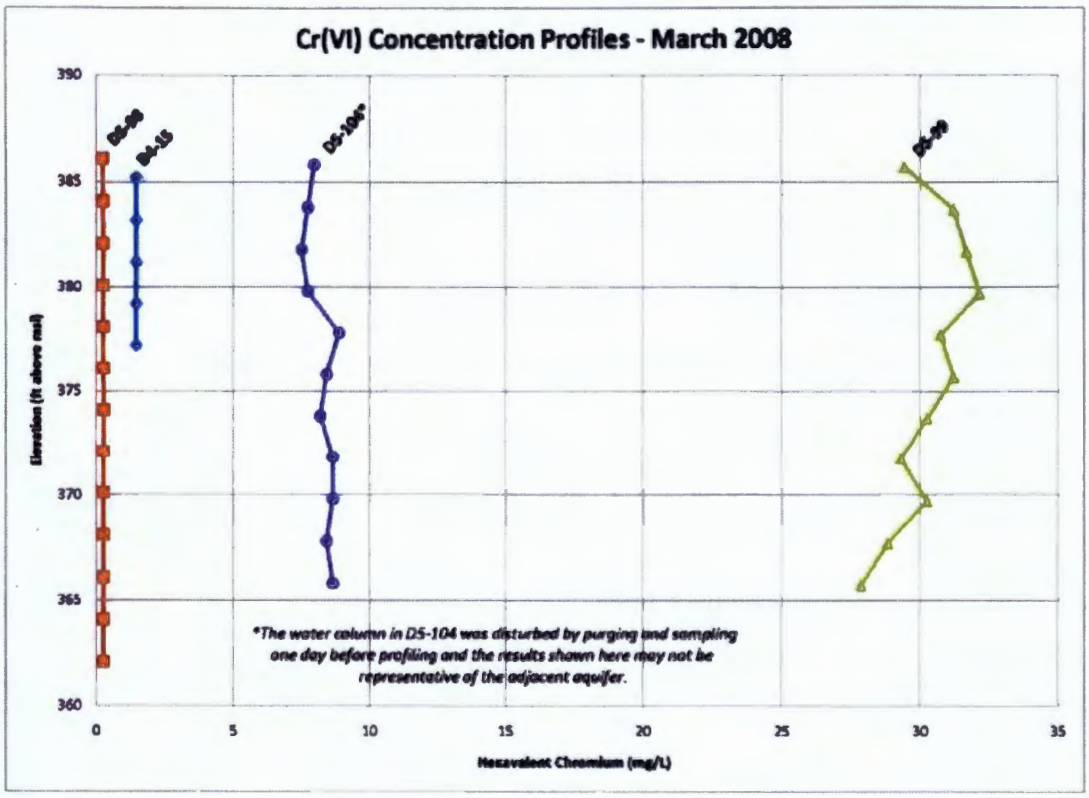
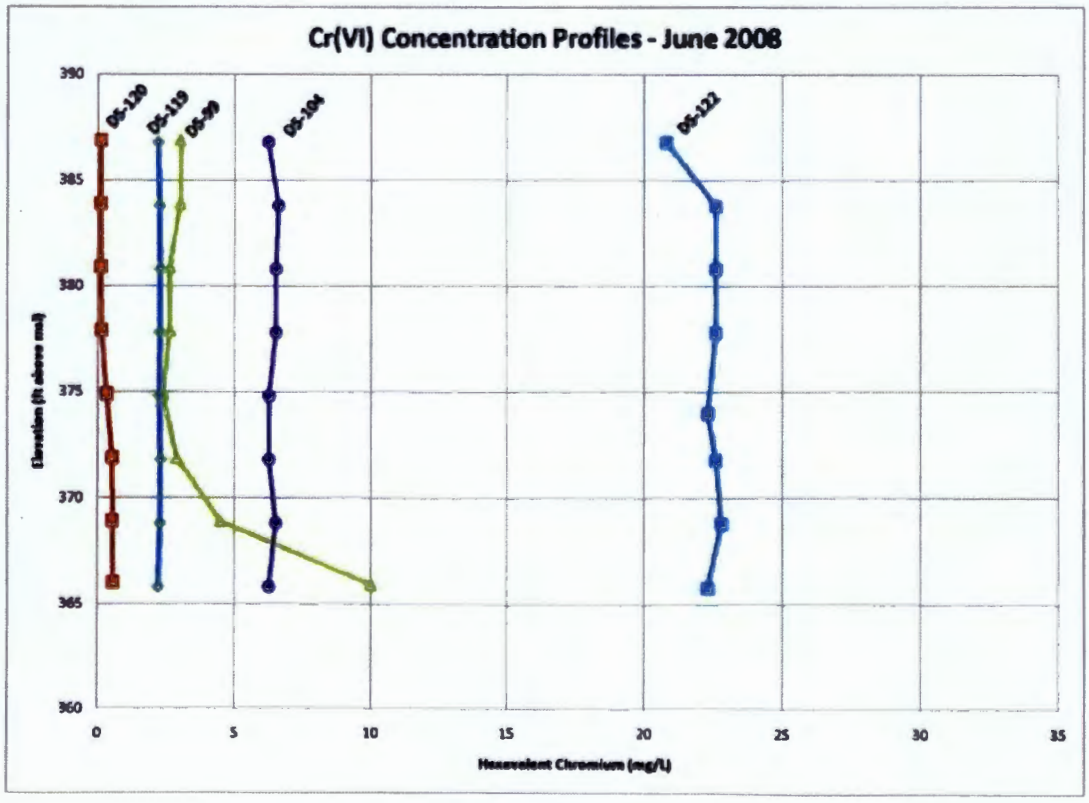


Figure 3-6. Concentration Profiles of Hexavalent Chromium for Wells Sampled in June 2008.



It is apparent from Figures 3-5 and 3-6 that the hexavalent chromium is not significantly more concentrated near the top of the water column in high concentration wells that are presumably near the vadose zone source. To the contrary, the data indicate substantially complete vertical dispersion regardless of location, and the June 2008 data from wells 199-D5-99 and 199-D5-120 actually show increased concentration with depth. These observations are not consistent with the original qualitative model described above.

In the earlier April 2007 program of depth-discrete sampling, analysis included measurement of nitrate as well as of hexavalent chromium. Nitrate is widespread in the unconfined aquifer in the northern Hanford site, and it was measured in depth-discrete samples to help determine if any observed geochemical stratification of the chromium might be due to admixture with a separate fresh water source, rather than to vertical dispersion. Nitrate measurement was discontinued for the depth-discrete sampling conducted in 2008 because results from the 2007 sampling showed no evidence of significant vertical chromium stratification and because the apparent precision of the nitrate measurement was poor compared to that of the chromium.

3.1.3 Statistical Method for Chrome Source Location

Original project planning provided for statistical analysis of hexavalent chromium concentrations in the groundwater to extrapolate the most probable location for the highest hexavalent chromium concentrations in the groundwater, i.e., for the head of the contaminant plume. The statistical method was chosen because of the significant seasonal variability of the plume configuration (DOE/RL-2006-74). However, given the discovery of the high concentrations of hexavalent chromium in closely spaced wells (e.g., see Figure 3-3) it was recognized that the results of statistical analysis would only reflect the results already achieved through direct observation. Therefore, the statistical approach was abandoned.

3.2 QUALITY ASSURANCE/QUALITY CONTROL

Data quality was evaluated based on the requirements listed in the Sampling and Analysis Plan (Appendix A, DOE/RL 2006-74). Soil and groundwater data were reviewed to confirm that sampling and chain-of-custody documentation were complete, sample numbers correlated to the correct sampling location, and that holding times were met.

The quality of the soil and groundwater analyses were verified by evaluating laboratory data for accuracy and precision, and split samples of groundwater were periodically analyzed at separate laboratories as a check on the primary laboratory. The QA/QC data for all the samples is summarized below.

3.2.1 Soil Analyses

Hexavalent and total chromium in soil samples were analyzed in fixed laboratories according to EPA protocol. Hexavalent chromium was detected in only eleven of the 109 soil samples collected. Thirty-four matrix spikes (a measure of accuracy) were performed for hexavalent chromium samples, with an average recovery of 91.0% and a standard deviation of 9.2. For total chromium, the average matrix spike recovery was 85.0%, with standard deviation of 30.0. The average relative percent difference (RPD; a measure of precision) for hexavalent chromium

matrix spike duplicates was 10.4, with a standard deviation of 9.9. For total chromium, the RPD averaged 21.4, with a standard deviation of 28.5. These values fall within the required precision of 70 – 130% precision and 30% accuracy, as stated in the Sampling and Analysis Plan (Appendix A, DOE/RL 2006-74).

3.2.2 Groundwater Analyses

Groundwater samples were analyzed at Hanford's onsite laboratory, the Waste Sampling and Characterization Facility. A total of 333 samples were analyzed during the period discussed in this report. The average matrix spike recovery was 98.7%, with an RPD of 5.3. The average RPD for matrix spike duplicates was 5.3.

Splits of seventeen of the groundwater samples were submitted to an offsite laboratory. Evaluation of these data shows that, for the 14 samples containing hexavalent chromium significantly above the detection limit (approximately 5 ug/L), the relative percent difference (RPD) is 4.5. This is well within the required 30% precision (Appendix A, DOE/RL 2006-74). The standard deviation for this subset of split samples was 6.28.

3.3 HYDROGEOLOGY

Hydraulic data collected during the project include hourly water level measurements and drawdown measurements made during the development of new wells drilled in FY2007 and FY2008.

In addition, it was originally envisioned that geochemical tracer tests, using bromide as a tracer and *in situ* measurement of the bromide as a function of both depth and time, would be used to interrogate the distribution of hydraulic conductivity with depth in the unconfined aquifer and to provide a reliable estimate of mass groundwater flux at selected wells. However, the unexpectedly high hexavalent chromium concentrations measured in the wells of greatest interest would have presented a direct chemical interference to the bromide-sensing probe. Therefore, the tracer tests were not performed.

3.3.1 Hydraulic Conductivity

Drawdown data from well development were used to estimate local aquifer hydraulic conductivity, k, from well transmissivities, T, calculated using the following relationships (Cooper and Jacob 1946):

$$T = {}^{264Q}/_{\Delta s}$$

and

$$k = {}^{T}/_{7.48b}$$

Where T = transmissivity in gpd/ft, Q = pumping rate in gpm, Δs is the slope of the straight-line portion of a plot of drawdown *versus* $\log_{10}$(time) expressed as the change in drawdown (ft) from time t to time $10t$, k = hydraulic conductivity in ft/d, and b = aquifer thickness (ft).

Table 3-1 lists the hydraulic conductivity estimates for the wells constructed under this project. The mean of the estimated hydraulic conductivities is 157 ft/d.

Note that the drawdown data collected during well development represent individual short-term, single-well pumping tests. The results of such tests are often difficult to evaluate, and in any case are representative of the aquifer only in the immediate vicinity of the pumped well. The time-drawdown data are expected to have been affected by borehole storage and/or delayed yield, so the Δs terms were evaluated based on best available late-time data, and the hydraulic conductivities shown in Table 3-1 are best interpreted as upper bounding values. Nevertheless, the results are useful for estimating groundwater flow and for evaluating remedial alternatives such as pump-and-treat.

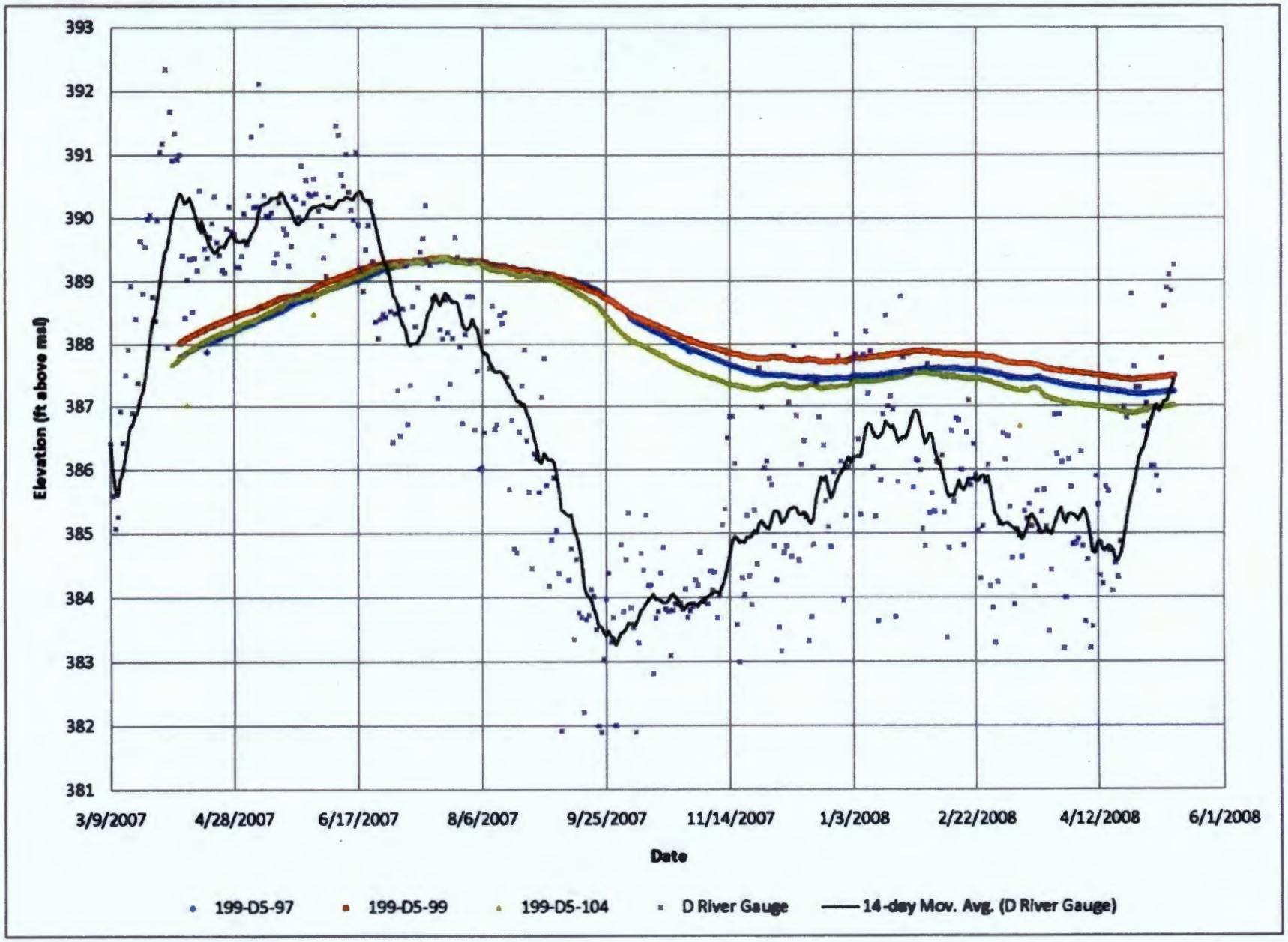
3.3.2 Hydraulic Gradients

The water levels in 100-D Area wells are strongly affected by river stage. By way of example, Figure 3-7 illustrates river stage and water levels for the period from March 2007 to May 2008 at three wells located in the immediate vicinity of the high concentration hexavalent chromium plume. Inspection of the figure shows that water levels at the wells, which are approximately 700 m inland from the river, are affected by seasonal variations in river stage, but with a response that lags river levels by several weeks. Also, the relative separation of the well hydrographs shown in the figure clearly shows that hydraulic gradient in the vicinity of the wells was greater following low river stage than following high river stage. For example, in mid-July 2007, the well water levels are seen to be relatively high in response to high river stage. The well water levels are also virtually identical so the local gradient is extremely shallow (calculated local gradient on July 9 was 0.00006). In contrast, water levels in the river and the wells were significantly lower from about September 2007 to May 2008, and the calculated gradient ranged during this period from 0.0012 to 0.0019, with flow towards the Columbia River.

Table 3-1. Single-Well Estimates of Hydraulic Conductivity.

Well	Date Developed	Saturated Thickness (ft)	Pumping Rate (gpm)	Δs (ft/log cycle)	Pumping Duration (min)	Maximum Drawdown (ft)	Δs (ft/log cycle)	Transmissivity T (ft^2/d)	Estimated k (ft/d)
199-D2-11	3/8/07	27.8	9.7	0.060	60	1.82	0.060	5700	205
199-D5-97	2/21/07	25.82	12.5	0.108	75	1.34	0.108	4080	158
199-D5-98	2/27/07	27.44	9.0	0.0685	56	1.92	0.0685	4640	169
199-D5-99	2/28/08	25.85	9.6	0.142	94	1.03	0.142	2380	92
199-D5-102	3/12/07	23.19	10.1	0.065	47	1.90	0.065	5500	237
199-D5-103	3/23/07	27.97	9.7	0.121	57	1.41	0.121	2820	101
199-D5-104	3/22/07	25.92	9.9	0.057	50	1.82	0.057	6120	236
199-D5-119	4/21/08	27.46	13	0.107	71	2.02	0.107	4280	156
199-D5-120	3/21/08	25.25	23	0.1815	119	2.77	0.1815	4470	177
199-D5-121	5/23/08	24.47	13	0.674	156	6.03	0.674	685	28
199-D5-122	5/15/08	23.63	12.5	0.112	141	1.70	0.112	3950	167

Figure 3-7. River Stage Versus Water Table Elevation for Three Wells.



3.3.3 Groundwater Flow

A comprehensive analysis of water level data and resultant flow vectors used mean daily water levels from 100-D Area wells of the Hanford Site automated water level network, the 100-D Area river stage recorder, and injection and extraction data for wells used in 100-D Area pump-and-treat and the electrocoagulation pilot plant (see Figure 2-1 for location of injection wells 199-D5-33 and 199-D5-42 and extraction wells 199-D5-39 and 199-D5-41). The analysis used universal kriging combined with analytical elements to approximate the effect of river stage and of injection and extraction at wells. A water level map was prepared for each day from April 17, 2007 to March 10, 2008. Further description of this analysis is included as Appendix D. The water level data are available in the project files.

The analysis presented in Appendix D highlights two important points. The first of these points is that the predominant direction of groundwater transport is generally northwest towards the river from the area of highest chromium contamination, which is consistent with the observed attitude of the extended hexavalent chromium plume. However, during high river stage the flow direction is temporarily reversed.

The second important point involves the results of a particle-tracking simulation set at the high concentration plume. In the simulation, a hypothetical particle was inserted in the aquifer near 199-D5-104. The drift period was from April 12, 2007 to March 10, 2008 (333 days). The resulting track was a skewed loop whose flow vector moved through approximately 360°, with a net movement of approximately 40 ft toward the river. An illustration of the particle track can be seen in Appendix D, Figure D4-1.

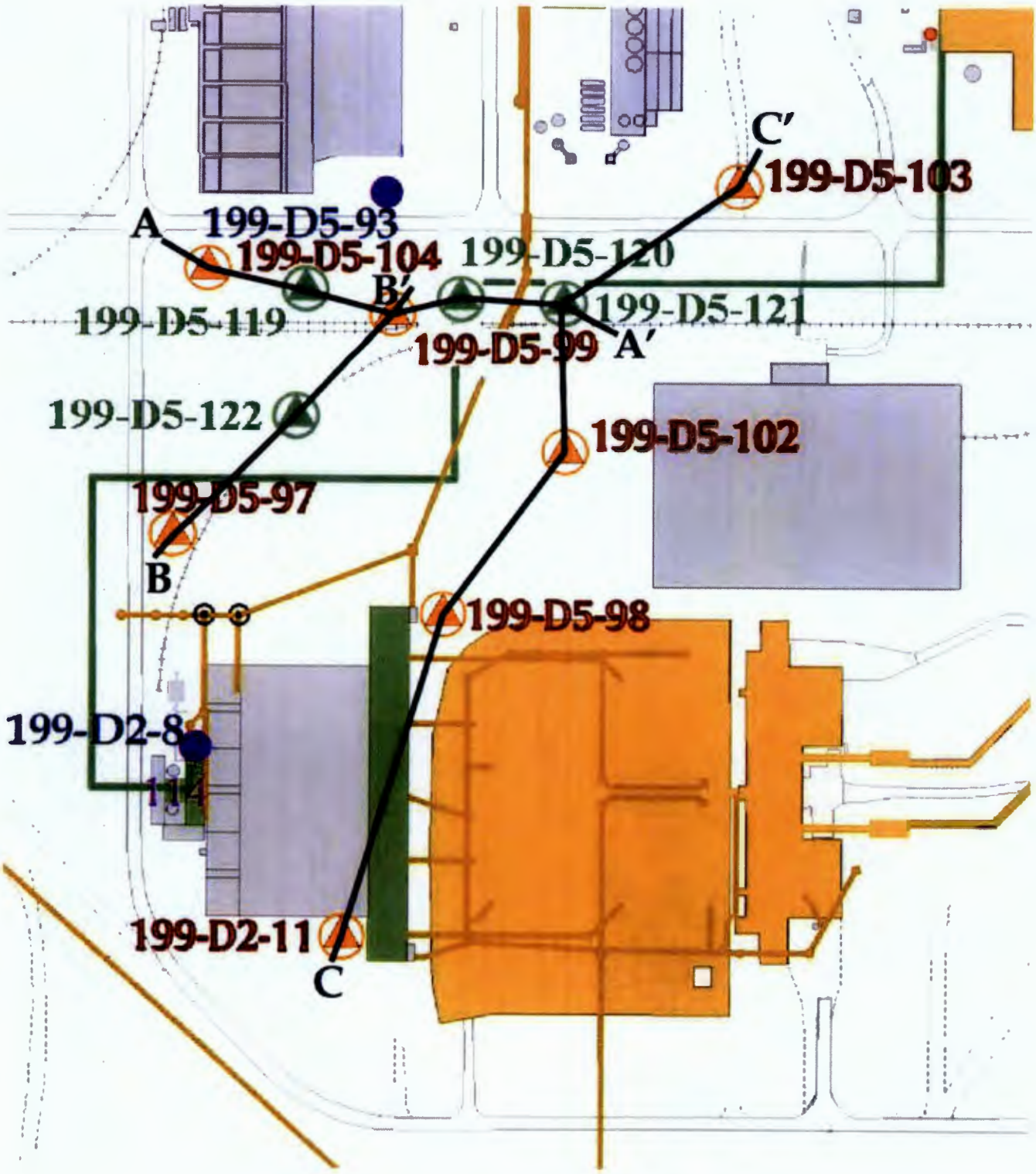
The inference that may be drawn from the particle track simulation is that flow vectors calculated over the "test year" using gradients calculated from observed water levels and assumed porosity and conductivity reflect little net movement of the groundwater towards the river.

3.4 GEOLOGY

The investigation has focused on the uppermost unconfined aquifer, which in the area of interest lies wholly within the Ringold Formation (Unit E). The aquifer is less than 30 ft thick, and its base is the Ringold Upper Mud.

Well construction and lithologic information is included in the well summary sheets shown in Appendix A. The stratigraphic interpretation based on field lithologic observations and water level measurements is reflected in the following cross sections. Figure 3-8 is the location map for the cross sections shown in Figures 3-9, 3-10, and 3-11. The cross-section C-C' shows conductive sand strata in the saturated zone both north and south of well 199-D5-121, which has low hydraulic conductivity compared to the other wells in the project area (see Table 3-1). Net annual groundwater flow is from the east towards the river, so well 199-D5-121 is considered upgradient, from the high concentration zone. Thus, the cross-section is consistent with possible preferential flow around the high concentration zone, because the path(s) of least flow resistance appear to be the sands to the north and south of 199-D5-121.

Figure 3-8. Location Map for Fence Diagrams.



This page intentionally left blank.

Figure 3-9. Cross-section A-A'.

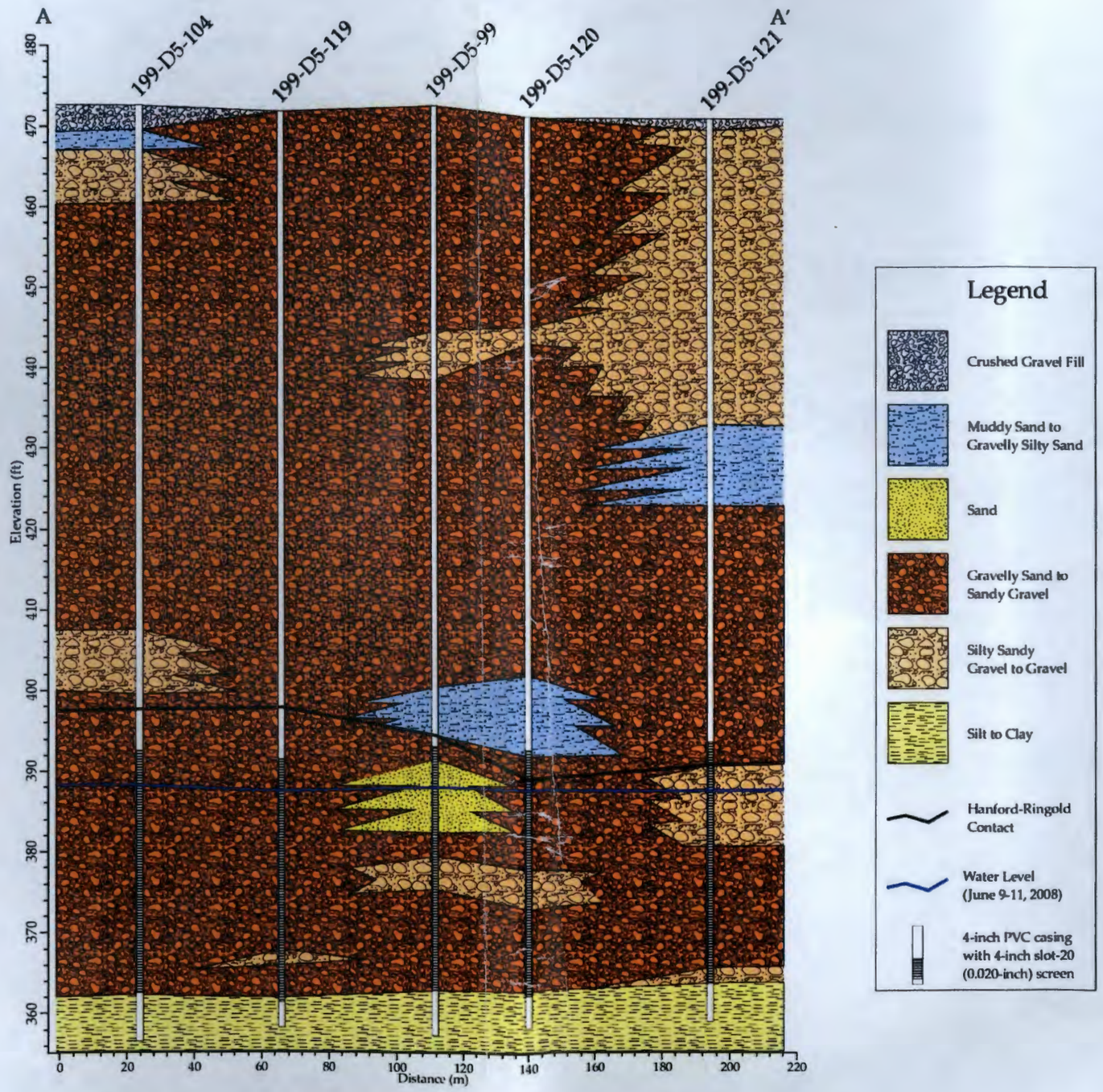


Figure 3-10. Cross-section B-B'.

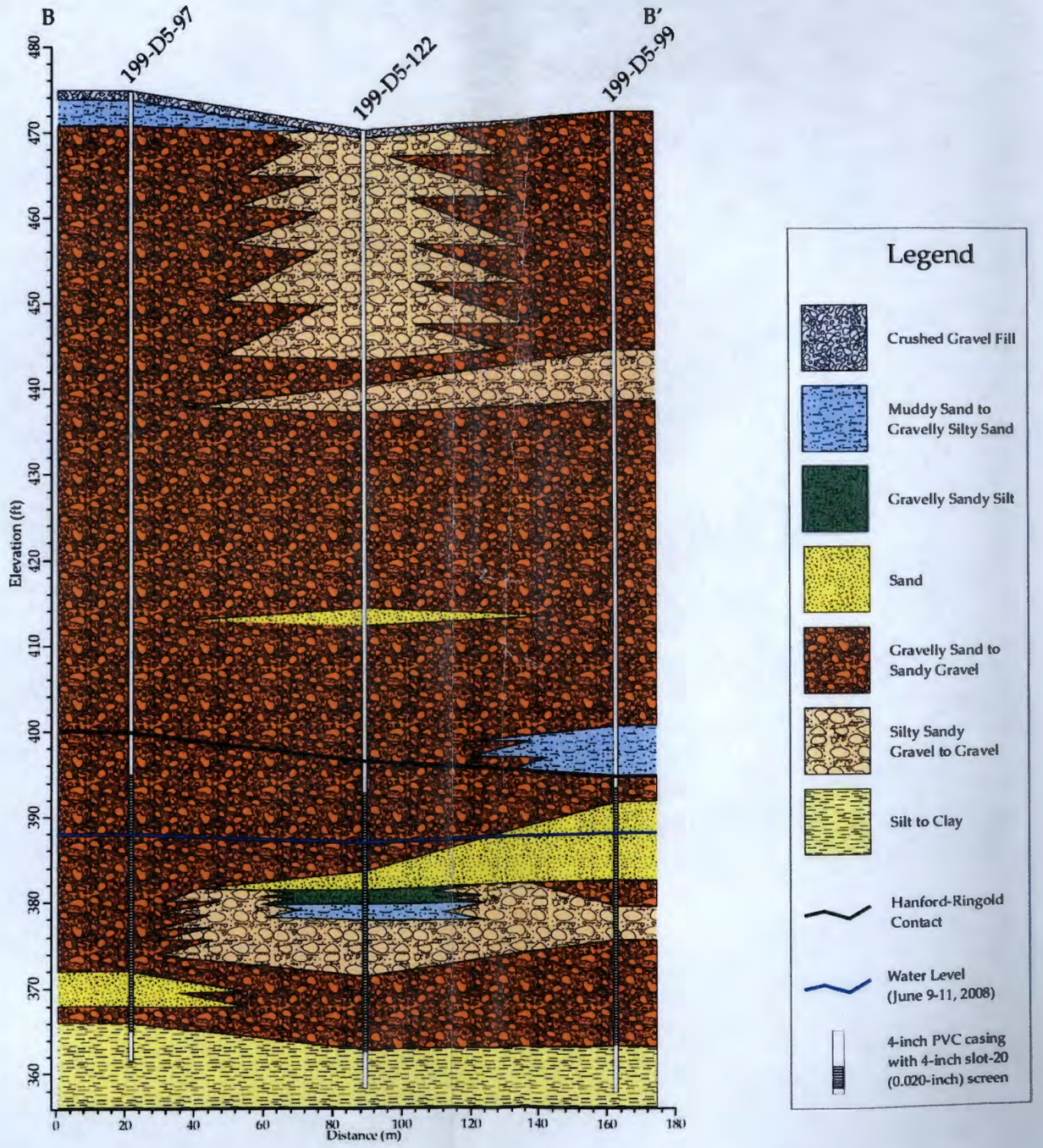
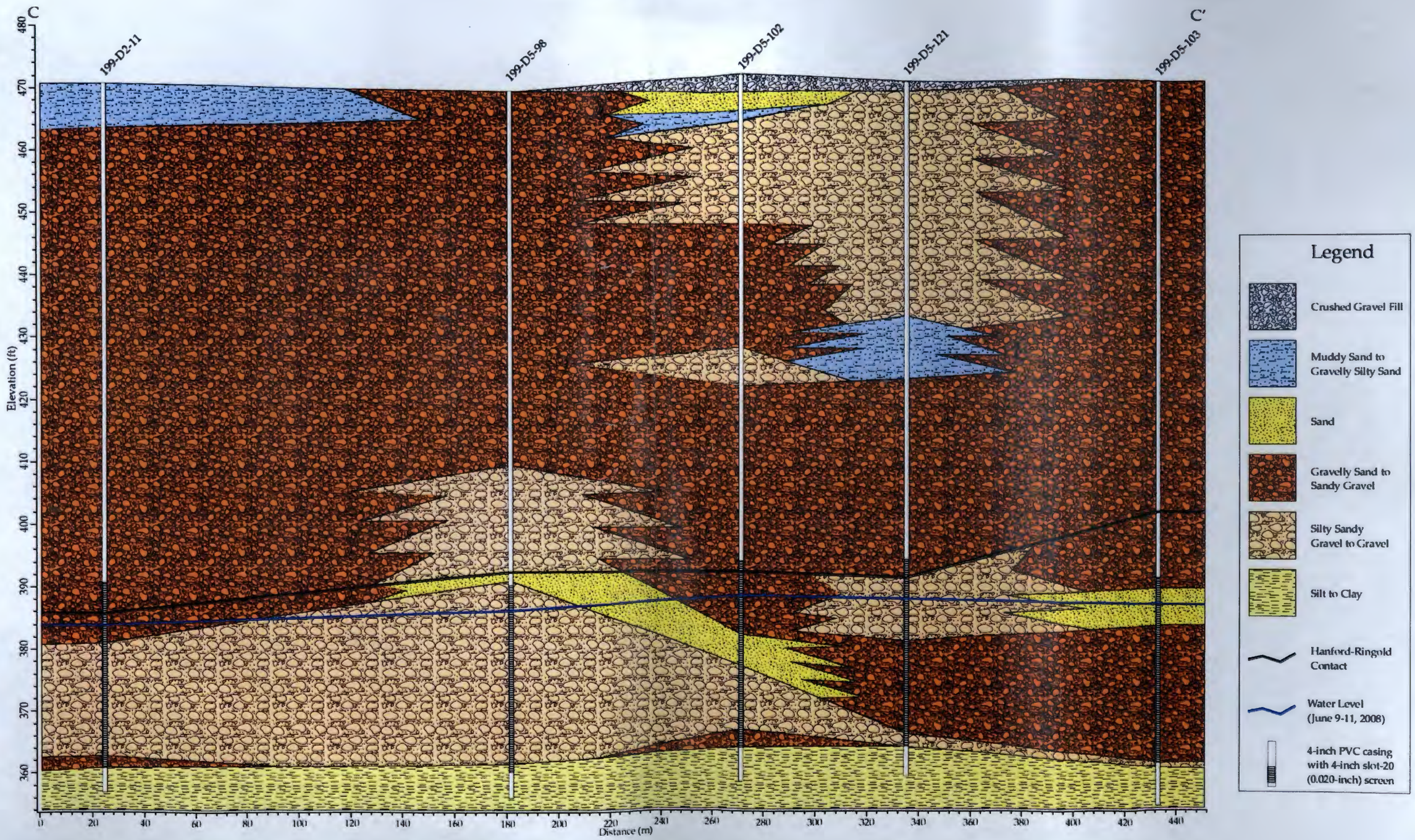


Figure 3-11. Cross-section C-C'.



4.0 CONCLUSIONS

The principal objective of this investigation has been to locate the source of hexavalent chromium in the southwestern contaminant plume of the 100-D Area. Surface sampling, excavations, and drilling have been, and have remained, ineffective for locating any reservoir within, or contaminated pathway through, the vadose zone. While evidence of minor leaks or spills has been discovered within a few meters of ground surface, no evidence of a major release has persisted. Thus, the surface origin of the hexavalent chromium remains unknown.

Because of the difficulty in locating a chromium source above the water table, the initial qualitative site model of the contamination assumed an active, highly localized and highly concentrated vadose zone source. Contamination entering the unconfined aquifer was assumed to continually migrate downgradient and disperse via horizontal advection.

Instead, field data gleaned from 11 new wells reveals a distinctly bimodal distribution of hexavalent chromium in the unconfined aquifer, where a sharply defined and relatively concentrated zone of contamination lies at the head of an extended zone of lower concentration in the form of a plume migrating towards the Columbia River. Note that the peak measured concentration in the high concentration zone is on the order of 20 times higher than peak concentrations observed in the extended low concentration zone. The high concentration zone displays several important characteristics:

- Analysis of groundwater samples shows that the peak measured concentration has moved, and has been found at various times in wells 199-D5-104, 199-D5-99, and 199-D5-122. This repetitive pattern is consistent with the particle-tracking simulation which indicated circular movement driven by seasonal variation and reversal of hydraulic gradients, but with very little net downgradient movement (see Appendix D).
- The repetitive circulation of the high concentration zone, over time, is consistent with the movement required to fully develop vertical dispersion and with the observed nearly homogeneous vertical distribution of chromium in the water column of the peak concentration wells. That is, dispersion, vertical as well as horizontal, requires that the groundwater move. If the high concentration zone were completely stagnant, dispersion could not occur.
- The low hydraulic conductivity (28 ft/d) estimated for well 199-D5-121, which is east of the source plume, suggests that there may be zones of low conductivity causing preferential flow that bypasses the high concentration zone. This may be a contributing factor to the apparent stagnation of the high concentration zone.
- The highest concentration measured to date (nearly 40 mg/L) was found in 199-D5-99.

The above plume characteristics have been considered in developing a revised hydrogeologic site model having the following characteristics.

- The annual hydraulic cycle and probable preferential flow paths combine to restrict the mobility of the groundwater within the zone of highest hexavalent chromium concentration. The extended downgradient low concentration zone is envisioned as being fed by solute dispersion at the margins of the relatively immobile high concentration zone.

- An order-of-magnitude estimate of the mass of hexavalent chromium within the source plume has been made by approximating the dimensions of the plume as a cylinder within the aquifer 25 ft deep, and having the wells 199-D5-104, 199-D5-99, and 199-D5-122 on the circumference. Porosity within the cylinder is taken as 8%, and the mean concentration of the chromium in the water is assumed to be 40 mg/L. The result is an estimate of 170 kg of hexavalent chromium in 4 million liters of groundwater.
- The field data collected to date do not reveal if there is still a significant or active contaminant reservoir in the vadose zone, nor do the data reveal the surface or near-surface location of an original leak or spill of sodium dichromate. Concentration data suggest that the three wells noted above, along with well 199-D5-119, represent the margins of the high concentration zone. It is reasonable to conclude that these four wells effectively constrain the location where hexavalent chromium entered or continues to enter the aquifer at the water table. The three wells are easily circumscribed by a one-hectare circle.

5.0 REFERENCES

BHI-01747, 2004, *Results of Hexavalent Chromium Sampling Near 100-D Area Sodium Dichromate Transfer Station Railroad Track*, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Cooper, H. H., Jr and C. E. Jacob, 1946, *A Generalized Graphical Method for Evaluating Formation Constants and Summarizing Well Field History,* Trans. Am. Geophysical Union, Vol. 27, pp. 524-526, Washington.

DOE/RL-92-24, 2001, *Hanford Site Background: Part 1, Soil Background for Nonradioactive Analytes,* Vol. 1, Rev. 4, U. S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2006-74, 2007, *Field Investigation Plan for the Southwestern Chromium Plume in the 100-D Area*, Rev. 0, U. S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2008-28, *Drilling Four New chromium Source Investigation Wells in the 100-D Area,* Rev. 0, U. S. Department of Energy, Richland Operations Office, Richland, Washington.

PNNL-15670, 2006, *Hanford Site Groundwater Monitoring for Fiscal Year 2005,* Pacific Northwest National Laboratory, Richland, Washington.

SGW-33472, 2007, *Borehole Summary Report for the Installation of Chromium Source Investigation Wells in the 100-D Area, FY2007,* Rev. 0, Fluor Hanford, Inc., Richland, Washington.

SGW-39028, 2008, *Borehole Summary Report for the Installation of Chromium Source Investigation Wells in the 100-D Area, FY2008,* Rev. 0, Fluor Hanford, Inc., Richland, Washington.

WAC 173-303, "Dangerous Waste Regulations," *Washington Administrative Code,* as amended, Washington State Department of Ecology, Olympia, WA.

This page intentionally left blank.

APPENDIX A

WELL SUMMARY SHEETS

This page intentionally left blank.

APPENDIX A

WELL SUMMARY SHEETS

199-D2-11

199-D5-97

199-D5-98

199-D5-99

199-D5-102

199-D5-103

199-D5-104

199-D5-119

199-D5-120

199-D5-121

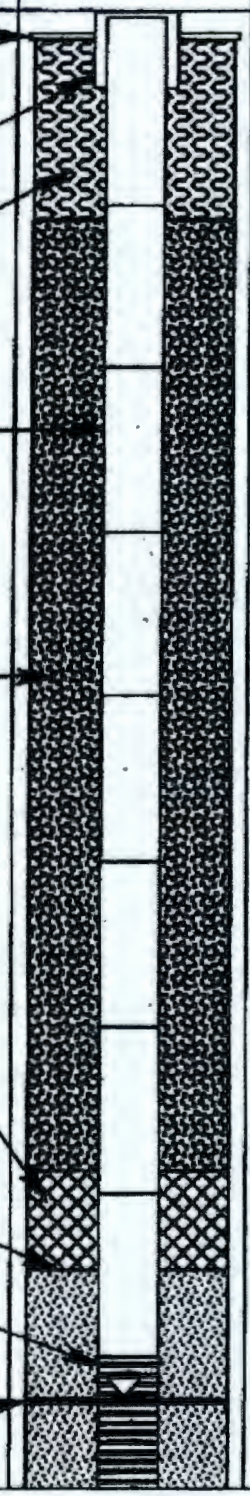
199-D5-122

WELL SUMMARY SHEET	Start Date: 02/28/07 Finish Date: 03/08/07	Page 1 of 2

Well ID: C5394	Well Name: 199-D2-11
Location: Approximately 525 meters Southwest of 105-DR	Project: CSI Wells at 100-D Area
Prepared By: Erika Rincon — Date: 3/21/07	Reviewed By: L.D. Walker — Date: 3/26/07
Signature: Erika R	Signature: LD Walker

CONSTRUCTION DATA

Description	Diagram
6-in Concrete Pad	
6-in I.D. Type 304/304L Stainless Steel Protective Casing: +3.0 ft ags	
Portland Cement Type I/II: 0 - 11.3 ft	
4-in I.D. Polyvinyl Chloride (PVC) Casing: +2.0 - 80.1 ft	
Granular Bentonite Crumbles: 11.3 - 68.5 ft	
3/8-in Bentonite Pellets: 68.5 - 74.7 ft	
Primary Filter Pack 10-20 Mesh Colorado Silica Sand: 74.7 - 114.0 ft	
4-in I.D. Polyvinyl Chloride (PVC), 20 Slot (0.020-in) Screen: 80.1 - 110.1 ft	
Static Water Level: 82.60 ft bgs (03-02-2007)	

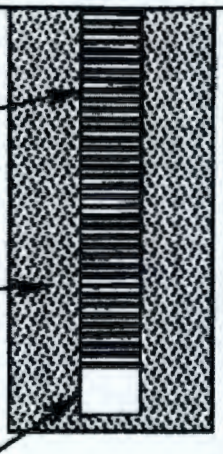


GEOLOGIC/HYDROLOGIC DATA

Depth in Feet	Graphic Log	Lithologic Description/Groundwater Sample Depths (ft bgs)
0		0-3 Gravelly Silty Sand; gmS
		3-7 Silty Sand; mS
		7-15 Sandy Gravel; sG
10		
		15-25 Gravelly Sand; gS
20		
		25-35 Sandy Gravel; sG
30		
		35-37 Gravelly Sand; gS
		37-45 Sandy Gravel; sG
40		
		45-79 Gravelly Sand; gS
50		
60		
70		
		79-90 Sandy Gravel; sG
80		
		84 Water Sample: HEIS B1MCP1

WELL SUMMARY SHEET	Start Date: 02/28/07 Finish Date: 03/08/07	Page 2 of 2
Well ID: C5394	Well Name: 199-D2-11	
Location: Approximately 525 meters Southwest of 105-DR	Project: CSI Wells at 100-D Area	
Prepared By: Erika Rincon — Date: 3/21/07	Reviewed By: L. D. Walker — Date: 3/26/07	
Signature: Erika	Signature: LD Walker	

CONSTRUCTION DATA

Description	Diagram
4-in I.D. Polyvinyl Chloride (PVC), 20 Slot (0.020-in) Screen: 80.1 - 110.1 ft Primary Filter pack 10-20 Mesh Colorado Silica Sand: 74.7 - 114.0 ft 4-in. I.D. Polyvinyl Chloride (PVC) Sump: 110.1 - 113.7 ft	

GEOLOGIC/HYDROLOGIC DATA

Depth in Feet	Graphic Log	Lithologic Description/Groundwater Sample Depths (ft bgs)
90		90-108 Silty Sandy Gravel; msG
100		107 Water Sample: HEIS # B1MCP2
		108.5 Water Sample: HEIS # B1ML59
		108-110 Sandy Gravel; sG
110		110-112 Clay/Mud; M
		112-114 Silty Sand; mS
		114 Total Depth Drilled (03-05-2007)
120		

All depths are in feet below ground surface.

Borehole drilled with 7 1/2 x 8 3/8 -inch casing.

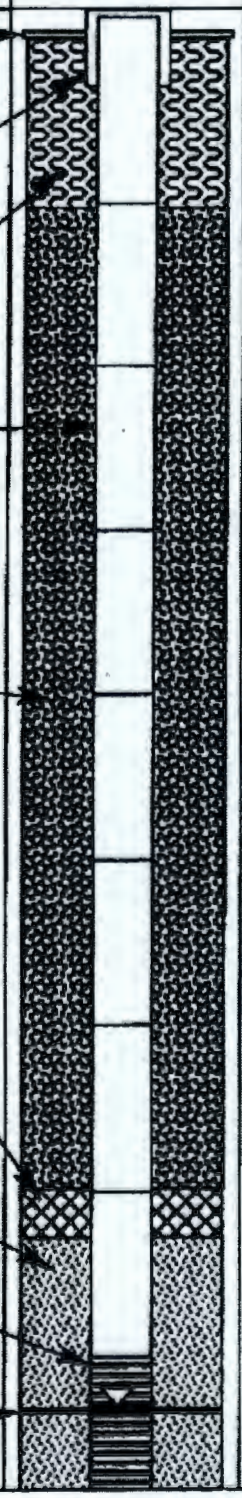
All temporary drill casing was removed from the ground.

WELL SUMMARY SHEET	Start Date: 02/09/07 Finish Date: 02/21/07	Page 1 of 2

Well ID: C5390		Well Name: 199-D5-97	
Location: Approximately 550 meters West of 105-DR		Project: CSI Wells at 100-D Area	
Prepared By: Erika Rincon	Date: 3/21/07	Reviewed By: L. D. Walker	Date: 3/26/07
Signature: Erika R		Signature:	

CONSTRUCTION DATA

Description	Diagram
6-in Concrete Pad	
6-in I.D. Type 304/304L Stainless Steel Protective Casing: +3.02 ft ags	
Portland Cement Type I/II: 0 - 10.0 ft	
4-in I.D. Polyvinyl Chloride (PVC) Casing: +2.0 - 80.0 ft	
Granular Bentonite Crumbles: 10.0 - 70.0 ft	
3/8-in Bentonite Pellets: 70.0 - 73.0 ft	
Primary Filter Pack 10-20 Mesh Colorado Silica Sand: 73.0 - 113.6 ft	
4-in I.D. Polyvinyl Chloride (PVC), 20 Slot (0.020-in) Screen: 80.0 - 110.0 ft	
Static Water Level: 83.18 ft bgs (2-21-2007)	



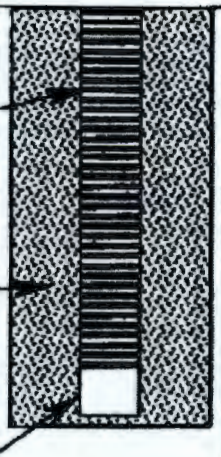
GEOLOGIC/HYDROLOGIC DATA

Depth in Feet	Graphic Log	Lithologic Description/Groundwater Sample Depths (ft bgs)
0		0-1 Gravelly Sand; gS (Fill)
		1-4 Silty Sand; mS
10		4-38 Sandy Gravel; sG
20		
30		
40		38-100 Gravelly Sand; gS
50		
60		
70		
80		87.5 Water Sample: HEIS # B1MCN5

WELL SUMMARY SHEET	Start Date: 02/09/07 Finish Date: 02/21/07	Page 2 of 2

Well ID: C5390		Well Name: 199-D5-97	
Location: Approximately 550 meters West of 105-DR		Project: CSI Wells at 100-D Area	
Prepared By: Erika Rincon	Date: 3/21/07	Reviewed By: L.D. Walker	Date: 3/26/07
Signature: Erika R		Signature: [illegible]	

CONSTRUCTION DATA

Description	Diagram
4-in I.D. Polyvinyl Chloride (PVC), 20 Slot (0.020-in) Screen: 80.0 - 110.0 ft Primary Filter pack 10-20 Mesh Colorado Silica Sand: 73.0 - 113.5 ft 4-in. I.D. Polyvinyl Chloride (PVC) Sump: 110.0 - 113.5 ft	

GEOLOGIC/HYDROLOGIC DATA

Depth in Feet	Graphic Log	Lithologic Description/Groundwater Sample Depths (ft bgs)
90		38-100 Gravelly Sand; gS
100		100-103 Sandy Gravel; sG
		103-107 Sand; S
		103.7 Water Sample: HEIS # B1ML55
		107 Water Sample: HEIS # B1MCN6
		107-109 Gravelly Sand; gS
110		109-111 Clay/Mud; M
		111-113.5 Silty Sand; mS
		113.5 Total Depth Drilled (02-14-2007)
120		

All depths are in feet below ground surface.

Borehole drilled with 7 1/2 x 8 5/8-inch casing.

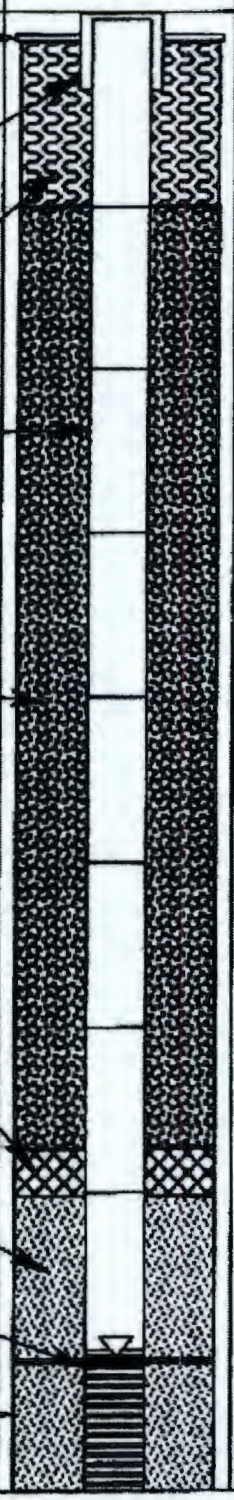
All temporary drill casing was removed from the ground.

WELL SUMMARY SHEET	Start Date: 02/08/07 Finish Date: 02/27/07	Page 1 of 2

Well ID: C5391		Well Name: 199-D5-98	
Location: 500 meters West of 105-DR		Project: CSI Wells at 100-D Area	
Prepared By: Erika Rincon	Date: 4/02/07	Reviewed By: L.D. Walker	Date: 4/9/07
Signature: Erika R		Signature: [illegible]	

CONSTRUCTION DATA

Description	Diagram
6-in Concrete Pad	
6-in I.D. Type 304/304L Stainless Steel Protective Casing: +2.49 ft ags	
Portland Cement Type I/II: 0 - 10.0 ft	
4-in I.D. Polyvinyl Chloride (PVC) Casing: +1.49 - 79.2 ft Sch. 40 wall thickness LW 4-9-07	
Granular Bentonite Crumbles: 10.0 - 67.5 ft	
3/8-in Bentonite Pellets: 67.5 - 70.5 ft	
Primary Filter Pack 10-20 Mesh Colorado Silica Sand: 70.5 - 112.7 ft	
4-in I.D. Polyvinyl Chloride (PVC), 20 Slot (0.020-in) Screen: 79.2 - 109.2 ft	
Static Water Level: 80.51 ft bgs (02-27-2007)	



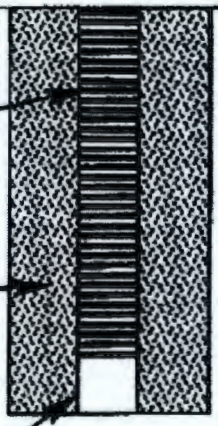
GEOLOGIC/HYDROLOGIC DATA

Depth in Feet	Graphic Log	Lithologic Description/Groundwater Sample Depths (ft bgs)
0		0-60 Sandy Gravel; sG
10		
20		
30		
40		
50		
60		60-77 Silty Sandy Gravel; msG
70		
80		77-78.5 Sand; S 78.5-85 Sandy Gravel; sG 85-103.5 Gravel; G 87 KABIS Water Sample: HEIS # B1MCN3

WELL SUMMARY SHEET	Start Date: 02/08/07 Finish Date: 02/27/07	Page 2 of 2

Well ID: C5391		Well Name: 199-D5-98	
Location: 500 meters West of 105-DR		Project: CSI Wells at 100-D Area	
Prepared By: Erika Rincon	Date: 4/02/07	Reviewed By: L. D. Walker	Date: 4/9/07
Signature: Erika R		Signature: D Walker	

CONSTRUCTION DATA

Description	Diagram
4-in I.D. Polyvinyl Chloride (PVC), 20 Slot (0.020-in) Screen: 79.2 - 109.2 ft Primary Filter pack 10-20 Mesh Colorado Silica Sand: 70.5 - 112.7 ft 4-in. I.D. Polyvinyl Chloride (PVC) Sump: 109.2 - 112.7 ft Natural Backfill: 112.7' → 113.4' LW 4/9/07 All depths are in feet below ground surface. Borehole drilled with 7 1/2 x 8 3/8 -inch casing. All temporary drill casing was removed from the ground.	

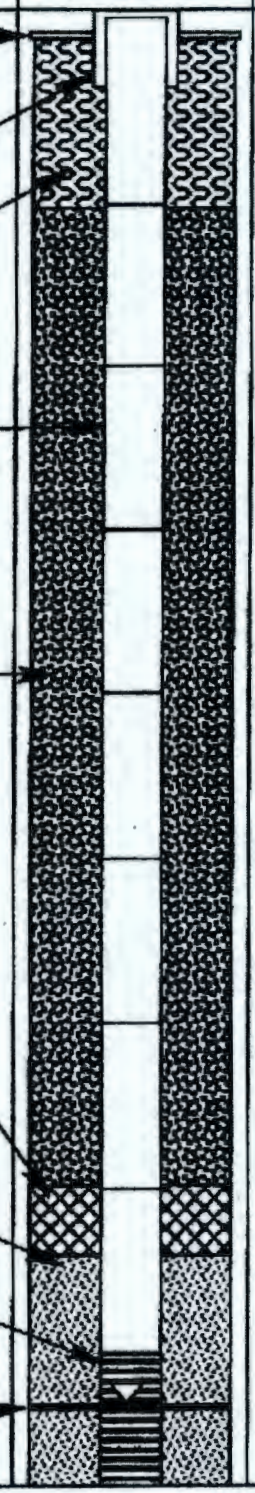
GEOLOGIC/HYDROLOGIC DATA

Depth in Feet	Graphic Log	Lithologic Description/Groundwater Sample Depths (ft bgs)
90		85-103.5 Gravel; G
100		102 KABIS Water Sample: HEIS# B1MCN4
		103.5-108 Silty Sandy Gravel; msG
		108.7 Water Sample: HEIS # B1MLS6
110		108-110 Mud; M
		110-113.4 Silty Sand; mS
		113.4 Total Depth Drilled (02-13-2007)
120		

WELL SUMMARY SHEET	Start Date: 02/14/07 Finish Date: 02/28/07	Page 1 of 2
Well ID: C5392	Well Name: 199-D5-99	
Location: Approximately 500 meters Northwest of 105-DR	Project: CSI Wells at 100-D Area	
Prepared By: Erika Rincon — Date: 3/21/07	Reviewed By: L. D. Walker — Date: 3/26/07	
Signature: Erika	Signature: LD Walker	

CONSTRUCTION DATA

Description	Diagram
6-in Concrete Pad	
6-in I.D. Type 304/304L Stainless Steel Protective Casing: +2.97 ft ags	
Portland Cement Type I/II: 0 - 10.1 ft	
4-in I.D. Polyvinyl Chloride (PVC) Casing: +2.0 - 79.3 ft	
Granular Bentonite Crumbles: 10.1 - 71.1 ft	
1/4-in Bentonite Pellets: 71.1 - 73.8 ft	
Primary Filter Pack 10-20 Mesh Colorado Silica Sand: 73.8 - 113.3 ft	
4-in I.D. Polyvinyl Chloride (PVC), 20 Slot (0.020-in) Screen: 79.3 - 109.4 ft	
Static Water Level: 83.66 ft bgs (02-26-2007)	



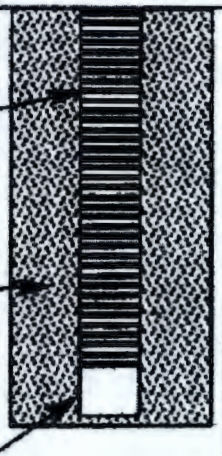
GEOLOGIC/HYDROLOGIC DATA

Depth in Feet	Graphic Log	Lithologic Description/Groundwater Sample Depths (ft bgs)
0		0-5 Sandy Gravel; sG (Fill)
		5-15 No Recovery
10		
		15-21 Sandy Gravel; sG
20		21-28 No Recovery
30		28-34 Silty Sandy Gravel; msG
		34-42 Sandy Gravel; sG
40		
		42-54 Gravelly Sand; gS
50		
		54-72 Sandy Gravel; sG
60		
70		
		72-78 Silty Gravelly Sand; msgS
		78-81 Sandy Gravel; sG
80		81-90 Sand; S
		86.5 Water Sample: HRIS B1MCN7

WELL SUMMARY SHEET	Start Date: 02/14/07 Finish Date: 02/28/07	Page 2 of 2

Well ID: C5392		Well Name: 199-D5-99	
Location: Approximately 500 meters Northwest of 105-DR		Project: CSI Wells at 100-D Area	
Prepared By: Erika Rincon	Date: 3/21/07	Reviewed By: L.D. Walker	Date: 3/26/07
Signature: Erika R		Signature: D Walker	

CONSTRUCTION DATA

Description	Diagram
4-in I.D. Polyvinyl Chloride (PVC), 20 Slot (0.020-in) Screen: 79.3 - 109.4 ft	
Primary Filter pack 10-20 Mesh Colorado Silica Sand: 73.8 - 113.3 ft	
4-in, I.D. Polyvinyl Chloride (PVC) Sump: 109.4 - 113.0 ft	
Natural Fill 113.3' → 115'	
LW 3/26/07	
All depths are in feet below ground surface.	
Borehole drilled with 7 1/2 x 8 5/8 -inch casing.	
All temporary drill casing was removed from the ground.	

GEOLOGIC/HYDROLOGIC DATA

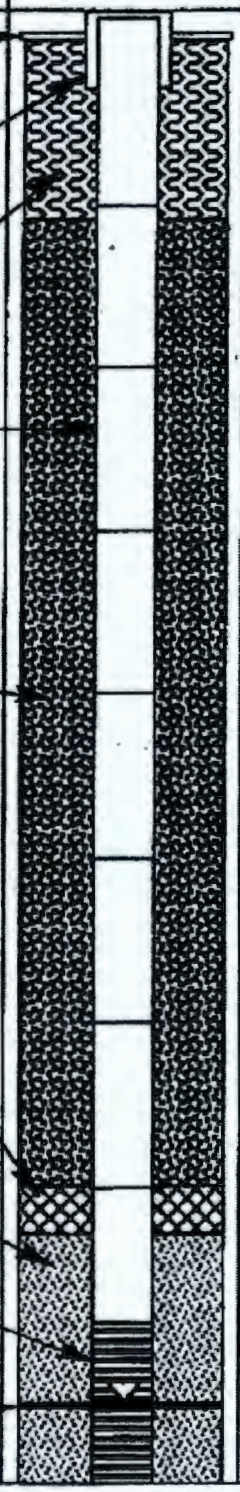
Depth in Feet	Graphic Log	Lithologic Description/Groundwater Sample Depths (ft bgs)
90		90-93 Gravelly Sand; gS
		93-97 Silty Sandy Gravel; msG
		97-109.5 Sandy Gravel; sG
100		
		108 Water Sample: HEIS # B1MCN8
		108.8 Water Sample: HEIS # B1MLS7
		109.5-113 Clay/Mud; M
110		113-115 Silty Sand; mS
		115 Total Depth Drilled (02-20-2007)
120		

WELL SUMMARY SHEET	Start Date: 03/01/07 Finish Date: 03/12/07	Page 1 of 2

Well ID: C5398		Well Name: 199-D5-102	
Location: 100-D Area/West of Substation		Project: CSI Wells at 100-D Area	
Prepared By: Erika Rincon	Date: 4/02/07	Reviewed By: L. D. Walker	Date: 4/9/07
Signature: Erika		Signature: LD Walker	

CONSTRUCTION DATA

Description	Diagram
6-in Concrete Pad	
6-in I.D. Type 304/304L Stainless Steel Protective Casing: +2.27 ft ags	
Portland Cement Type I/II: 0 - 11.4 ft	
4-in I.D. Polyvinyl Chloride (PVC) Casing: +1.24 - 78.1 ft Sch. 40 wall thickness LW 4-9-07	
Granular Bentonite Crumbles: 11.4 - 70.2 ft	
3/8-in Bentonite Pellets: 70.2 - 73.0 ft	
Primary Filter Pack 10-20 Mesh Colorado Silica Sand: 73.0 - 113.5 ft	
4-in I.D. Polyvinyl Chloride (PVC), 20 Slot (0.020-in) Screen: 78.1 - 108.1 ft	
Static Water Level: 83.14 ft bgs (03-09-2007)	



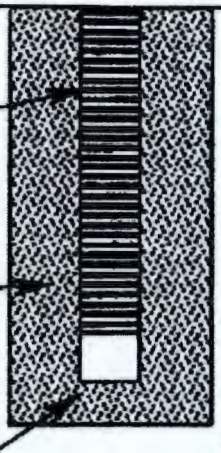
GEOLOGIC/HYDROLOGIC DATA

Depth in Feet	Graphic Log	Lithologic Description/Groundwater Sample Depths (ft bgs)
0		0-3 Sandy Gravel; sG (Fill)
		3-6 Sand; S
		6-7.5 Silty Sand; mS
		7.5-24 Gravel; G
10		
20		
		24-40 Sandy Gravel; sG
30		
40		40-44 Gravelly Sand; gS
		44-50 Gravel; G
50		50-55 Sandy Gravel; sG
		55-65 Gravelly Sand; gS
60		
		65-70 Sandy Gravel; sG
70		70-75 Gravelly Sand; gS
		75-85 Sandy Gravel; sG
80		
		85-90 Gravelly Sand; gS

WELL SUMMARY SHEET	Start Date: 03/01/07 Finish Date: 03/12/07	Page 2 of 2

Well ID: C5398		Well Name: 199-D5-102	
Location: 100-D Area/West of Substation		Project: CSI Wells at 100-D Area	
Prepared By: Erika Rincon	Date: 4/02/07	Reviewed By: L. D. Walker	Date: 4-9-07
Signature: Erika R		Signature: [illegible]	

CONSTRUCTION DATA

Description	Diagram
4-in I.D. Polyvinyl Chloride (PVC), 20 Slot (0.020-in) Screen: 78.1 - 108.1 ft Primary Filter pack 10-20 Mesh Colorado Silica Sand: 73.0 - 113.5 ft 4-in, I.D. Polyvinyl Chloride (PVC) Sump: 108.1 - 111.6 ft	

GEOLOGIC/HYDROLOGIC DATA

Depth in Feet	Graphic Log	Lithologic Description/Groundwater Sample Depths (ft bgs)
90		90-95 Sand; S
		90 KABIS Water Sample: HEIS # B1MCP9
		95-105 Silty Sandy Gravel; msG
100		
		105-108 Sandy Gravel; sG
		107.5 KABIS Water Sample: HEIS # B1MCR0
110		108-113.5 Mud; M
		111.2 Water Sample: HEIS # B1ML63
		113.5 Silty Sand; mS
		113.5 Total Depth Drilled (03-07-2007)
120		

All depths are in feet below ground surface.

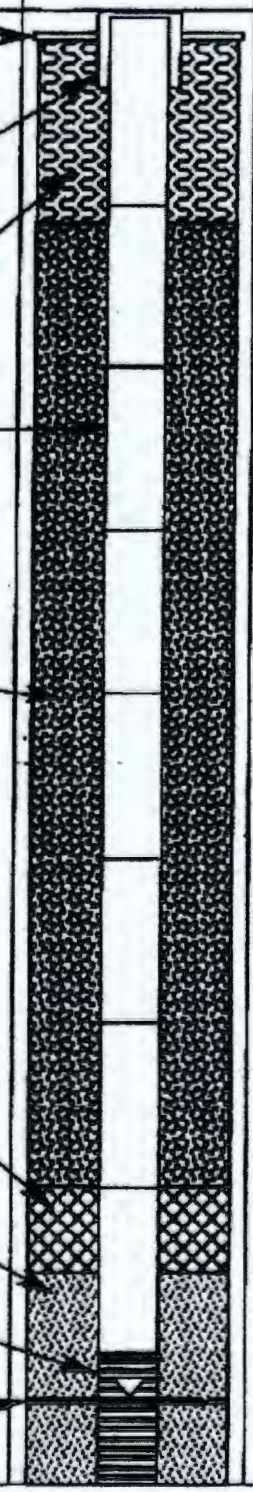
Borehole drilled with 7 1/2 x 8 5/8-inch casing.

All temporary drill casing was removed from the ground.

WELL SUMMARY SHEET	Start Date: 03/12/07 Finish Date: 03/23/07	Page 1 of 2
Well ID: C5399	Well Name: 199-D5-103	
Location: Approximately 400 m. Northwest of 105-DR	Project: CSI Wells at 100-D Area	
Prepared By: Erika Rincon — Date: 4/02/07	Reviewed By: L. D. Walker — Date: 4/4/07	
Signature: Erika R	Signature: L D Walker	

CONSTRUCTION DATA

Description	Diagram
6-in Concrete Pad	
6-in I.D. Type 304/304L Stainless Steel Protective Casing: +2.37 ft ags	
Portland Cement Type I/II: 0 - 11.5 ft	
4-in I.D. Polyvinyl Chloride (PVC) Casing: +1.87 - 79.2 ft Sch. 40 wall thickness LW 4-4-07	
Granular Bentonite Crumbles: 11.5 - 70.5 ft	
3/8-in Bentonite Pellets: 70.5 - 75.1 ft	
Primary Filter Pack 10-20 Mesh Colorado Silica Sand: 75.1 - 113.7 ft	
4-in I.D. Polyvinyl Chloride (PVC), 20 Slot (0.020-in) Screen: 80.3 - 110.1 ft	
Static Water Level: 82.73 ft bgs (03-23-2007)	

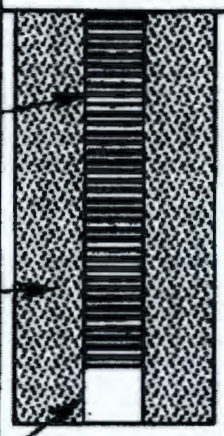


GEOLOGIC/HYDROLOGIC DATA

Depth in Feet	Graphic Log	Lithologic Description/Groundwater Sample Depths (ft bgs)
0		0-10 Gravelly Sand; gS
10		10-25 Sandy Gravel; sG
20		
		25-47 Gravelly Sand; gS
30		
40		
		47-55 Sandy Gravel; sG
50		
		55-60 Gravelly Sand; gS
60		60-82 Sandy Gravel; sG
70		
80		
		82-88 Sand; S (possible heave)
		88 KABIS Water Sample: HEIS # B1MCR1

WELL SUMMARY SHEET	Start Date: 03/12/07 Finish Date: 03/23/07	Page 2 of 2
Well ID: C5399	Well Name: 199-D5-103	
Location: Approximately 400 m. Northwest of 105-DR	Project: CSI Wells at 100-D Area	
Prepared By: Erika Rincon — Date: 4/02/07	Reviewed By: L. D. Walker — Date: 4/5/07	
Signature: Erika R	Signature: D Walker	

CONSTRUCTION DATA

Description	Diagram
4-in I.D. Polyvinyl Chloride (PVC), 20 Slot (0.020-in) Screen: 80.3 - 110.1 ft Primary Filter pack 10-20 Mesh Colorado Silica Sand: 75.1 - 113.7 ft 4-in. I.D. Polyvinyl Chloride (PVC) Sump: 110.1 - 113.7 ft Natural Backfill 113.7' → 117' LW 4-4-07 All depths are in feet below ground surface. Borehole drilled with 7 1/2 x 8 5/8 -inch casing. All temporary drill casing was removed from the ground.	

GEOLOGIC/HYDROLOGIC DATA

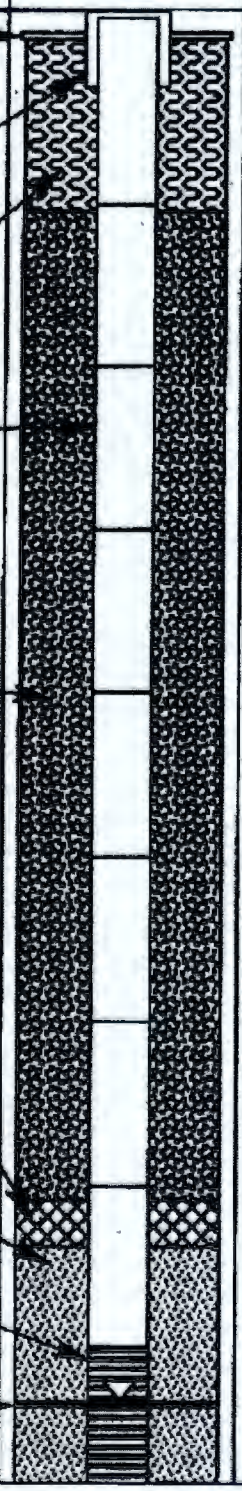
Depth in Feet	Graphic Log	Lithologic Description/Groundwater Sample Depths (ft bgs)
90		88-110 Sandy Gravel; sG
100		
		108 KABIS Water Sample: HEIS# B1MCR2
		109 Water Sample: HEIS # B1ML64
		110-110.7 Silty Sandy Gravel; msG
110		110.7-117 Mud; M
		117 Sandy Mud; sM
		117 Total Depth Drilled (03-19-2007)
120		

WELL SUMMARY SHEET	Start Date: 03/13/07 Finish Date: 03/22/07	Page 1 of 2

Well ID: C5400		Well Name: 199-D5-104	
Location: 100-D Area		Project: CSI Wells at 100-D Area	
Prepared By: Erika Rincon	Date: 4/02/07	Reviewed By: L. D. Walker	Date: 4/9/07
Signature: Erika R		Signature:	

CONSTRUCTION DATA

Description	Diagram
6-in Concrete Pad	
6-in I.D. Type 304/304L Stainless Steel Protective Casing: +2.48 ft ags	
Portland Cement Type I/II: 0 - 10.3 ft	
4-in I.D. Polyvinyl Chloride (PVC) Casing: +1.48 - 80.0 ft Sch. 40 wall thickness LW 4-9-07	
Granular Bentonite Crumbles: 10.3 - 71.2 ft	
3/8-in Bentonite Pellets: 71.2 - 73.8 ft	
Primary Filter Pack 10-20 Mesh Colorado Silica Sand: 73.8 - 116.0 ft	
4-in I.D. Polyvinyl Chloride (PVC), 20 Slot (0.020-in) Screen: 80.0 - 110.0 ft	
Static Water Level: 83.95 ft bgs (03-16-2007)	

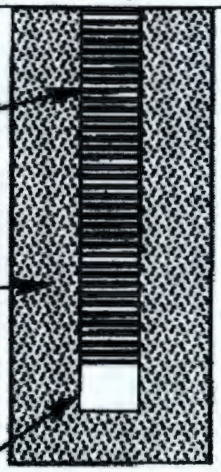


GEOLOGIC/HYDROLOGIC DATA

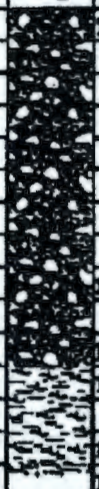
Depth in Feet	Graphic Log	Lithologic Description/Groundwater Sample Depths (ft bgs)
0		0-3 Sandy Gravel; sG (Fill)
		3-5.5 Silty Sand; mS
		5.5-12 Gravel; G
10		
		12-15 Sandy Gravel; sG
		15-22 Gravelly Sand; gS
20		
		22-25 Sandy Gravel; sG
		25-30 Gravelly Sand; gS
30		30-65 Sandy Gravel; sG
40		
50		
60		
		65-73 Silty Sandy Gravel; msG
70		73-110.3 Sandy Gravel; sG
80		
		88.5 KABIS Water Sample: HEIS # B1MCR3

WELL SUMMARY SHEET	Start Date: 03/13/07 Finish Date: 03/22/07	Page 2 of 2
Well ID: C5400	Well Name: 199-D5-104	
Location: 100-D Area	Project: CSI Wells at 100-D Area	
Prepared By: Erika Rincon — Date: 4/02/07	Reviewed By: L.D. Walker — Date: 4/9/07	
Signature: Erika R	Signature: L.D. Walker	

CONSTRUCTION DATA

Description	Diagram
4-in I.D. Polyvinyl Chloride (PVC), 20 Slot (0.020-in) Screen: 80.0 - 110.0 ft Primary Filter pack 10-20 Mesh Colorado Silica Sand: 73.8 - 116.0 ft 4-in, I.D. Polyvinyl Chloride (PVC) Sump: 110.0 - 113.5 ft All depths are in feet below ground surface. Borehole drilled with 7 1/2 x 8 3/8 -inch casing. All temporary drill casing was removed from the ground.	

GEOLOGIC/HYDROLOGIC DATA

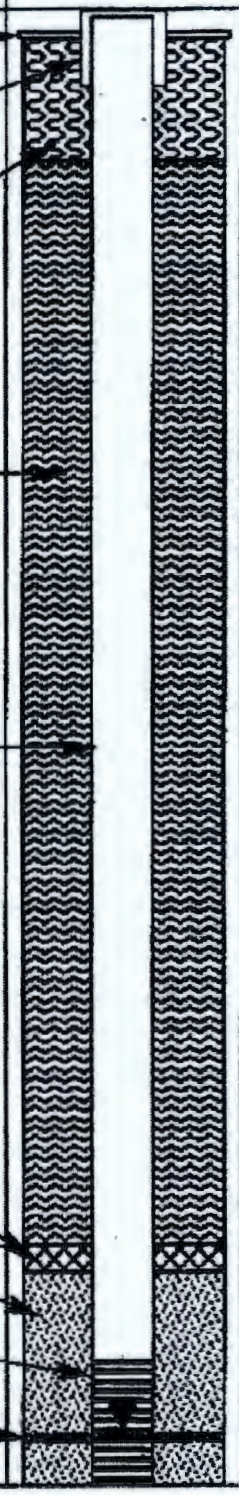
Depth in Feet	Graphic Log	Lithologic Description/Groundwater Sample Depths (ft bgs)
90		73-110.3 Sandy Gravel; sG
100		
		108 KABIS Water Sample: HEIS# B1MCR4
		109.8 Water Sample: HEIS # B1ML65
110		110.3-116 Mud; M
		116 Silty Sand; mS
		116 Total Depth Drilled (03-19-2007)
120		

WELL SUMMARY SHEET	Start Date: 3/18/08 Finish Date: 4/21/08	Page 1 of 2

Well ID: C5933	Well Name: 199-D5-119
Location: 100 D Area	Project: 100-D CSI
Prepared By: John Houck — Date: 5/27/08	Reviewed By: [illegible] — Date: 5/2/08
Signature: [illegible]	Signature: [illegible]

CONSTRUCTION DATA

Description	Diagram
6-in Concrete Pad	
6-in I.D. Type 304/304L Stainless Steel Protective Casing: 2.75 ft above Ground Surface	
Portland Cement Type I/II: 0 - 7.5 ft	
Granular Bentonite Crumbles: 7.5 - 73.6 ft	
4-in I.D. Type PVC, Schedule 40 Permanent Casing: +1.75 - 80.43 ft	
All depths are in feet below ground surface. Borehole drilled with 10 -in threaded casing 0.0-110.3 ft bgs. All temporary drill casing was removed from the ground.	
3/8-in Bentonite Pellets: 73.6 - 75.0 ft	
Primary Filter pack 10-20 Mesh Colorado Silica Sand: 75.0 - 113.6 ft	
4-in I.D. PVC, Slot 20 (.020-in) Screen: 80.43 - 110.58 ft bgs	
Static Water Level: 85.28 ft bgs (4-21-08)	



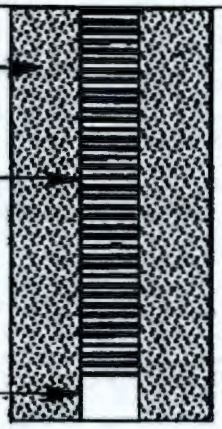
GEOLOGIC/HYDROLOGIC DATA

Depth in Feet	Graphic Log	Lithologic Description/Groundwater Sample Depths (ft bgs)
0		0-1 Gravel Pad (Crushed)
		1-4 Sandy Gravel sG
		4-5.5 Gravelly Sand gS
		5.5-9 Sandy Gravel sG
		9-26 Sandy Gravel sG
10		
20		
		26-31 Gravelly Sandy gS
30		31-68 Sandy Gravel sG
40		
50		
60		
		68-74 Gravelly Sand gS
70		
		74-89 Sandy Gravel sG
80		
		89-92 Gravelly Sand gS

WELL SUMMARY SHEET	Start Date: 3/18/08 Finish Date: 4/21/08	Page 2 of 2
Well ID: C5933	Well Name: 199-D5-119	
Location: 100-D Area	Project: 100-D CSI	
Prepared By: John Houck — Date: 5/27/08	Reviewed By: L.D. Walker — Date: 9/9/08	
Signature: John Houck	Signature: L.D. Walker	

CONSTRUCTION DATA

Description	Diagram
Primary Filter pack 10-20 Mesh Colorado Silica Sand: 75.0 - 113.6 ft	
4-in I.D. PVC, Slot 20 (.020-in) Screen: 80.43 - 110.58 ft bgs	
4-in I.D. PVC Sump W/ End Cap 110.58 - 113.60 ft bgs	



All depths are in feet below ground surface.
Borehole drilled with 10 -in threaded casing 0.0-110.3 ft bgs
All temporary drill casing was removed from the ground.

GEOLOGIC/HYDROLOGIC DATA

Depth in Feet	Graphic Log	Lithologic Description/Groundwater Sample Depths (ft bgs)
90		89-92 Gravelly Sand gS
		92-101 Sandy Gravel sG
100		101-104 Sandy Gravel sG (Cemented)
		104-106 Silty Sandy Gravel msG
		106-110 Sandy Gravel sG
110		110-113.6 Silt/Clay (R.U.M) (M)
		T.D. = 113.6 ft bgs
		Static Water Level = 85.28 ft bgs (4-21-08)
120		
130		
140		
150		
160		
170		

WELL SUMMARY SHEET	Start Date: 2/20/08 Finish Date: 3/25/08	Page 1 of 2
Well ID: C5934	Well Name: 199-D5-120	
Location: 105 ft. East of 199-D5-99	Project: 100-D CSI (4 wells)	
Prepared By: Kim Royal — Date: 5/27/08	Reviewed By: L. D. Walker — Date: 7/29/08	
Signature: Kim Royal	Signature: [illegible]	

CONSTRUCTION DATA

Description	Diagram
6-in Concrete Pad	
6-in I.D. Type 304/304L Stainless Steel Protective Casing: 2 - +3.0 ft	
Portland Cement Type I/II: 0 - 9.0 ft	
Granular Bentonite Crimbles: 9.0 - 71.4 ft	
4-in I.D. Type PVC, Schedule 40 Permanent Casing: +2.27 - 78.24 ft	
All depths are in feet below ground surface. Borehole drilled with 10-in threaded casing 0.0-112.4 ft bgs	
3/8-in Bentonite Pellets: 71.4-72.7	
Primary Filter pack 10-20 Mesh Colorado Silica Sand: 72.7-112.4	
Static Water Level: 83.11 ft. (3/21/08)	
4-in I.D. 20 slot Slotted PVC: 78.24-108.36 ft	

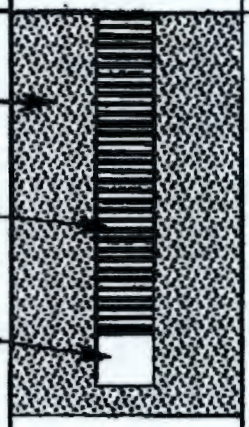
GEOLOGIC/HYDROLOGIC DATA

Depth in Feet	Graphic Log	Lithologic Description/Groundwater Sample Depths (ft bgs)
0		0-13.8 Sandy Gravel sG (Fill, recent)
10		
		13.8-26.0 Sandy Gravelly sG
20		
		26-28 Gravel G
		28-36 Sandy Gravel sG (grey)
30		
		36-53 Sandy Gravel sG (greyish-brown, increase in sand)
40		
50		
		53-60 Sandy Gravel sG (olive grey)
60		60-69 Sandy Gravel sG (with caliche at 62, silt layer at 67)
70		69-79 Gravelly Silty Sand gmS
		79-82 Gravelly Sand gS (light grey, vf-f)
80		82-93 Sandy Gravel sG (wet below 83)

WELL SUMMARY SHEET	Start Date: 2/20/08 Finish Date: 3/25/08	Page 2 of 2

Well ID: C5934		Well Name: 199-D5-120	
Location: 105 ft. East of 199-D5-99		Project: 100-D CSI (4 wells)	
Prepared By: Kim Royal	Date: 5/27/08	Reviewed By: C. D. Walker	Date: 7/29/08
Signature: Kim Royal		Signature: [illegible]	

CONSTRUCTION DATA

Description	Diagram
Primary Filter pack 10-20 Mesh Colorado Silica Sand: 72.7-112.4 4-in I.D. 20 slot Slotted PVC: 78.24-108.36 ft 4-in I.D. PVC sump: 108.36-111.38 ft All depths are in feet below ground surface. Borehole drilled with 10-in threaded casing 0.0-112.4 ft bgs All temporary drill casing was removed from the ground.	

GEOLOGIC/HYDROLOGIC DATA

Depth in Feet	Graphic Log	Lithologic Description/Groundwater Sample Depths (ft bgs)
90		82-93 Sandy Gravel sG (wet below)
		93-97.8 Silty Sandy Gravel msG (wet)
100		97.8-101 Sandy Gravel sG
		101-106 Gravelly Sand sG
		106-108 Sandy Gravel sG
110		108-112.4 Silty Clay M (R.U.M)
120		
130		
140		
150		
160		
170		

WELL SUMMARY SHEET	Start Date: 5/12/08 Finish Date: 5/23/08	Page 1 of 2

Well ID: C5935		Well Name: 199-D5-121	
Location: 100 D Area		Project: 100-D Chromium Source investigation	
Prepared By: John Houck	Date: 5/27/08	Reviewed By: Jim Fritz	Date: 9/4/08
Signature: John Houck		Signature: [illegible]	

CONSTRUCTION DATA

Description	Diagram
6-in Concrete Pad	
6-in I.D. Type 304/304L Stainless Steel Protective Casing: 2.4 ft above Concrete Pad	
Portland Cement Grout Type I/II: 0 - 8.2 ft	
Granular Bentonite Crumbles: 8.2 - 69.5 ft	
4-in I.D. Type PVC, Schedule 40 Permanent Casing: +1.4 - 77.0 ft	
3/8-in Bentonite Pellets: 69.5 - 71.8 ft	
Primary Filter pack 10-20 Mesh Colorado Silica Sand: 71.8 - 111.8 ft	
4-in I.D. PVC, Slot 20 (.020-in) Screen: 77.0 - 107.0 ft bgs	
Static Water Level: 83.4 ft bgs (5-22-08)	

GEOLOGIC/HYDROLOGIC DATA

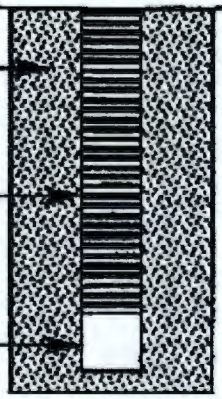
Depth in Feet	Graphic Log	Lithologic Description/Groundwater Sample Depths (ft bgs)
0		0-1.5 Gravel Pad (Crushed)
		1.5-18 Silty Sandy Gravel msG
10		
		18-20 Gravel G
20		20-38 Silty Sandy Gravel msG
30		
		38-48 Gravel Silty Sandy gmS
40		
		48-80 Sandy Gravel sG
50		
60		
70		
		80-90 Silty Sandy Gravel msG
80		

WELL SUMMARY SHEET	Start Date: 5/12/08 Finish Date: 4/23/08	Page 2 of 2

Well ID: C5935	Well Name: 199-D5-121
Location: 100-D Area	Project: 100-D Chromium Source investigation
Prepared By: John Houck — Date: 5/27/08	Reviewed By: L. J. Walker — Date: 9/9/08
Signature: John Houck	Signature:

CONSTRUCTION DATA

Description	Diagram
Primary Filter pack 10-20 Mesh Colorado Silica Sand: 71.8 - 111.8 ft	
4-in I.D. PVC, Slot 20 (.020-in) Screen: 77.0 - 107.0 ft bgs	
4-in I.D. PVC Sump W/ End Cap 107.0 - 110.3 ft bgs	



GEOLOGIC/HYDROLOGIC DATA

Depth in Feet	Graphic Log	Lithologic Description/Groundwater Sample Depths (ft bgs)
90		80-90 Silty Sandy Gravel msG
		90-105 Sandy Gravel sG
100		
		105-107 Silty Sandy Gravel msG
		107-111.8 Silt/Clay M
110		(Ringold Upper Mud)
		T.D. = 111.8 ft bgs (5-19-08)
120		Static Water Level = 83.4 ft bgs (5-22-08)
130		
140		
150		
160		
170		

All depths are in feet below ground surface.

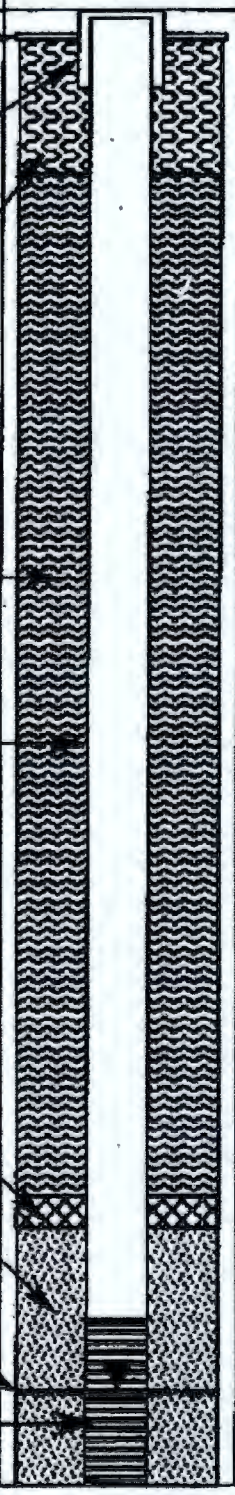
Borehole drilled with 10.75-in threaded casing 0.0-107.0 ft bgs

All temporary drill casing was removed from the ground.

WELL SUMMARY SHEET	Start Date: 4/4/08 Finish Date: 5/16/08	Page 1 of 2
Well ID: C5936	Well Name: 199-D5-122	
Location: 250 ft. SW of 199-D5-122	Project: 100-D CSI (4 wells)	
Prepared By: Kim Royal — Date: 5/27/08	Reviewed By: [illegible] — Date: 7/14/08	
Signature: Kim Royal	Signature: [illegible]	

CONSTRUCTION DATA

Description	Diagram
6-in Concrete Pad	
6-in I.D. Type 304/304L Stainless Steel Protective Casing: 2.46- +2.54 ft	
Portland Cement Type I/II: 0 - 8.5 ft	
Granular Bentonite Crumbles: 8.5 - 70.5 ft	
4-in I.D. Type PVC, Schedule 40 Permanent Casing: 77.7 - +2.0 ft.	
All depths are in feet below ground surface. Borehole drilled with 10-in threaded casing 0.0-112.3 ft bgs	
3/8-in Bentonite Pellets: 70.5-72.5 ft	
Primary Filter pack 10-20 Mesh Colorado Silica Sand: 72.5-108 ft	
Static Water Level: 83.80 ft. (5/1/08)	
4-in I.D. 20 slot Slotted PVC: 77.7-107.9 ft	



GEOLOGIC/HYDROLOGIC DATA

Depth in Feet	Graphic Log	Lithologic Description/Groundwater Sample Depths (ft bgs)
0		0-1.0 Gravel pad
		1.0-16 Silty Sandy Gravel msG
10		
		16-27 Gravel G
20		
		27-30 Gravelly Sand gS
30		30-33 Gravel G
		33-38 Sandy Gravel sG
		38-40 Gravelly Sand gS
40		40-56 Sandy Gravel sG
50		
		56-58 Sand S
		58-87 Sandy Gravel sG
60		
70		
80		
		87-89 Sand S

WELL SUMMARY SHEET	Start Date: 4/4/08 Finish Date: 5/16/08	Page 2 of 2
Well ID: C5936	Well Name: 199-D5-122	
Location: 250 ft. SW of 199-D5-122	Project: 100-D CSI (4 wells)	
Prepared By: Kim Royal — Date: 5/27/08	Reviewed By: L. J. Walker	Date: 9/9/08
Signature: Kim Royal	Signature: [illegible]	

CONSTRUCTION DATA

Description	Diagram
Primary Filter pack 10-20 Mesh Colorado Silica Sand: 72.5-108	
4-in I.D. 20 slot Slotted PVC: 77.73-107.90 ft	
4-in I.D. PVC sump: 107.90-110.92 ft	
Slough: 108-112.3	
All depths are in feet below ground surface.	
Borehole drilled with 10-in threaded casing 0.0-112.3 ft bgs	
All temporary drill casing was removed from the ground.	

GEOLOGIC/HYDROLOGIC DATA

Depth in Feet	Graphic Log	Lithologic Description/Groundwater Sample Depths (ft bgs)
90		89-90.5 Gravelly Sandy Silt gsM
		90.5-92.5 Gravelly Silty Sand gmS
		92.5-94 Silty Sandy Gravel msG
		94-96 Sandy Gravel sG
		96-99 Silty Sandy Gravel msG
100		99-107.7 Sandy Gravel sG
		107.7-112.3 Silty Clay M (R.U.M)
110		
120		
130		
140		
150		
160		
170		

This page intentionally left blank.

APPENDIX B

SUMMARY OF GROUNDWATER AND SEDIMENT ANALYSIS

This page intentionally left blank.

APPENDIX B

SUMMARY OF GROUNDWATER AND SEDIMENT ANALYSIS

B1.0 QUALITY ASSURANCE

The following types of analytical measurements were performed for the purpose of reconnaissance characterization of the distribution of hexavalent chromium within and near the southwestern hexavalent chromium plume in the 100-D Area:

- Hexavalent chromium in groundwater samples.
- Nitrate in groundwater samples.
- Hexavalent chromium in sediment samples (drill cuttings and split-spoon samples).
- Total chromium in sediment samples (drill cuttings and split-spoon samples).

Specific requirements for analytical methods, field and laboratory quality control samples and quality control procedures, and data validation and verification in accordance with EPA QA/R-5 are shown in DOE/RL-2006-74.

Results of analysis are listed in Table B-1 through Table B-6.

B2.0 REFERENCES

DOE/RL-2006-74, 2007, *Field Investigation Plan for the Southwestern Chromium Plume in the 100-D Area*, Rev. 0, U. S. Department of Energy, Richland Operations Office, Richland, Washington

EPA/240/B-01/003, 2001, *EPA Requirements for Quality Assurance Project Plans*, EPA QA/R-5, Quality Assurance Division, U.S. Environmental Protection Agency, Washington, D.C.

Table B-1. PERIODIC GROUNDWATER SAMPLES

Well	HEIS #	Date	Cr6+ (ug/L)
199-D2-11	B1ML59	8-Mar-07	16
	B1MCP1	1-Mar-07	5
	B1MCP2	2-Mar-07	5
	B1NP17	25-Jun-07	9
	B1N7C6	29-May-07	5
	B1N759	26-Apr-07	7
	B1N787	11-May-07	5
	B1N788	11-May-07	5.5
	B1P069	9-Jul-07	5
	B1P0D7	24-Jul-07	5
	B1P0D9	9-Aug-07	5
	B1NP42	11-Jun-07	6
	B1P7P2	5-Sep-07	5
	B1P805	22-Aug-07	5
	B1PFC9	19-Sep-07	5
	B1RC66	27-Dec-07	4
	B1RC67	27-Dec-07	6.7
	B1RC84	13-Dec-07	7.2
	B1PY89	15-Nov-07	4.2
	B1PY31	4-Oct-07	6
	B1PPR1	18-Oct-07	5.2
	B1R516	29-Nov-07	5
	B1R524	1-Nov-07	12
	B1R525	1-Nov-07	5
	B1T2H4	12-Feb-08	8.5
	B1RR27	7-Jan-08	8.7
	B1TVR7	21-Apr-08	6
	B1TJ26	10-Mar-08	8.7
	B1TJ27	10-Mar-08	8.7

Well	HEIS #	Date	Cr6+ (ug/L)
199-D5-97	B1ML55	21-Feb-07	758
	B1MCN5	13-Feb-07	5
	B1MCN6	14-Feb-07	5
	B1NP35	25-Jun-07	615
	B1N7F4	31-May-07	642
	B1N7F5	31-May-07	675
	B1N778	26-Apr-07	855
	B1N7B6	11-May-07	784
	B1P088	9-Jul-07	562
	B1P0D1	24-Jul-07	563
	B1P0H8	9-Aug-07	545
	B1NP60	11-Jun-07	614
	B1P7T1	5-Sep-07	542
	B1MW70	4-Apr-07	797
	B1P824	22-Aug-07	580
	B1PFF8	19-Sep-07	470
	B1RC80	27-Dec-07	562
	B1RCB3	13-Dec-07	635
	B1PY85	17-Oct-07	490
	B1PY86	17-Oct-07	486
	B1PYB7	15-Nov-07	522
	B1PY50	4-Oct-07	480
	B1R544	1-Nov-07	500
	B1R1V7	29-Nov-07	550
	B1T277	19-Feb-08	710
	B1THX7	10-Mar-08	715

Well	HEIS #	Date	Cr6+ (ug/L)
199-D5-98	B1ML56	27-Feb-07	465
	B1MCN3	12-Feb-07	6
	B1MCN4	12-Feb-07	7
	B1NP37	25-Jun-07	271
	B1NP38	25-Jun-07	271
	B1N780	24-Apr-07	327
	B1N7F7	29-May-07	338
	B1N7B8	11-May-07	312
	B1P090	9-Jul-07	237
	B1P0D3	24-Jul-07	329
	B1P0J0	9-Aug-07	325
	B1NP62	11-Jun-07	327
	B1P7T3	5-Sep-07	367
	B1MW71	4-Apr-07	343
	B1P826	22-Aug-07	348
	B1PFH0	19-Sep-07	403
	B1RCB5	13-Dec-07	437
	B1PYB8	15-Nov-07	405
	B1PYB9	15-Nov-07	418
	B1PY52	4-Oct-07	431
	B1PPV1	17-Oct-07	413
	B1R546	1-Nov-07	429
	B1RB26	27-Dec-07	470
	B1RB27	27-Dec-07	464
	B1R1V9	29-Nov-07	419
	B1T279	29-Feb-08	448
	B1RR54	7-Jan-08	490
	B1THX8	26-Mar-08	327

Table B-1. PERIODIC GROUNDWATER SAMPLES (CONTINUED)

Well	HEIS #	Date	Cr6+ (ug/L)
199-D5-99	B1ML57	28-Feb-07	10580
	B1MCN7	16-Feb-07	187
	B1MCN8	20-Feb-07	6
	B1MWY1	19-Mar-07	12560
	B1NP40	25-Jun-07	1370
	B1N782	26-Apr-07	2370
	B1N7F9	29-May-07	1740
	B1N7C0	11-May-07	1800
	B1P092	9-Jul-07	1260
	B1P0D5	24-Jul-07	1110
	B1P0J2	9-Aug-07	1020
	B1NP64	11-Jun-07	1580
	B1NP65	11-Jun-07	1480
	B1P7T5	5-Sep-07	1180
	B1MW72	5-Apr-07	8160
	B1P828	22-Aug-07	960
	B1PFH2	19-Sep-07	2250
	B1RC82	27-Dec-07	7900
	B1RCB7	13-Dec-07	5990
	B1PYC2	15-Nov-07	4300
	B1PY54	4-Oct-07	3130
	B1PPV2	17-Oct-07	3410
	B1R522	29-Nov-07	5410
	B1R523	29-Nov-07	6740
	B1R548	1-Nov-07	4460
	B1T280	22-Feb-08	16000
	B1THY2	26-Mar-08	39900

Well	HEIS #	Date	Cr6+ (ug/L)
199-D5-102	B1ML63	12-Mar-07	540
	B1MCP9	5-Mar-07	5
	B1MCR0	6-Mar-07	6
	B1NP21	25-Jun-07	414
	B1N7D0	30-May-07	347
	B1N764	24-Apr-07	231
	B1N792	11-May-07	287
	B1P073	9-Jul-07	321
	B1P074	9-Jul-07	314
	B1P0B6	24-Jul-07	300
	B1P0F3	9-Aug-07	353
	B1NP46	11-Jun-07	393
	B1P7P6	5-Sep-07	379
	B1P809	22-Aug-07	352
	B1PFD3	19-Sep-07	529
	B1RC89	13-Dec-07	475
	B1PY93	15-Nov-07	465
	B1PY35	4-Oct-07	431
	B1PPR7	18-Oct-07	470
	B1R530	1-Nov-07	453
	B1R1B2	29-Nov-07	502
	B1RB16	27-Dec-07	386
	B1RB17	27-Dec-07	446
	B1T2J7	12-Feb-08	266
	B1RR32	7-Jan-08	345
	B1TVT1	21-Apr-08	453
	B1TVT2	21-Apr-08	449
	B1TJ32	10-Mar-08	304

Well	HEIS #	Date	Cr6+ (ug/L)
199-D5-103	B1ML64	23-Mar-07	393
	B1MCR1	16-Mar-07	5
	B1MCR2	19-Mar-07	5
	B1NP23	25-Jun-07	240
	B1N7D2	30-May-07	286
	B1N766	24-Apr-07	250
	B1N794	10-May-07	254
	B1P076	9-Jul-07	221
	B1P0B8	24-Jul-07	221
	B1P0B9	24-Jul-07	220
	B1P0F5	9-Aug-07	185
	B1NP48	11-Jun-07	275
	B1P7P8	5-Sep-07	180
	B1P811	22-Aug-07	185
	B1PFD5	19-Sep-07	176
	B1RC70	27-Dec-07	155
	B1RC91	13-Dec-07	154
	B1PY95	15-Nov-07	148
	B1PY37	4-Oct-07	157
	B1PPR9	17-Oct-07	149
	B1R532	1-Nov-07	144
	B1R1B4	29-Nov-07	158
	B1T2J9	12-Feb-08	172
	B1RR33	7-Jan-08	164
	B1RR34	7-Jan-08	161
	B1TVT5	21-Apr-08	147
	B1TJ34	10-Mar-08	149

Table B-1. PERIODIC GROUNDWATER SAMPLES (CONTINUED)

Well	HEIS #	Date	Cr6+ (ug/L)
199-D5-104	B1ML65	22-Mar-07	6840
	B1MCR3	15-Mar-07	523
	B1MCR4	16-Mar-07	5
	B1NP25	25-Jun-07	7260
	B1N7D4	31-May-07	7040
	B1N768	24-Apr-07	6720
	B1N796	17-May-07	7290
	B1P078	9-Jul-07	6570
	B1P0C1	24-Jul-07	5610
	B1P0F7	9-Aug-07	5270
	B1P0F8	9-Aug-07	5520
	B1NP50	11-Jun-07	6670
	B1P7R0	5-Sep-07	4840
	B1P813	22-Aug-07	6090
	B1PFD7	19-Sep-07	5330
	B1RC72	27-Dec-07	12200
	B1RC93	13-Dec-07	11400
	B1PY97	15-Nov-07	10900
	B1PY39	4-Oct-07	6690
	B1PPT1	18-Oct-07	8560
	B1R534	1-Nov-07	9940
	B1R1B6	29-Nov-07	10900
	B1T2K1	19-Feb-08	9550
	B1RR37	11-Jan-08	1110
	B1TVT7	21-Apr-08	6310

Well	HEIS #	Date	Cr6+ (ug/L)
199-D5-119	B1V254	21-Apr-08	5050
199-D5-120	B1V255	25-Mar-08	521
199-D5-121	*	23-May-08	60
199-D5-122	*	16-May-08	22400

*Entries in the HEIS database for these sample ID numbers are incorrect.

Table B-2. APRIL 2007 DEPTH-DISCRETE GROUNDWATER SAMPLING

Well	Date Sampled	HEIS #	Samping depth (ft)	Cr6+ (mg/L)	NO3 (mg/L)
199-D5-97	4/4/2007	B1MLT4	85.9	0.794	47
		B1MW70	85.9	0.797	50
		B1MLT5	87.9	0.793	50
		B1MLT6	89.9	0.792	50
		B1MLT7	91.9	0.793	53
		B1MLT8	93.9	0.791	53
		B1MLT9	95.9	0.784	56
		B1MLV0	97.9	0.793	53
		B1MLV1	99.9	0.788	54
		B1MLV2	101.9	0.79	52
		B1MLV3	103.9	0.799	54
		B1MLV4	105.9	0.816	53
		B1MLV5	107.7	0.787	50
		B1MLV6	109.9	0.785	50
		B1MLV7	111.9	0.786	53
		B1MLV8	113.2	0.55	52
199-D5-98	4/4/2007	B1MLV9	83.4	0.35	57
		B1MLW0	85.4	0.343	58
		B1MW71	87.4	0.343	57
		B1MLW1	87.4	0.355	58
		B1MLW2	89.4	0.347	58
		B1MLW3	91.4	0.353	64
		B1MLW4	93.4	0.363	57
		B1MLW5	95.4	0.35	60
		B1MLW6	97.4	0.344	58
		B1MLW7	99.4	0.344	56
		B1MLW8	101.4	0.346	53
		B1MLW9	103.4	0.345	57
		B1MLX0	105.4	0.347	60
		B1MLX1	107.4	0.346	58
		B1MLX2	109.4	0.35	55
		B1MLX3	111.4	0.343	59
199-D5-99	4/5/2007	B1MLX4	86.6	8.72	42
		B1MLX5	88.6	8.74	39
		B1MLX6	90.6	4.86	40
		B1MLX7	92.6	7.4	40
		B1MLX8	94.6	8.7	34
		B1MLX9	96.6	8.56	34
		B1MLY0	98.6	7.22	49
		B1MW72	98.6	8.16	43
		B1MLY1	100.6	8.42	41
		B1MLY2	102.6	8.5	63
		B1MLY3	104.6	8.74	41
		B1MLY4	106.6	8.48	41
		B1MLY5	108.6	6.26	52
		B1MLY6	112.6	9.1	47
		B1MLY7	112.6	6.72	43
199-D2-11	4/5/2007	B1MW89	84.7	0.011	24
		B1MW90	86.7	0.008	25
		B1MW91	88.7	0.007	21
		B1MW92	88.7	0.008	22
		B1MW93	90.7	0.008	21
		B1MW94	92.7	0.011	22
		B1MW95	94.7	0.009	22
		B1MW96	96.7	0.01	22
		B1MW97	98.7	0.009	20
		B1MW98	100.7	0.01	23
		B1MW99	102.7	0.013	21
		B1MWB0	104.7	0.014	22
		B1MWB1	106.7	0.015	22
		B1MWB2	108.7	0.016	20
		B1MWB3	110.7	0.024	22
		B1MWB4	112.7	0.005	21

Table B-2. APRIL 2007 DEPTH-DISCRETE GROUNDWATER SAMPLING (CONTINUED)

Well	Date Sampled	HEIS #	Sampling depth (ft)	Cr6+ (mg/L)	NO3 (mg/L)
199-D5-103	4/10/2007	B1MWD1	87.8	0.17	58
		B1MWD2	89.8	0.17	52
		B1MWD3	91.8	0.18	55
		B1MWD4	93.8	0.18	54
		B1MWD5	95.8	0.18	52
		B1MWD6	95.8	0.18	53
		B1MWD7	97.8	0.18	55
		B1MWD8	99.8	0.18	53
		B1MWD9	101.8	0.19	53
		B1MWF0	103.8	0.19	57
		B1MWF1	105.8	0.19	52
		B1MWF2	107.8	0.19	55
		B1MWF3	109.8	0.19	52
		B1MWF4	111.8	0.19	55
		B1MWF5	113.8	0.19	55
		B1MWF6	114.8	0.08	52

Well	Date Sampled	HEIS #	Sampling depth (ft)	Cr6+ (mg/L)	NO3 (mg/L)
199-D5-104	4/9/2007	B1MWF7	84.8	5.1	75
		B1MWF8	86.8	5.36	75
		B1MWF9	88.8	5.1	77
		B1MWH0	90.8	5.1	74
		B1MWH1	92.8	5.12	80
		B1MWH2	94.8	5.36	75
		B1MWH3	96.8	5.3	74
		B1MWH4	98.8	5.06	76
		B1MWH5	100.8	5.36	79
		B1MWH6	100.8	5.1	82
		B1MWH7	102.8	4.88	74
		B1MWH8	106.8	5.06	81
		B1MWH9	106.8	5.44	85
		B1MWJ0	108.8	4.76	77
		B1MWJ1	110.8	5	83
		B1MWJ2	111.8	4.4	81

Table B-3. MARCH 2008 DEPTH-DISCRETE GROUNDWATER SAMPLING

Well	Sample depth (ft bgs)	Elevation (ft msl)	Cr(VI) mg/L	HEIS #	Static water level (ft bgs) plus sampling time/date
199-D4-15	86.1	384.99	1.45	B1TV52	84.1 (12:15 3/11)
	88.1	382.99	1.45	B1TV53	
	90.1	380.99	1.45	B1TV54	
	92.1	378.99	1.45	B1TV55	
	94.1	376.99	1.45	B1TV56	
199-D5-98	83	385.76	0.235	B1TV67	81.0 (08:55 3/12)
	85	383.76	0.252	B1TV68	
	87	381.76	0.261	B1TV69	
	89	379.76	0.263	B1TV70	
	91	377.76	0.273	B1TV71	
	93	375.76	0.267	B1TV72	
	95	373.76	0.29	B1TV73	
	97	371.76	0.28	B1TV74	
	99	369.76	0.28	B1TV75	
	101	367.76	0.276	B1TV76	
	103	365.76	0.278	B1TV77	
	105	363.76	0.278	B1TV78	
	107	361.76	0.272	B1TV79	
199-D5-99	86.7	385.54	29.4	B1TV37	84.6 (13:00 3/12)
	88.7	383.54	31.1963	B1TV38	
	90.7	381.54	31.6719	B1TV39	
	92.7	379.54	32.1476	B1TV40	
	94.7	377.54	30.7206	B1TV41	
	96.7	375.54	31.1963	B1TV42	
	98.7	373.54	30.2449	B1TV43	
	100.7	371.54	29.2936	B1TV44	
	102.7	369.54	30.2449	B1TV45	
	104.7	367.54	28.818	B1TV46	
	106.7	365.54	27.8666	B1TV47	
199-D5-104	86.8	385.38	7.97	B1TV22	84.8 (09:44 3/11)
	88.8	383.38	7.74	B1TV23	
	90.8	381.38	7.51	B1TV24	
	92.8	379.38	7.74	B1TV25	
	94.8	377.38	8.89	B1TV26	
	96.8	375.38	8.43	B1TV27	
	98.8	373.38	8.2	B1TV28	
	100.8	371.38	8.66	B1TV29	
	102.8	369.38	8.66	B1TV30	
	104.8	367.38	8.43	B1TV31	
	106.8	365.38	8.66	B1TV32	
199-D5-120*	87.5 - 88.4		271	B1TC79	13:05 3/3**
	92.5 - 93.5		114	B1TC80	11:14 3/5**
	97.8 - 98.5		189	B1TC81	11:35 3/6**
	102.0 - 103.2		226	B1TC82	14:00 3/10**
	106.5 - 107.5		544	B1TVJ0	11:00 3/12**

*Data for this well obtained through a drill-and-test sequence during well construction.

**Static water level not recorded.

Table B-4. JUNE 2008 DEPTH-DISCRETE GROUNDWATER SAMPLING

Well	Sample depth (ft bgs)	Elevation (ft msl)	Cr(VI) mg/L	HEIS #	Static water level (ft bgs)
199-D5-99	85.5	386.9	2.99	B1W053	84.0 (11:30 6/11)
	88.5	383.9	2.99	B1W054	
	91.5	380.9	2.61	B1W055	
	94.5	377.9	2.61	B1W056	
	97.5	374.9	2.36	B1W057	
	100.5	371.9	2.86	B1W058	
	103.5	368.9	4.48	B1W059	
	106.5	365.9	10	B1W060	
199-D5-104	85.7	386.8	6.23	B1W037	84.2 (09:35 6/11)
	88.7	383.8	6.61	B1W038	
	91.7	380.8	6.51	B1W039	
	94.7	377.8	6.51	B1W040	
	97.7	374.8	6.26	B1W041	
	100.7	371.8	6.26	B1W042	
	103.7	368.8	6.51	B1W043	
	106.7	365.8	6.26	B1W044	
199-D5-119	85.7	386.8	2.18	B1VYX9	84.2 (08:05 6/11)
	88.7	383.8	2.23	B1VYY0	
	91.7	380.8	2.25	B1VYY1	
	94.7	377.8	2.25	B1VYY2	
	97.7	374.8	2.23	B1VYY3	
	100.7	371.8	2.27	B1VYY4	
	103.7	368.8	2.26	B1VYY5	
	106.7	365.8	2.2	B1VYY6	
199-D5-120	84.4	386.9	0.138	B1VYW3	82.9 (09:22 6/9)
	87.4	383.9	0.129	B1VYW4	
	90.4	380.9	0.123	B1VYW5	
	93.4	377.9	0.149	B1VYW6	
	96.4	374.9	0.333	B1VYW7	
	99.4	371.9	0.544	B1VYW8	
	102.4	368.9	0.552	B1VYW9	
	105.3	366	0.578	B1VYX0	
	EQUIP BLANK		<0.002	B1W079(EB)	
199-D5-122	84.6	386.8	20.8	B1W021	83.1 (11:40 6/9)
	87.6	383.8	22.6	B1W022	
	90.6	380.8	22.6	B1W023	
	93.6	377.8	22.6	B1W024	
	97.4	374	22.3	B1W025	
	99.6	371.8	22.6	B1W026	
	102.6	368.8	22.8	B1W027	
	105.6	365.8	22.3	B1W028	

Table B-5. FY2007 SEDIMENT SAMPLES

Well	Date	Depth (ft)	Cr6+ (mg/kg)	Total Cr (mg/kg)
199-D5-97	9-Feb-07	5	<2	
	9-Feb-07	10	<2	
	9-Feb-07	15	<2	
	9-Feb-07	20	<2	
	9-Feb-07	26	<2	
	9-Feb-07	30	<2	
	9-Feb-07	35	<2	
	9-Feb-07	40	<2	
	12-Feb-07	45	<2	
	12-Feb-07	50	<2	
	12-Feb-07	55	<2	
	12-Feb-07	60	<2	
	12-Feb-07	65	<2	
	12-Feb-07	70	<2	
	12-Feb-07	75	<2	
	13-Feb-07	80	<2	
	13-Feb-07	85	<2	

Well	Date	Depth (ft)	Cr6+ (mg/kg)	Total Cr (mg/kg)
199-D5-98	2/8/2007	5	<2	
	2/8/2007	10	<2	
	2/8/2007	15	<2	
	2/8/2007	20	<2	
	2/8/2007	25	<2	
	2/8/2007	30	<2	
	2/8/2007	35	<2	
	2/9/2007	40	<2	
	2/9/2007	45	<2	
	2/9/2007	50	<2	
	2/9/2007	55	<2	
	2/9/2007	60	<2	
	2/9/2007	65	<2	
	2/9/2007	70	<2	
	2/9/2007	75	<2	
	2/9/2007	77	<2	
	2/9/2007	80	<2	
	2/9/2007	85	<2	

Well	Date	Depth (ft)	Cr6+ (mg/kg)	Total Cr (mg/kg)
199-D5-99	2/14/2007	5	<2	
	2/14/2007	15-17	<2	9.7
	2/14/2007	17-21	<2	
	2/14/2007	28-31	<2	8.5
	2/14/2007	34-35	<2	4.4
	2/15/2007	40	<2	
	2/15/2007	45	<2	5.6
	2/15/2007	50	<2	
	2/15/2007	55	<2	5.2
	2/15/2007	60	<2	
	2/15/2007	65	<2	4.2
	2/15/2007	70	<2	
	2/15/2007	75	<2	6
	2/15/2007	80	<2	
	2/15/2007	81	<2	9.2
	2/15/2007	85	<2	9.4

Well	Date	Depth (ft)	Cr6+ (mg/kg)	Total Cr (mg/kg)
199-D2-11	2/28/2007	5	<2	
	2/28/2007	10	<2	
	2/28/2007	15	<2	
	2/28/2007	20	<2	
	2/28/2007	25	<2	
	2/28/2007	30	<2	
	2/28/2007	35	<2	
	2/28/2007	40	<2	
	2/28/2007	45	<2	
	3/1/2007	50	<2	
	3/1/2007	55	<2	
	3/1/2007	60	<2	
	3/1/2007	65	<2	
	3/1/2007	70	<2	
	3/1/2007	75	<2	
	3/1/2007	80	<2	
	3/1/2007	85	<2	

Table B-5. FY2007 SEDIMENT SAMPLES (CONTINUED)

Well	Date	Depth (ft)	Cr6+ (mg/kg)	Total Cr (mg/kg)
199-D5-102	3/1/2007	5	<2	
	3/1/2007	10	<2	
	3/2/2007	15	<2	
	3/2/2007	20	<2	
	3/2/2007	25	<2	
	3/2/2007	30	<2	
	3/2/2007	35	<2	
	3/2/2007	40	<2	
	3/2/2007	45	<2	
	3/2/2007	50	<2	
	3/2/2007	55	<2	
	3/2/2007	60	<2	
	3/5/2007	65	<2	
	3/5/2007	70	<2	
	3/5/2007	75	<2	
	3/5/2007	80	<2	

Well	Date	Depth (ft)	Cr6+ (mg/kg)	Total Cr (mg/kg)
199-D5-103	3/12/2007	5	<2	
	3/12/2007	10	<2	
	3/12/2007	15	<2	
	3/12/2007	20	<2	
	3/12/2007	25	<2	
	3/12/2007	30	<2	
	3/12/2007	35	<2	
	3/12/2007	40	<2	
	3/12/2007	45	<2	
	3/13/2007	50	<2	
	3/13/2007	55	<2	
	3/13/2007	60	<2	
	3/13/2007	65	<2	
	3/14/2007	70	<2	
	3/15/2007	75	<2	
	3/15/2007	80	<2	
	3/16/2007	84	<2	

Well	Date	Depth (ft)	Cr6+ (mg/kg)	Total Cr (mg/kg)
199-D5-104	3/13/2007	5	<2	
	3/14/2007	15	<2	
	3/14/2007	20	<2	
	3/14/2007	25	<2	
	3/14/2007	30	<2	
	3/14/2007	35	<2	
	3/14/2007	40	<2	
	3/14/2007	45	<2	
	3/14/2007	55	<2	
	3/14/2007	60	<2	
	3/14/2007	65	<2	
	3/14/2007	70	<2	
	3/15/2007	75	<2	
	3/15/2007	80	<2	

Table B-6. FY2008 SEDIMENT SAMPLES

Well	HEIS #	Depth (ft)	Cr+6 (mg/kg)	Total Cr (mg/kg)
199-D5-119	B1TJ64	5	<0.2	13.4
	B1TJ65	10	<0.2	6.9
	B1TJ66	15	<0.2	5.9
	B1TJ67	20	<0.2	5.7
	B1TJ68	25	<0.2	6.0
	B1TJ69	30	<0.2	5.2
	B1TJ70	35	<0.2	4.0
	B1TJ71	40	<0.2	7.0
	B1TJ72	45	<0.2	3.6
	B1TJ73	50	<0.2	4.7
	B1TJ74	55	<0.2	4.5
	B1TJ75	60	<0.2	5.6
	B1TJ76	65	<0.2	4.8
	B1TJ77	70	<0.2	8.3
	B1TJ78	75	<0.2	7.5
	B1TJ79	80	<0.2	8.8

Well	HEIS #	Depth (ft)	Cr+6 (mg/kg)	Total Cr (mg/kg)
199-D5-120	B1TC57	15-17	0.22	8.4
	B1TC58	20-22	0.85	9.9
	B1TC59	25-27	0.34	9.3
	B1TC60	30	<0.2	9.1
	B1TC61	35	<0.2	6.9
	B1TC62	40-42	1.5	4.5
	B1TC63	45	<0.2	8.5
	B1TC64	50	<0.2	5.4
	B1TC65	55-57	0.25	54.4
	B1TC66	60	<0.2	8.1
	B1TC67	65-67	<0.2	9.5
	B1TC68	67-69	<0.2	7.4

Well	HEIS #	Depth (ft)	Cr+6 (mg/kg)	Total Cr (mg/kg)
199-D5-121	B1TJ96	5	<0.2	9.5
	B1TJ97	10	<0.2	7.1
	B1TJ98	15	<0.2	5.5
	B1TJ99	20	<0.2	6.4
	B1TJB0	25	<0.2	6.4
	B1TJB1	30	0.21	5.7
	B1TJB2	35	0.31	5.6
	B1TJB3	40	<0.2	6.9
	B1TJB4	45	<0.2	6.7
	B1TJB5	50	<0.2	4.7
	B1TJB6	55	<0.2	7.1
	B1TJB7	60	<0.2	7.1
	B1TJB8	65	<0.2	4.3
	B1TJB9	70	<0.2	6.3
	B1TJC0	75	<0.2	5.9
	B1TJC1	80	<0.2	8.1

Well	HEIS #	Depth (ft)	Cr+6 (mg/kg)	Total Cr (mg/kg)
199-D5-122	B1TJ80	5	<0.2	12.8
	B1TJ81	10	<0.2	5.9
	B1TJ83	20	<0.2	7.5
	B1TJ84	25	<0.2	20.9
	B1TJ85	30	<0.2	5.1
	B1TJ86	35	<0.2	6.0
	B1TJ87	40	<0.2	4.4
	B1TJ88	45	<0.2	3.9
	B1TJ89	50	<0.2	6.3
	B1TJ90	55	<0.2	8.3
	B1TJ91	60	<0.2	5.1
	B1TJ92	65	<0.2	5.9

This page intentionally left blank.

APPENDIX C

DEPTH-DISCRETE GROUNDWATER SAMPLING

This page intentionally left blank.

APPENDIX C

DEPTH-DISCRETE GROUNDWATER SAMPLING

FIELD LOGS – MARCH 2008

199-D4-15

199-D5-98

199-D5-99

199-D5-104

FIELD LOGS – JUNE 2008

199-D5-99

199-D5-104

199-D5-119

199-D5-120

199-D5-122

LETTER REPORT *Demonstration of Depth-Discrete Sampling using the Solinst® Model 425 Discrete Interval Sampler**, S. H. Hall, 2008.

Planning for Depth-Discrete Groundwater Sampling in the 100-D Area, S. H. Hall , 2008.

*Appendices to the original letter report omitted.

FIELD ~~BOREHOLE~~ LOG

Page 1 of 1

Date: MAR 11, '08

Well ID: B8073 | Well Name: 199-D4-15 | Location: 100-HR-3

Project: Solinst Demo / Vert. sampling | Reference Measuring Point: Top of casing

Depth (Ft.) BGS	Sample Type/No.	Sample Blows Recovery	Graphic Log	Sample Description: Group Name, Grain Size Distribution, Soil Classification, Color, Moisture Content, Sorting, Angularity, Mineralogy, Max Particle Size, Reaction to HCl	Comments: Depth of Casing, Drilling Method, Method of Driving Sampling Tool, Sampler Size, Water Level
75	TARGET BGS				Screen 77.6-97.6' bgs
					DTB 100.6' bgs
					Outer casing 3.0'
					Pad ~0.2'
					TOC = 3.2' > ground surface
80					SWL 87.29' TOC @ 1215'
				TARGET:	Elev TOC = 144.565 m
				Below TOC / At hose guide / bgs	Sampling time
	▽			89.3 / 89.1 / 86.1	1247
85				91.3 / 91.1 / 88.1	1256
				93.3 / 93.2 / 90.1	1307
				95.3 / 95.1 / 92.1	1315
				97.3 / 97.1 / 94.1	1325
90			SCREEN		
95					
100					
105					
110					

Reported By: S.H. Hall | Reviewed By: S.W. Petersen

Title: Geochemist | Title: Manager, DA, M, & Tech

Signature: SHHall | Date: 3/11/08 | Signature: SWPetersen | Date: 9/10/08

FIELD ~~BOREHOLE~~ LOG

Page 1 of 1
Date: MAR 12, '08

Well ID: C5391	Well Name: 199-D5-98	Location: ~~[illegible]~~ N/A 100-HR-3	
Project: Solinst Demo/Vert. Sampling		Reference Measuring Point: N/A Top of casing 9/10/08	

Depth (Ft.) BGS	Sample Type No.	Sample Blows Recovery	Graphic Log	Sample Description: Group Name, Grain Size Distribution, Soil Classification, Color, Moisture Content, Sorting, Angularity, Mineralogy, Max Particle Size, Reaction to HCl	Comments: Depth of Casing, Drilling Method, Method of Driving Sampling Tool, Sampler Size, Water Level
75	TARGET BGS			Transducer pulled at 0859, replaced @ 1207	Screen 79.2-109.2 bgs
					DTB 112.7' bgs
					Outer casing 2.5'
					Pad 0.3'
					TOC 2.8' > ground surface
80					DTW 83.85' TOC @ 0855
					Elev TOC = 143.732 m
				TARGET:	
				Below TOC / At hose guide / bgs	Sampling time
85				85.8 / 85.6 / 83.0	0953
				87.8 / 87.6 / 85.0	1005
				89.8 / 89.6 / 87.0	1014
				91.8 / 91.6 / 89.0	1025
				93.8 / 93.6 / 91.0	1036
90				95.8 / 95.6 / 93.0	1046
				97.8 / 97.6 / 95.0	1111
				99.8 / 99.6 / 97.0	1120
				101.8 / 101.6 / 99.0	1128
				103.8 / 103.6 / 101.0	1135
95			SCREEN	105.8 / 105.6 / 103.0	1144
				107.8 / 107.9 / 105.0	1151
				109.8 / 109.6 / 107.0	1200
100					
105					
110					

Reported By: S.H. HALL		Reviewed By: S.W. Petersen	
Title: GEOCHEMIST		Title: Mgr., QA, M & Tech	
Signature: SHHall	Date: 3/12/08	Signature: SWPetersen	Date: 9/10/08

FIELD ~~BOREHOLE~~ LOG

Page 1 of 1

Date: MAR 12, '08

Well ID: C5392	Well Name: 199-D5-99	Location: ~~N/A~~ 100-HR-3	
Project: Solinst Demo/Vert. Sampling		Reference Measuring Point: N/A Top of casing	

Depth (Ft.) BGS	Sample Type/No.	Sample Blows Recovery	Graphic Log	Sample Description: Group Name, Grain Size Distribution, Soil Classification, Color, Moisture Content, Sorting, Angularity, Mineralogy, Max Particle Size, Reaction to HCl	Comments: Depth of Casing, Drilling Method, Method of Driving Sampling Tool, Sampler Size, Water Level
75	TARGET BGS			Transducer removed @ 1305 for sampling, and replaced at 1447	Screen 79.8 -109.4' bgs
					DTB 113.0' bgs
					Outer casing 2.2'
					Pad 0.3'
					TOC 2.5' > ground surface
80					DTW 87.06' (TOC) @ 1300
					Elev TOC = 144.669 m
85				TARGET:	
				Below TOC / At hose side / bgs	Sampling time
				89.1 / 89.0 / 86.7	1314
				91.1 / 91.0 / 88.7	1323
90				93.1 / 93.0 / 90.7	1330
				95.1 / 95.0 / 92.7	1337
				97.1 / 97.0 / 94.7	1344
				99.1 / 99.0 / 96.7	1358
				101.1 / 101.0 / 98.7	1405
95			SCREEN	103.1 / 103.0 / 100.7	1414
				105.1 / 105.0 / 102.7	1420
				107.1 / 107.0 / 104.7	1429
				109.1 / 109.0 / 106.7	1436
100					
105					
110					

Reported By: S.H. HALL		Reviewed By: S.W. Petersen	
Title: GEOCHEMIST		Title: Mgr., DA, M, & Tech	
Signature: SHHall	Date: 3/12/08	Signature: SWPetersen	Date: 9/10/08

FIELD
~~BOREHOLE LOG~~

Page 1 of 1
Date: MAR 11, '08

Well ID: C5400	Well Name: 199-D5-104	Location: 100-HR-3	
Project: Solinst Demo / Vert. Sampling		Reference Measuring Point: N/A Top of casing	

Depth (Ft.) BGS	Sample Type/No.	Sample Blows Recovery	Graphic Log	Sample Description: Group Name, Grain Size Distribution, Soil Classification, Color, Moisture Content, Sorting, Angularity, Mineralogy, Max Particle Size, Reaction to HCl	Comments: Depth of Casing, Drilling Method, Method of Driving Sampling Tool, Sampler Size, Water Level
75	TARGET BGS			Transducer removed @ 0951 for sampling, re-installed @ 11:57	Screen 80.0-110.0' bgs
					DTB 113.5' bgs
					Outer casing 2.5'
					Pad 0.4'
					TOC 2.9' > ground surface
80					DTW @ 0944 87.70' TOC
					Elev TOC = 144.805 m
85	▽			TARGET:	
				Below TOC / At hose guide / bgs	Sampling time
				89.7 / 89.5 / 86.8	1015
				91.7 / 91.5 / 88.8	1025
				93.7 / 93.5 / 90.8	1035
90				95.7 / 95.5 / 92.8	1045
				97.7 / 97.5 / 94.8	1055
				99.7 / 99.5 / 96.8	1103
				101.7 / 101.5 / 98.8	1112
				103.7 / 103.5 / 100.8	1120
95				105.7 / 105.5 / 102.8	1128
				107.7 / 107.5 / 104.8	1138
			SCREEN	109.7 / 109.5 / 106.8	1147
100					
105					
110					

Reported By: S. H. HALL		Reviewed By: S. W. Petersen	
Title: Geochemist		Title: Mgr., DA, M, & Tech	
Signature: SHHall	Date: 3/11/08	Signature: SWPetersen	Date: 9/10/08

FIELD ~~BOREHOLE~~ LOG

Page 1 of 1
Date: 6/11/08

Well ID: C5392 | Well Name: 199-D5-99 | Location: 100-HR-3

Project: Vert. sampling | Reference Measuring Point: Top of casing

Depth (Ft.)	Sample Type No.	Sample Blows Recovery	Graphic Log	Sample Description: Group Name, Grain Size Distribution, Soil Classification, Color, Moisture Content, Sorting, Angularity, Mineralogy, Max Particle Size, Reaction to HCl	Comments: Depth of Casing, Drilling Method, Method of Driving Sampling Tool, Sampler Size, Water Level
75	TARGET BGS			Transducer removed @ 1126 hr	Screen 79.3-109.4' bgs
				Replaced @ 1310 hr	PTB 113.0' bgs
					Outer casing 2.2'
					Pad 0.3'
					TOC 2.5' > ground surface
80			screen		▽Twest. ~34.5' bgs
					Water @ 86.57' ~~bgs~~ bTOC @ 11:30 9/10/08
	▽				
85					
				Target bgs / Target bTOC / Sample time	
				85.5 / 88.0 / 12:24	
90				88.5 / 91.0 / 12:30	
				91.5 / 94.0 / 12:40	
				94.5 / 97.0 / 12:46	
				97.5 / 100.0 / 12:52	
95				100.5 / 103.0 / 12:57	
				103.5 / 106.0 / 13:03	
				106.5 / 109.0 / 13:08	
100					
105					
110					

Reported By: SAHall		Reviewed By: S. W. Petersen	
Title: Geochemist		Title: Mgr., WA, M & Tech	
Signature: SAHall	Date: 6/11/08	Signature: [illegible]	Date: 9/10/08

~~BOREHOLE~~ FIELD LOG

Page 1 of 1

Date: 6/11/08

SHH 9/10/08

Well ID: C5400	Well Name: 199-D5-104	Location: N/A 100-HR-3	
Project: Vert. Sampling		Reference Measuring Point: ~~SHH~~ Top of casing SHH 9/10/08	

Depth (Ft.)	Sample Type No.	Sample Blows Recovery	Graphic Log	Sample Description: Group Name, Grain Size Distribution, Soil Classification, Color, Moisture Content, Sorting, Angularity, Mineralogy, Max Particle Size, Reaction to HCl	Comments: Depth of Casing, Drilling Method, Method of Driving Sampling Tool, Sampler Size, Water Level
75	TARGET BGS			Removed xducer at 0935	Screen 80-110' bgs
				Replaced at 1032	DTB 113.5' bgs
					Outer casing 2.5'
					Pad 0.4'
					TOC 2.9' > ground surface
80			screen		DTW - est. ~84.8' bgs
					Water 87.17' bgs TOC @ 0935 SHH 9/10/08
					stickup 2.5
				Target bgs / Target bTOC / Sampling time	Pad .5
85				85.7 / 88.7 / 0951	TOC 3.0' > ground surface
				88.7 / 91.7 / 0957	
				91.7 / 94.7 / 1004	
				94.7 / 97.7 / 1012	
				97.7 / 100.7 / 1017	
90				100.7 / 103.7 / 1023	
				103.7 / 106.7 / 1028	
				106.7 / 109.7 / 1034	
95					
100					
105					
110					

Reported By: S. H. Hall		Reviewed By: S. W. Petersen	
Title: Geochemist		Title: Mgr., DA, M, & Tech	
Signature: S H Hall	Date: 6/11/08	Signature: S W Petersen	Date: 9/10/08

~~BOREHOLE~~ FIELD LOG

Page 1 of 1
Date: 6/11/08

Well ID: C5933	Well Name: 199-D5-119	Location: N/A 100-HR-3	
Project: Vert. sampling		Reference Measuring Point: N/A Top of casing	

Depth (Ft)	Sample Type No.	Sample Blows Recovery	Graphic Log	Sample Description: Group Name, Grain Size Distribution, Soil Classification, Color, Moisture Content, Sorting, Angularity, Mineralogy, Max Particle Size, Reaction to HCl	Comments: Depth of Casing, Drilling Method, Method of Driving Sampling Tool, Sampler Size, Water Level
75	TARGET BGS				Screen 80.45-110.58' bgs
					TD 113.6' bgs
					Est. water 95.28 bgs
					Water @ 87.18 bTOC
					@ 0805
80					2.71 stickup
					0.3' Pad
					TOC 3.0 > ground surface
	▽				
85				TARGET BGS / TARGET TOC / TIME	
				85.7 / 88.7 / 0825	
				88.7 / 91.7 / 0833	
90				91.7 / 94.7 / 0850	
				94.7 / 97.7 / 0856	
				97.7 / 100.7 / 0907	
				100.7 / 103.7 / 0912	
				103.7 / 106.7 / 0920	
95			SCREEN	106.7 / 109.7 / 0927	
100					
105					
110					

Reported By: S. H. HALL		Reviewed By: S. W. Petersen	
Title: Geochemist		Title: Mgr., D.A.M. & Tech	
Signature: S H Hall	Date: 6/11/08	Signature: S W Petersen	Date: 9/10/08

FIELD ~~BOREHOLE~~ LOG

Page 1 of 1
Date: 6/9/08

Well ID: C5934	Well Name: 199-D5-120	Location: ~~N/A~~ SW 9/10/08 100-HR-3	
Project: Vert. Sampling		Reference Measuring Point: ~~N/A~~ Top of Casing SW 9/10/08	

Depth (Ft.)	Sample Type No.	Sample Blows Recovery	Graphic Log	Sample Description: Group Name, Grain Size Distribution, Soil Classification, Color, Moisture Content, Sorting, Angularity, Mineralogy, Max Particle Size, Reaction to HCl	Comments: Depth of Casing, Drilling Method, Method of Driving Sampling Tool, Sampler Size, Water Level
75	TARGET BGS			Note: 5.2' from intake to 5.0 mark	Screen 78.24-108.36' bgs
				Use hoseguide which add .3', so	DTB 112.4' bgs
				no tape correction need	DTW Est ~ 83.1' bgs
					Water below TOC 85.60'
					@ 0922
80					Casing stickup 2.4'
					Pad thickness 0.3'
					TOC 2.7' bgs
85				TARGET BGS / TARGET TOC / Time	
				84.4 / 87.1 / 9:50	
				87.4 / 90.1 / 10:10	
90				90.4 / 93.1 / 10:20	
				93.4 / 96.1 / 10:30	
				96.4 / 99.1 / 10:43	
				99.4 / 102.1 / 10:55	
				102.4 / 105.1 / 11:02	
95				105.4 / 108.1 / 11:12	
				EB / 11:17	
100					
105					
110					

Screen

Reported By: S. H. HALL		Reviewed By: S. W. Petersen	
Title: Geochemist		Title: Mgr., QA, M, & Tech	
Signature: S H Hall	Date: 6/9/08	Signature: SW Petersen	Date: 9/10/08

FIELD
~~BOREHOLE~~ LOG

SHH 9/10/08

Page 1 of 1
Date: 6/9/08

Well ID: C5936 | Well Name: 199-D5-122 | Location: ~~N/A~~ 100-HR-3

Project: Vert. sampling | Reference Measuring Point: N/A Top of casing

Depth (Ft.)	Sample Type No.	Sample Blows Recovery	Graphic Log	Sample Description: Group Name, Grain Size Distribution, Soil Classification, Color, Moisture Content, Sorting, Angularity, Mineralogy, Max Particle Size, Reaction to HCl	Comments: Depth of Casing, Drilling Method, Method of Driving Sampling Tool, Sampler Size, Water Level
75	TARGET bgs			No tape correction needed (see 199-D5-120)	Screen 77.7-107.9' bgs
					DTB 110.92' bgs
					DTW Est ~93.8' bgs
					Water 86.11' bTOC
					@ 11:40
80					Stickup = 2.55'
					Pad 0.4'
					TOC 3.0' > bgs
	▽				
85				TARGET bgs / TARGET bTOC / Time	
				84.6 / 87.6 / 12:30	
				87.6 / 90.6 / 12:42	
90				90.6 / 93.6 / 12:50	
				93.6 / 96.6 / 13:03	
				96.6+.8 / 99.6 / 13:11	← measured to 100.4
				99.6 / 102.6 / 13:22	instead of 99.6 !!
95			Screen	102.6 / 105.6 / 13:30	
				105.6 / 108.6 / 13:40	
100					
105					
110					

Reported By: S. H. HALL		Reviewed By: S. W. Petersen	
Title: GEOCHEMIST		Title: Mgr., DA, M, & Tech	
Signature: SHHall	Date: 6/9/08	Signature: SWPetersen	Date: 9/10/08

Demonstration of Depth-Discrete Sampling using the Solinst® Model 425 *Discrete Interval Sampler*

Stephen H. Hall

May 28, 2008

Introduction

In March, 2008, Freestone Environmental Services, Inc. ("Freestone"), demonstrated the use of a Solinst® Model 425 *Discrete Interval Sampler* at four 4-inch ID groundwater monitoring wells located in the 100-D Area of the Hanford Site. The demonstration had two goals, the first of which was to evaluate the practicality and ease of use of the Model 425 sampler for the purpose of obtaining depth-discrete groundwater samples from Hanford monitoring wells, which in some cases may be as narrow as two inches ID. The second goal was to determine the vertical distribution of hexavalent chromium contamination in each of the four wells, and to examine the results as possible clues to the proximity of the source of chromium contamination. The demonstration was sponsored by Fluor Hanford's 100-D Chromium Source Investigation, and the field work was conducted March 11 – 12, 2008. Results and discussion relating to each of these goals are presented below.

Depth-Discrete Sampler Description

The Solinst® Model 425 sampler, shown in Figure 1, is a manually operated, reel-deployed, pressure-activated device that is available in a wide range of sizes and materials of construction, as described in the Solinst literature shown in Appendix A. The sampler used in this demonstration is the smallest standard size (nominally 1 inch in diameter by 24 inches long), is made of stainless steel, and is attached to 200 feet of 0.25-inch OD polyethylene tubing. The tubing is marked in 5-foot intervals. Using this configuration (sampler size and tubing length) the tubing can safely support the weight of the deployed sampler. According to the manufacturer's representative, a separate stainless steel suspension cable is required for deploying a larger-size sampler, or for deployment to greater than 200 ft. A suitable cable is available from the manufacturer.

Figure C-1. Solinst sampler, hose, and reel.

Sources of Sampling Error

Sampling depth uncertainty. Depth-discrete sampling using any type of apparatus is subject to uncertainty caused by water displacement, the volume of water removed, and induced vertical mixing. The 1-inch OD x 24 inch sampler used in the present project collects approximately 175 mL of sample volume (when fully submerged) at each sampling depth. However, the fully submerged sampler displaces approximately 350 mL of water and an additional 10 mL is displaced for each foot of submerged tubing. The sampler's displacement necessarily moves water in the well bore and aquifer, thus causing some uncertainty in the effective sampling depth. For example, if the sampler's intake is lowered to precisely 6 feet below static water table in a 2-inch ID well, the sampler displaces water equivalent to the contained volume of 8 inches of the well bore. In a 4-inch ID well, the displacement is equivalent to 2 inches of well bore. The displacement will be partially compensated when groundwater flows into the sampler body. The

actual magnitude and direction of net sampling depth error depends upon well hydraulics, but it is clear that the narrower well presents the greater potential for offset error.

Similarly, the cumulative volume of water samples removed from the well forces movement of water in the well bore and aquifer, and the magnitude of the possible error increases as the number of collected samples increases.

Finally, the physical act of repetitively lowering and retrieving the sampler will cause some mixing within the well bore, so it is important to collect samples beginning with the shallowest and working downward.

These sources of error can be mitigated by collecting samples and using sampling apparatus that are as small as practical, and by minimizing the number of sampling intervals in a well. The net error is extremely difficult to predict, but the author's experience in conducting tracer experiments using a submersible sensor comparable in dimensions to the 1x24-inch Solinst sampler suggests that net sampling depth error in a 4-inch ID well, sampled at 2 to 3-foot intervals, is likely to have little or no practical effect on the representativeness of a vertical profile of chemical distribution.

Water column representativeness. For depth-discrete sampling to be meaningful, it is necessary that the composition of the water in the well bore at any given depth be representative of the groundwater in the adjacent aquifer. An activity such as pumping the well or the installation or removal of the pump itself, which is usually a sizeable object, will clearly mix the water and disrupt compositional equilibrium between the well bore and the aquifer. Based on a review of the hydrogeology at the 100-D project site, it was estimated that a period of not less than two weeks should suffice to allow horizontal advection to flush a disturbed water column from the well bore and re-establish compositional equilibrium between the aquifer and the well.

Field Campaign

The pumps were removed from the four test wells in late January. Because of schedule constraints, however, the sampling was delayed until March 11 – 12. It was learned after the fact that one of the wells (199-D5-104, see below) had been sampled by purging and pumping just the day before the depth discrete sampling was performed. The data for that well are presented here for completeness, but cannot be viewed as representative of the adjacent aquifer.

A detailed procedure for deploying the Solinst sampler was prepared by Freestone and is included in Appendix B. For this demonstration, the wells were sampled at 2-foot intervals, from 2 feet below static water level to approximately 1.5 to 2 feet above the bottom of the screened interval. Depth to water was measured at each well using an electric tape just prior to sampling. Depth to bottom and screened interval were obtained from the *Hanford Well Information System* during the sampling planning process. Appendix C contains the field logs for each of the tested wells.

Maximum well depth in this demonstration was approximately 110 feet below the top-of-casing, and maximum submergence (i.e., sampling depth) was approximately 30 feet. The internal pressure of the sampler was raised to 40 psig for lowering and retrieving the sampler for all sample depths (see Appendix B). This pressure is nearly double that required pressure for the maximum submergence, and was chosen for convenience (no field calculations required).

Figure C-2. Draining a sample from the Solinst Model 425.

For each sampling depth, after retrieving the sampler, the polyethylene tube was disconnected, the sampler was wiped dry, and the sample was drained directly into the sample container (see Figure 2). Then, the sampler was disassembled, rinsed with DI water, wiped dry, and reassembled. With two people working at a steady pace, samples were easily retrieved from a well at the rate of one sample every 7 to 10 minutes.

A red dry-erase marker and measuring tape were used to temporarily mark target depths on the polyethylene tube. The use of the black plastic hose guide, which is supplied with the sampler, is required to prevent chafing of the tubing by the top edge of the well casing. The hose guide is shown in Figure 3. Note that a lanyard was used to ensure that the hose guide did not inadvertently drop into the well.

Figure C-3. Hose guide with lanyard on outer well casing.

Samples were submitted to the Waste Sampling and Characterization Facility (WSCF) for determination of hexavalent chromium. (Note that on-site field analysis can be both practical and inexpensive and should be considered for future field work.)

Chromium Data Interpretation

For the Chromium Source Investigation, depth-discrete sampling and analysis were used to construct vertical profiles of hexavalent chromium contamination in four wells within the study area. Each of the four wells fully penetrates the unconfined aquifer. The concept being tested is that the nearer a well is to a vadose zone source of concentrated hexavalent chromium, the more likely it is that chromium concentrations near the top of the water column will be significantly greater than near the bottom.

The reasoning for this is straightforward:

- Chromium from a vadose zone source necessarily enters the aquifer at the water table.

- In an aquifer dominated by horizontal advection, contamination entering the aquifer from the vadose zone source begins immediately to be transported downgradient.
- Downward spread of contamination in the aquifer is dominated by the vertical component of dispersion as the plume moves downgradient.

Because there is not necessarily a direct correlation between source proximity and contaminant concentration (i.e., a well near the source may be cross-gradient or upgradient from source) the examination of vertical contaminant distribution complements conventional plume visualization based on contouring mean concentrations.

Results of analysis. Figure 4 is a map of the area of interest that shows the location of the four wells sampled with the Solinst sampler, which are 199-D4-15, 199-D5-98, 199-D5-99, and 199-D5-104. Figure 5 shows the vertical hexavalent chromium concentration profile for each of the wells.

Results from well 199-D5-99 generally support the notion that a well near a vadose zone contaminant source ought to show higher concentrations near the top of the water column than near the bottom. However, profiling of additional wells in the vicinity of 199-D5-99 will be needed before the utility of concentration profiling for estimating source proximity can be evaluated.

The general direction of groundwater flow and contaminant plume migration is westerly towards the Columbia River. To date, the highest hexavalent chromium concentrations have been measured in samples from well 199-D5-99, which is presumed to be near the source, i.e., near the head of the plume. The vertical concentration profile for this well shows a small but distinct decrease of concentration with depth. Wells 199-D4-15 and 199-D5-104 are generally downgradient from 199-D5-99, while 199-D5-98 is cross-gradient. In both of the wells 199-D4-15 and 199-D5-98 the chromium concentration is uniform within the water column. As noted above, measured concentrations in well 199-D5-104 cannot be considered representative.

Conclusions

Performance of the Solinst sampler used in this field demonstration proved satisfactory in all respects although practical application requires two pairs of hands. There's one cautionary note: It's important to use the hose guide to prevent damage to the polyethylene tube, which is fragile compared to the deployment cable of an e-tape, pressure transducer, or similar field equipment. Achieving a rate of 7 to 10 minutes per sampling interval became routine with a bit of practice.

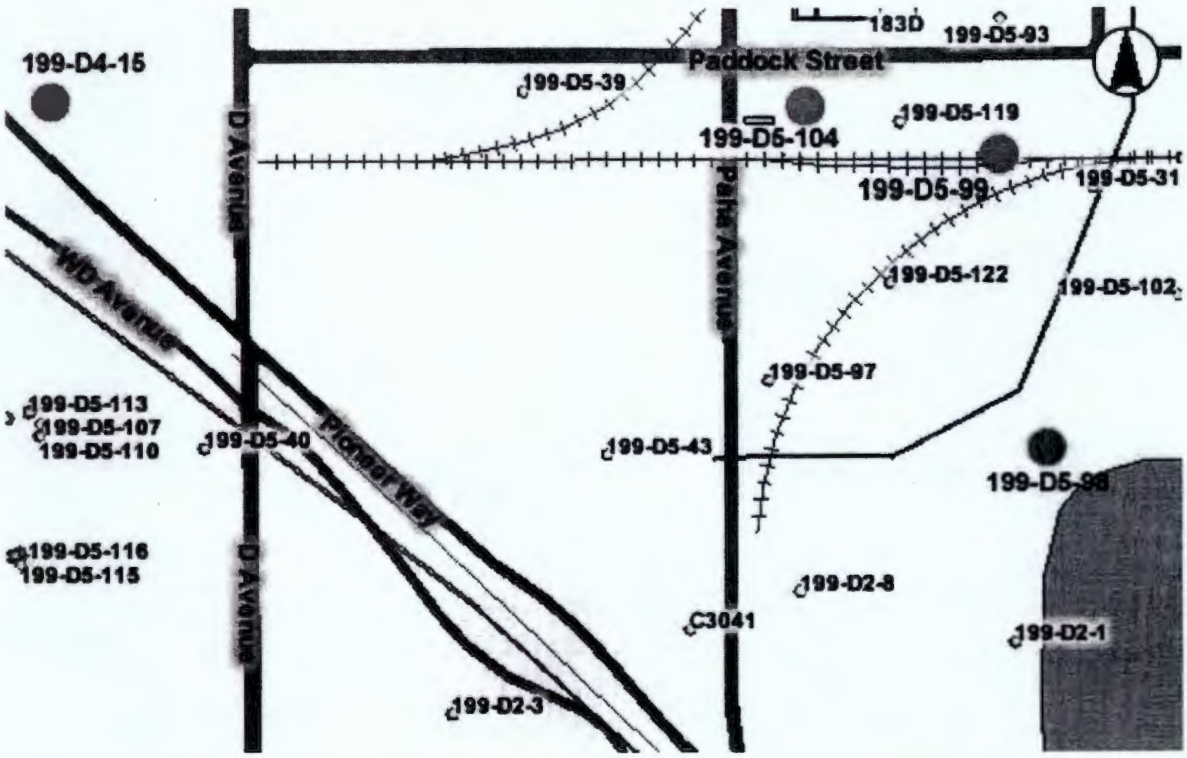


Figure C-4. Well locations for the chrome source investigation.

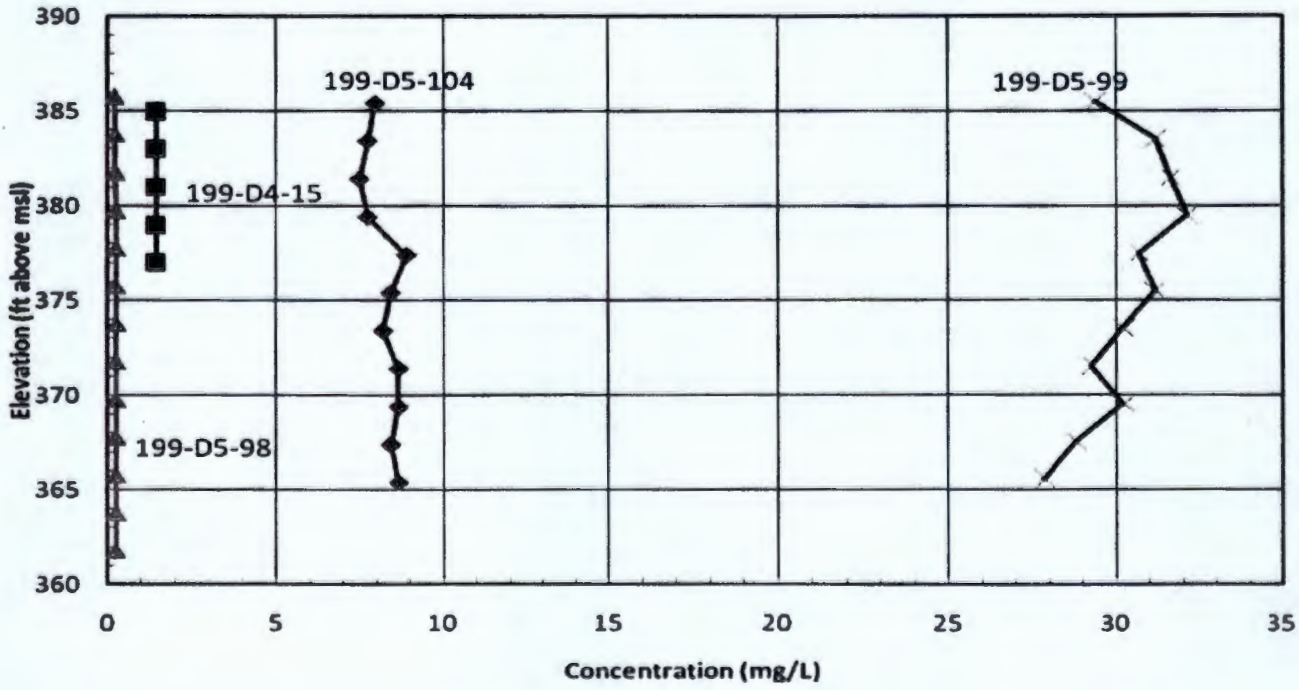


Figure C-5. Vertical distribution of CrVI in selected 100-D wells.

Planning for Depth-Discrete Groundwater Sampling in the 100-D Area

If depth-discrete sampling of the water column in a well is to be meaningful, the contents of the well bore at any given depth needs to be representative of the adjacent aquifer. If the water column has been disturbed, such as by purging and sampling or even by removing a pump and pipe string to allow sampling access, it is necessary to delay depth-discrete sampling until horizontal advection has effectively swept non-representative water from the well bore. For the 100-D Chrome Source Investigation, the period of time necessary to flush non-representative water from the well bore was estimated as presented here.

The period of delay is calculated using a form of the mathematical expression used to evaluate point-dilution tests (Hall 1993). The required input parameters are hydraulic conductivity, local hydraulic gradient, and an estimate of a flow distortion factor (in the absence of field data, the value of the flow distortion factor is commonly taken as equal to 2). The mathematical expression is:

$$t = -\frac{V}{r} lnC$$

Where t = time in days, V = the volume of a 1-ft section of well bore (0.087 ft^3 for 4-in ID screen), and r = the advective rate of flux (ft^3/d) of groundwater through a 1-ft section of the well bore as calculated below. The variable C is the remaining volume fraction of the non-representative water in the well bore. For example, when $C = 0.1$ (i.e., 10%) 90% of the non-representative water has been replaced by groundwater from the adjacent aquifer.

The variable r is calculated as follows:

$$r = \alpha A k I$$

Where α = flow distortion factor (i.e., 2), A = maximum vertical cross-sectional area of a 1-ft length of the well screen (0.333 ft^2 for 4-in ID wells), k = hydraulic conductivity (ft/d), and I = local hydraulic gradient.

Given a mean hydraulic conductivity of 157 ft/d and a local hydraulic gradient of 0.0016 (mid-March 2008), the value for r is 0.17 in the vicinity of the high concentration plume, and:

$$t = -.51 lnC$$

Given these values, flushing of the non-representative water is 90% complete in approximately 1.2 days. However, the variable r is directly proportional to hydraulic conductivity which in turn varies significantly from well to well, and is likely to vary with depth within each well. Therefore, a delay of at least one week was recommended, thus allowing 90% water replacement in zones having hydraulic conductivity as small as 26 ft/d (17% of the mean hydraulic conductivity of the 11 wells drilled for the project).

This page intentionally left blank

APPENDIX D

FLOW MODELING REPORT

This page intentionally left blank.

TABLE OF CONTENTS

D1.0 INTRODUCTION D-6

D2.0 DATA PREPARATION D-2

D3.0 WATER LEVEL MAPS D-3

D4.0 PARTICLE TRACKING D-4

D5.0 DISCUSSION D-5

D6.0 GROUNDWATER ELEVATION CONTOURING METHODS D-6
- D6.1 UNIVERSAL KRIGING D-7
  - D6.1.1 Pumped Well Drift Term D-8
  - D6.1.2 The Inclusion of Line Sinks/Sources D-9
- D6.2 PARTICLE TRACKING D-10

D7.0 REFERENCES D-11

FIGURES

Figure D1-1. Principle Site Features D-6
Figure D3-1. Water elevation maps showing seasonal fluctuation in flow direction. D-4
Figure D4-1. Results of transient tracking, using water level maps generated according to Case 4, Table D3-1. ..... D-5
Figure D5-1. Hydrographs of selected wells in OU100D D-6

TABLES

Table D2-1. Summary of Data Provided for Use in Water Level Mapping and Particle Tracking Analysis. D-3
Table D3-1. Summary of Drift Terms Used in Kriging Scenarios. D-4

This page intentionally left blank.

APPENDIX D

FLOW MODELING REPORT

D1.0 INTRODUCTION

This appendix describes the analysis of groundwater elevation data to evaluate the likely directions and rates of groundwater flow and contaminant migration in the vicinity of the area of high chromium contamination. The analysis focuses on mapping of groundwater elevation data obtained from a series of dataloggers recording continuous water levels in monitoring wells throughout 100-D (Figure D1-1).

This appendix summarizes:

- The data that were obtained
- The data preparations that were undertaken to make the data amenable to analysis
- The water level mapping analyses
- A particle tracking analysis
- Results and preliminary interpretation of the analysis

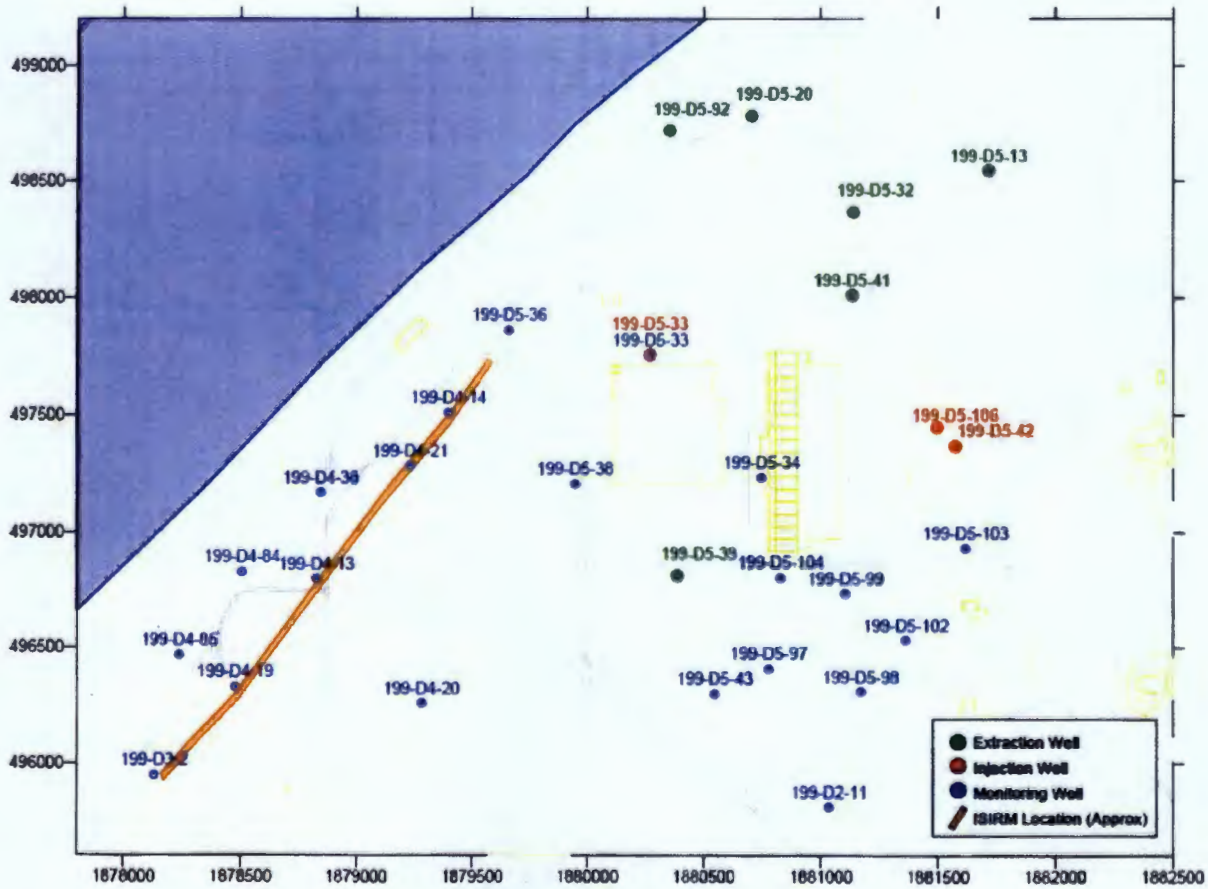


Figure D1-1. Principle Site Features.

D2.0 DATA PREPARATION

Table D2-1 lists date ranges and measurement interval for water level and injection/extraction data used in this water level mapping/particle tracking analysis.

The method used to prepare data for use in the water level mapping and particle tracking analyses for the various data were the following:

1. *Water Levels from Monitoring Wells*: Daily average water levels were calculated from hourly datalogger measurements for each well. A few anomalous points were deleted or corrected based on the well hydrographs.
2. *River Gauge*: Daily average gauge elevation was calculated from hourly datalogger measurements at the 100-D river gauge. For some cases in the water level mapping/particle tracking analyses, several control points were added along the shoreline of the river. In these cases, daily average water elevation for all control points was set to equal the daily average at River Gauge D.
3. *DR-5 Pump and Treat System*: Daily average extraction (GPM) was calculated from hourly datalogger measurements for the four extraction wells in the DR-5 system. Daily average injection rate (GPM) was set to equal the sum of the daily average extraction of all wells. All injection was through well 199-D5-42.
4. *Electrocoagulation Treatability Test* (5/17/2007 to 10/25/2007): Daily total gallons processed data (GPM) were provided. Total injection rate was set to equal total extraction rate. All injection was through well 199-D5-106, except for the 17 days between 8/21/2007 and 9/6/2007. During this time, well 199-D5-106 was being refurbished and all water was injected through 199-D5-33. Extraction was divided between well 199-D5-13 and 199-D5-41 at a ratio of 1:4 for all days.

Table D2-1. Summary of Data Provided for Use in Water Level Mapping and Particle Tracking Analysis.

Well ID	Water Levels		DR5 Extraction		EC Test: Injection/Extraction Inferred from Provided Totals	
	Date Range	Interval	Date Range	Interval	Date Range and Type	Interval
199-D2-11	4/6/07 11:00 AM - 3/31/08 7:00 AM	hourly				
199-D3-2	4/1/07 12:00 AM - 3/31/08 7:00 AM	hourly				
199-D4-13	4/1/07 12:00 AM - 3/31/08 3:00 AM	hourly				
199-D4-14	4/1/07 12:00 AM - 3/31/08 3:00 AM	hourly				
199-D4-19	4/1/07 12:00 AM - 3/31/08 3:00 AM	hourly				
199-D4-20	4/1/07 12:00 AM- 3/31/08 4:00 AM	hourly				
199-D4-21	4/1/07 12:00 AM - 3/31/08 3:00 AM	hourly				
199-D4-38	4/1/07 12:00 AM - 3/31/08 3:00 AM	hourly				
199-D4-84	4/1/07 12:00 AM - 3/31/08 3:00 AM	hourly				
199-D4-85	4/1/07 12:00 AM - 3/31/08 3:00 AM	hourly				
199-D5-102	4/6/07 8:00 AM - 3/31/08 7:00 AM	hourly				
199-D5-103	4/6/07 7:00 AM - 3/31/08 7:00 AM	hourly				
199-D5-104	4/3/07 10:00 AM - 3/31/08 7:00 AM	hourly				
199-D5-106					Injection: 5/17/2007 - 8/20/2007 and 9/7/2007 - 10/25/2007	daily
199-D5-13					Extraction: 5/17/2007 - 10/25/2007	daily
199-D5-20			1/1/2007 11:00:00 PM - 3/10/2008 12:00 AM	hourly		
199-D5-32			1/1/2007 11:00:00 PM - 3/10/2008 12:00 AM	hourly		
199-D5-33	4/1/07 12:00 AM - 8/13/2007 9:00 AM and 9/20/2007 9:00 AM - 3/31/08 4:00 AM	hourly			Injection: 8/21/2007 - 9/6/2007	daily
199-D5-34	4/1/07 12:00 AM - 3/31/08 4:00 AM	hourly				
199-D5-36	4/1/07 12:00 AM - 3/31/08 2:00 AM	hourly				
199-D5-38	4/1/07 12:00 AM - 3/31/08 4:00 AM	hourly				
199-D5-39			1/1/2007 11:00:00 PM - 3/10/2008 12:00 AM	hourly		
199-D5-41					Extraction: 5/17/2007 - 10/25/2007	daily
199-D5-43	4/1/07 1:00 AM - 3/31/08 4:00 AM	hourly				
199-D5-92			1/1/2007 11:00:00 PM - 3/10/2008 12:00 AM	hourly		
199-D5-97	4/6/07 8:00 AM - 3/31/08 7:00 AM	hourly				
199-D5-98	4/6/07 10:00 AM - 3/31/08 7:00 AM	hourly				
199-D5-99	4/6/07 7:00 AM - 3/31/08 10:00 AM	hourly				
D-River Gauge	4/1/07 12:00 AM - 3/31/08 4:00 AM	hourly				

D3.0 WATER LEVEL MAPS

Using data prepared as described above, water level maps were generated for each day between April 17, 2007 and March 10, 2008. Water level mapping was accomplished using a method that combines universal kriging (UK) (Deutsch and Journal, 1992) with analytical elements representing the approximate effect of groundwater extraction/injection, and losses to/gains from rivers to aquifers (Rouse, 1949; Tonkin and Larson, 2002; Tonkin and Muffels, 2004) (see Attachment A).

The choice of drift terms used in kriging may influence the resulting water level maps. In order to insure the most appropriate drift terms were selected, seven cases were considered. Each case represents a different combination of drift terms (Table D3-1). Drift terms described in Case 4 and Case 7 result in maps that appear to illustrate features expected at the site, plus previous knowledge of the site. Representative (seasonal) maps from Case 4 are shown in Figure D3-1. All daily maps for each case are provided as part of the electronic data transmittal.

Table D3-1. Summary of Drift Terms Used in Kriging Scenarios.

Case Number	XY (Planar) Drift	River Line Sink	River Control Points	Well Drift	Image Wells
1	yes	one drift term	yes	injection and extraction in two seperate drift terms	none
2	yes	one drift term	yes	injection and extraction in one drift term	none
3	yes	none	no	injection, extraction, and image wells in one drift term	all injection and extraction wells
4	yes	one drift term	yes	none	none
5	yes	one drift term	yes	extraction at 199-D5-39 only (no injection)	none
6	yes	one drift term	yes	injection at 199-D5-42 and injection at 199-D5-39 in one drift term	none
7	yes	one drift term	yes	injection at 199-D5-42 and injection at 199-D5-39 in two seperate drift terms	none

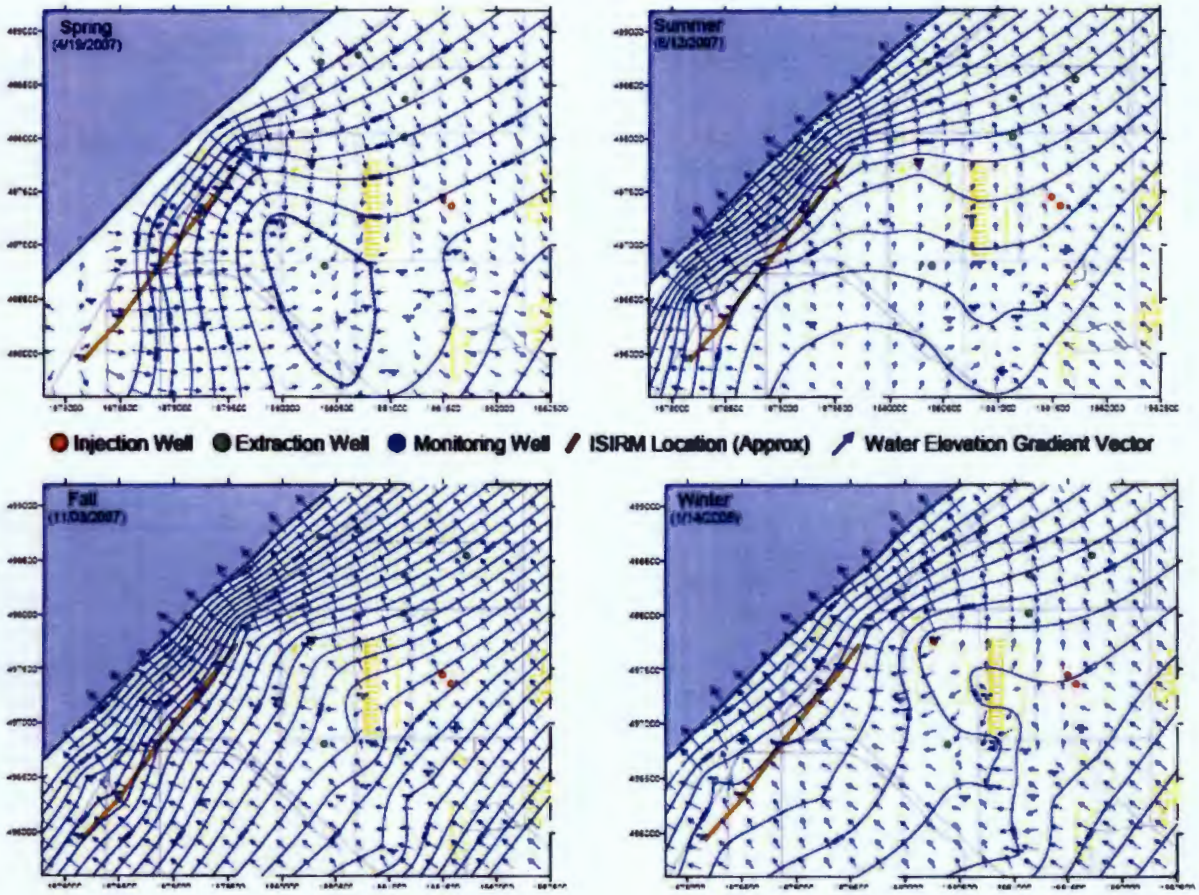


Figure D3-1. Water elevation maps showing seasonal fluctuation in flow direction. Surfaces were kriged using the parameters listed in Table D3-1, Case 4. Contour interval is 0.2 feet.

D4.0 PARTICLE TRACKING

Water level maps generated using drift parameters from Table D3-1, Case 4 were used for transient tracking using the fourth-order Runge-Kutta scheme (Press et al, 1996). One particle was released near well 199-D5-104 on April 17, 2007 and tracked along the daily water level surfaces until March 10, 2008 (328 days). Hydraulic conductivity was set to 100 ft/day and porosity was set to 0.2: note that equivalent results would be obtained using a hydraulic conductivity of 50 ft/d and a porosity of 0.1.

After about 11 months of simulated migration, the net travel distance of the particle from the well towards the river was about 40 ft. Principal changes in the flow direction and rate are expected to have occurred in response to changes in river stage; local changes in the flow direction and rate may have occurred in response to changes in groundwater extraction/injection, perhaps coinciding with the commencement of the EC test and/or changes in pumping rate at 199-D5-39 (Figure D4-1).

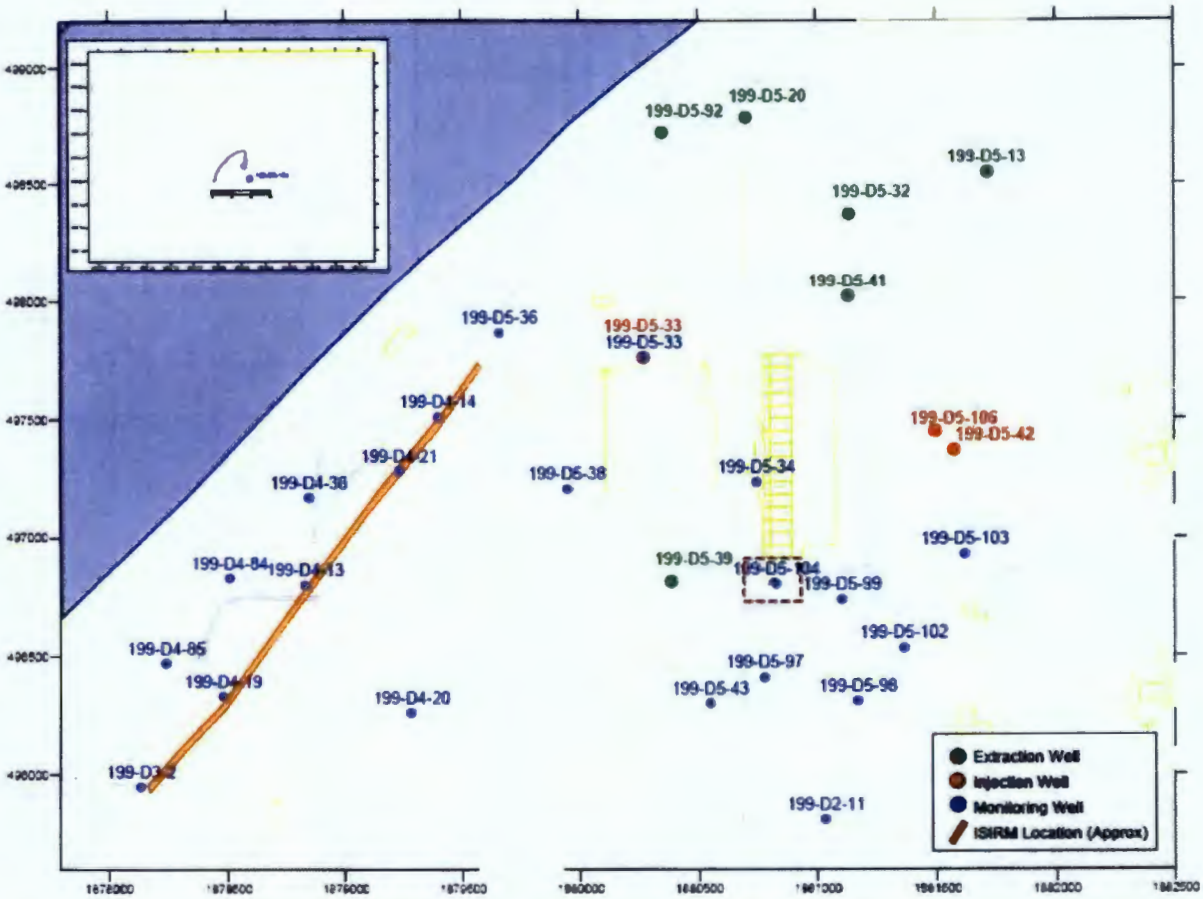


Figure D4-1. Results of transient tracking, using water level maps generated according to Case 4, Table D3-1. Particle track is shown in violet. Aquifer parameters used for tracking are: hydraulic conductivity = 100 ft/day, porosity = 0.2. Inset shows area inside red dotted line.

D5.0 DISCUSSION

Inspection of hydrographs for selected wells (Figure D5-1) suggests that some of the monitoring wells may be grouped by their responses as follows:

1. Wells D5-99, D5-104 and D5-34 show very similar and very detailed (nuanced) responses, similar response times, patterns, and frequencies/wavelengths

2. Wells D5-102 and D5-103 show similar but quite muted responses, where the detail is smoothed.
3. Well D5-97 shows a yet more muted and smoothed response.
4. Well D5-43 shows a variable response that has features of the above, plus its own very distinct characteristics.

Though it is presently unclear what leads to these groups, it is likely that it is due to the wells that show similar responses lying within similar – and laterally contiguous – aquifer materials.

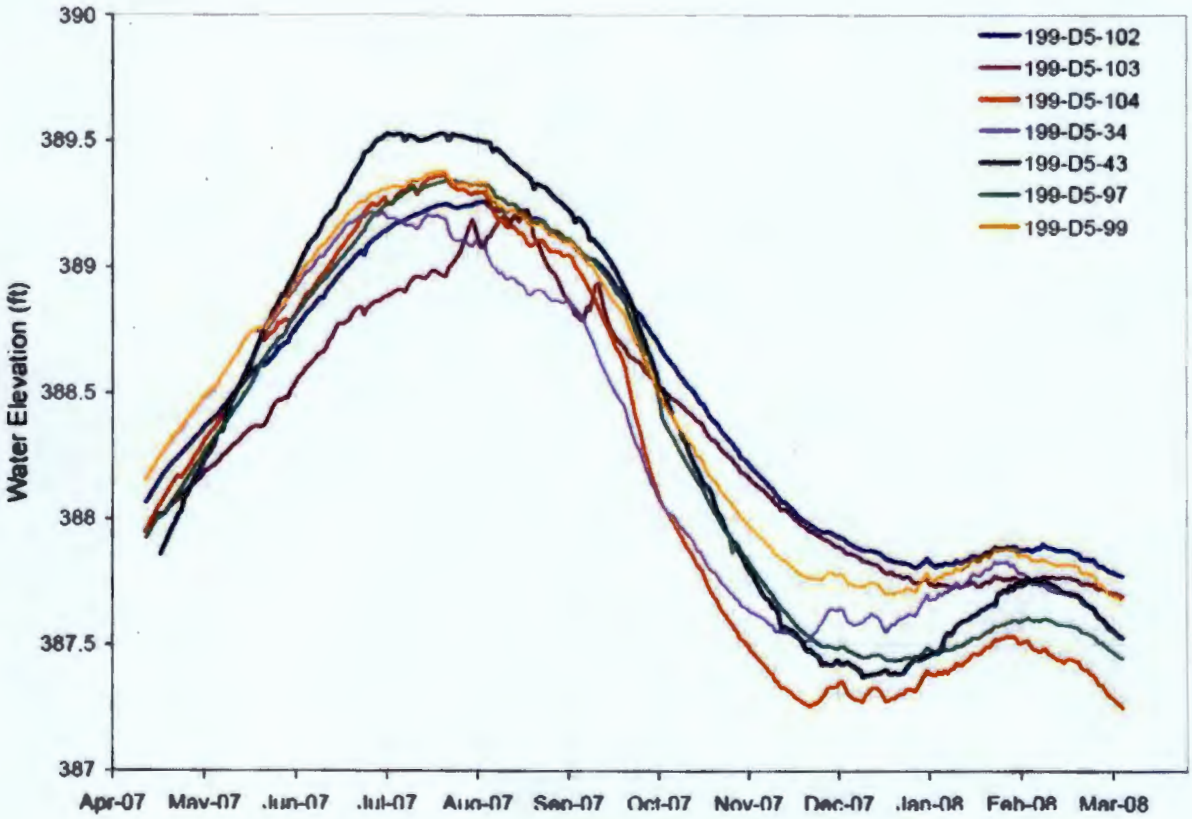


Figure D5-1. Hydrographs of selected wells in OU100D.

D6.0 GROUNDWATER ELEVATION CONTOURING METHODS

The following discussion outlines a method for interpolating from measured groundwater elevations to produce contour maps of approximate groundwater elevations. Since the method is based on automated gridding, it can be more consistent between data sets and between analysts than methods based on hand contouring. Since the method is based on Universal Kriging, it can support the inclusion of information about stresses and boundaries that can affect groundwater elevations, such as pumping wells. A brief overview of Universal Kriging is provided first.

D6.1 UNIVERSAL KRIGING

Kriging is employed in the hydrologic disciplines for interpolating measured data to regular grids suitable for contouring. One advantage of kriging over other interpolation methods is that, in the absence of measurement error or replicates (co-located data), it is an exact interpolator. Chiles and Delfiner (1999) provide a detailed summary of kriging.

Two popular forms of kriging employed for interpolating real-valued data are (1) simple kriging and (2) ordinary kriging. In simple kriging, the mean of the data, m, is assumed to be constant everywhere and its value known a-priori. In ordinary kriging the mean is assumed to be unknown a-priori, and is estimated using either all or some local (moving) neighborhood of the measured data. The methods described in this discussion are based upon ordinary kriging. In the most common implementation of ordinary kriging, the mean is assumed to be constant and equivalent to the mean of the data – that is, $m = m(x)$. However, ordinary kriging can support a spatially varying mean which is commonly described as a smoothly-varying mean or "drift." When a spatially varying mean is incorporated, the kriging estimate can be illustrated as the sum of two components, the mean and a zero-mean residual:

$$H(x) = m(x) + \varepsilon(x) \qquad \text{(D-1)}$$

where:

$H(x)$ = the kriging estimate

$m(x)$ = the smoothly-varying trend or drift

$\varepsilon(x)$ = the zero-mean random residual from the drift

This approach is commonly referred to as Universal Kriging (UK), and the spatially varying mean or drift is commonly determined or provided in one of two distinct ways (see Deutsch and Journel, 1992; Volpi and Gambolati, 1978, for further details):

- A linear combination of known functions, the coefficients of which are estimated as part of the kriging process on the basis of the data. This approach to UK is often referred to as kriging with a drift or trend model. The drift is often a low-order linear function of the coordinates.
- Through the incorporation of a smoothly-varying mean that was calculated on the basis of other information. This is usually referred to as a "secondary variable" since the "primary variable" is the water level. Because the secondary variable is used to provide an estimate of the smoothly-varying mean of the primary variable, it should be correlated with the primary variable. This variant of the UK approach is often referred to as kriging with an external drift.

Kriging with a linear trend model or drift is available through popular programs such as Surfer® and TecPlot®. A linear drift is suitable in situations where unidirectional regional groundwater flow exists, a condition often encountered. Use of the linear drift equates to fitting a plane to the water level data. The UK estimator for gridding water level data using this approach can be illustrated as:

$$H(x,y) = A + BX + CY + \varepsilon(x,y) \tag{D-2}$$

where:

H(x,y) = the estimated elevation at location (X,Y)

X = the easting or X ordinate

Y = the northing or Y ordinate

A, B, C = coefficients for the plane fitting the groundwater heads

ε (x,y) = the residual from the drift

The linear drift described by (D-2) may not be suitable in areas (a) where singularities occur within the data field such as created by pumping wells, (b) where lateral hydrologic boundaries such as the lateral termination of aquifer materials are present, (c) where there is a significant vertical component of flow, and/or (d) where there are substantial changes in aquifer properties or preferential pathways. If these effects can be represented in the trend using appropriate functions with linear coefficients, these difficulties can be resolved and kriging can produce suitable maps. Tonkin and Larson (2002) and Brochu and Marcotte (2003) describe the incorporation of analytic elements within the kriging method to account for effects due to pumped wells and boundaries. A brief discussion of relevant aspects of this topic follows.

D6.1.1 Pumped Well Drift Term

For a single well, the Thiem equation states that, for consistent units:

$$s_r = \frac{2.3Q}{2\pi T}\log_{10}\left(\frac{R}{r}\right) \tag{D-3}$$

where:

r = radial distance from the pumped well

R = radius of influence

s_r = drawdown due to pumping

Q = pumping rate

T = aquifer transmissivity

Examination of (D-3) indicates that pumping at a single well produces a logarithmic pattern of drawdown centered on the pumping well. Under certain assumptions, superposition can be used to sum the effect of multiple extracting or injecting wells. This essential information can be distilled and combined with the linear drift shown in (D-2) to give:

$$H(x,y) = A + BX + CY + D\sum_{1}^{n} Q_i \log_{10}(r_i) + \varepsilon(x,y) \qquad \text{(D-4)}$$

where:

$Q_i \log_{10}(r_i)$ = drawdown factor due to pumping at the ith well

D = the linear regression coefficient for the drawdown factors

$\sum_{1}^{n}$ = the summation from 1 to n where n = the number of pumped wells

A full derivation of (D-4) is given in Tonkin and Larson (2002). They illustrate that, for synthetic and real-world applications where assumptions of the Thiem equation are reasonably adhered to, (D-4) provides an improved interpolation of measured water level data that can extend inferences about groundwater levels. The drift described by (D-4) is implemented in a version of the popular kriging program KT3D (Deutsch and Journel, 1992) that is freely available at www.sspa.com. This drift term can be used in combination with any of the standard two-dimensional drifts included with KT3D.

D6.1.2 The Inclusion of Line Sinks/Sources

Mounding or drawdown of groundwater elevations in response to horizontal linear features, such as interception trenches, infiltration galleries, or rivers, can under some circumstances be represented using the analytic element solution for line sinks/sources of known strength. The approach is based on the Analytic Element Method (AEM) described by Strack (1989) and further documented and incorporated into the AEM program TWODAN (Fitts, 2004). The complex potential representing a line sink is:

$$\Omega = \frac{\sigma L}{4\pi}\left((Z+1)Ln(Z+1) - (Z-1)Ln(Z-1)\right) \qquad \text{(D-5)}$$

where L is the length of the line sink/source and Z is a dimensionless complex variable defined as (Strack, 1989; Fitts, 2004):

$$Z = \frac{2z - (z1 + z2)}{(z2 - z1)} \qquad \text{(D-6)}$$

where:

$z1$ = complex ordinate of one end of the line

$z2$ = complex ordinate of the other end of the line

z = $x + iy$ is the point where Z and Ω are evaluated.

Since σL, the discharge-per-unit-length is considered known out the outset the solution for Ω is a linear problem that can be included in the linear kriging system of equations. This drift can be used in combination with the drift term describing mounding or drawdown in response to pumping, and with any of the standard two-dimensional drifts included with the program KT3D. This essential information can be distilled and combined with the linear and logarithmic drifts shown in (D-4) to give:

$$H(x,y) = A + BX + CY + D\sum_{1}^{n} Q_i \log_{10}(r_i) + E\sum_{1}^{m} L(r_i) + \varepsilon(x,y) \qquad \text{(A-7)}$$

where:

$L(r_i)$ = drawdown factor due to effects of the ith line sink

E = the linear regression coefficient for the line sink factors

$\sum_{1}^{m}$ = the summation from 1 to n where n = the number of pumped wells

D6.2 PARTICLE TRACKING

When the groundwater elevation data have been used to generate a map of groundwater levels, whether through kriging or another method, the resulting surface may be suitable for particle tracking to estimate groundwater flow directions and the approximate extent of hydraulic capture. In this particle tracking method massless, inert particles are considered to be placed at user-specified starting points in the aquifer. At any point in the aquifer, the slope of the estimated groundwater head surface can be determined using finite differences, for example, and the estimated slope can be combined with estimated hydraulic conductivity K and effective porosity to estimate the average velocity of any particle:

$$V(x,y) = Ki / n_e \qquad \text{(D-8)}$$

where:

V (x,y)	= groundwater velocity
K	= hydraulic conductivity
i	= hydraulic gradient
n_e	= effective porosity

Then, the particle's movement in the velocity field can be integrated using a Runge-Kutta or other integration scheme (Press et al., 1996).

D7.0 REFERENCES

Brochu, Y., and D. Marcotte. 2003. A Simple Approach to Account for Radial Flow and Boundary Conditions When Kriging Hydraulic Head Fields for Confined Aquifers: *Mathematical Geology* 35, no. 2, February: 111-139.

Chiles, J., and P. Delfiner. 1999. *Geostatistics: Modeling Spatial Uncertainty*. New York: John Wiley & Sons.

Deutsch, C., and Journel, A., (1992). GSLIB: Geostatistical Software Library and User's Guide. Oxford University Press, 340 pp.

Fitts, C., (2004). TWODAN - Manual. Fitts Geosolutions, Scarborough, Maine.

Press, W.H., B.P. Flannery, S.A. Teukolsky, and W.T. Vetterling. 1996. *Numerical Recipes in Fortran-90* (2nd ed.). Vol. 2. Cambridge: Cambridge University Press.

Rouse, H. (ed). 1949. Engineering Hydraulics: Proceedings of the Fourth Hydraulics Conference. Iowa Institute of Hydraulic Research, June 12-15, 1949. John Wiley and Sons, New York.

Strack, O.D.L., (1989). Groundwater Mechanics. Prentice-Hall, Englewood Cliffs, New Jersey.

Tonkin, M.J., and S.P. Larson. 2002. Kriging Water Levels with a Regional-Linear and Point-Logarithmic Drift: *Ground Water* 40, no. 2, March/April: 185-193.

Tonkin, M.J., and C. Muffels. 2004. Assessing Hydraulic Capture through Combined Analytic Elements and Interpolation. EPA Groundwater Forum, October 2004, Sacramento, California (invited).

Volpi, G., and G. Gambolati. 1978. On the Use of a Main Trend for the Kriging Technique in Hydrology: *Advances in Water Resources* 1: 345-349.

This page intentionally left blank.

DISTRIBUTION

Onsite			
6	U.S. Department of Energy, Richland Operations Office		
	DOE Public Reading Room		H2-53
	J. P. Hanson	(2)	A5-11
	T. C. Post		A3-04
	K. M. Thompson	(3)	A6-38
12	Fluor Hanford, Inc.		
	R. Jackson		E6-35
	S. W. Petersen (3)		E6-35
	B. F. Raidl		E6-35
	K. K. Schneider (3)		E6-35
	D. J. Shrimpton		E6-44
	L. C. Swanson		E6-35
	J. A. Winterhalder		E6-35
	C. S. Wright		E6-35
1	Lockheed Martin Services, Inc.		
	Document Processing Center		H6-08
2	Pacific Northwest National Laboratory		
	Hanford Technical Library		P8-55
	E. P. Dresel		K6-96
2	Washington Closure Hanford, LLC		
	E. T. Feist		H4-22
	M. A. Buckmaster		X9-08
1	Freestone Environmental Services, Inc.		
	S. H. Hall		B2-63

This page intentionally left blank