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Fiscal Year 2006 Annual Summary Report for the In Situ Redox Manipulation Operations

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

United States Department of Energy
P.O. Box 550
Richland, Washington 99352

Approved for Public Release;
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EXECUTIVE SUMMARY

This report presents the annual summary and evaluation of the performance of the In Situ Redox (reduction-oxidation) Manipulation (ISRM) interim remedial action located in the 100-D Area, within the 100-HR-3 Operable Unit (OU) at the Hanford Site. The ISRM is a groundwater permeable reactive barrier established to remedy a hexavalent chromium plume. This report covers the period of October 1, 2005, through September 30, 2006.

The remedial action objectives (RAOs) of the ISRM treatment zone are presented in the original Record of Decision (ROD) for the 100-HR-3 OU (*Declaration of the Record of Decision for the 100-HR-3 and 100-KR-4 Operable Units at the Hanford Site [Interim Remedial Actions]* [EPA et al. 1996]). The specific RAOs are identified as follows.

- **RAO #1:** Protect aquatic receptors in the river substrate from exposure to contamination in groundwater entering the Columbia River.
- **RAO #2:** Protect human health by preventing exposure to contaminants in the groundwater.
- **RAO #3:** Provide information that will lead to the final remedy.

An ISRM treatability test was conducted in the 100-D Area in 1997 and 1998 in the center of the most contaminated portion of the groundwater plume. The purpose of the test was to evaluate the technology in Hanford Site groundwater for large-scale implementation.

The 1999 amended ROD decision for the 100-HR-3 OU (*U.S. Department of Energy Hanford Site – 100 Area Benton County, Washington – Amended Record of Decision Summary and Responsiveness Summary [100-HR-3 Operable Unit]* [EPA et al. 1999]) identified ISRM as the selected remediation alternative to address a newly defined groundwater plume located west of the D/DR Reactors. The amended ROD authorized large-scale deployment of the ISRM technology to remediate the plume and deferred the details of the design to the *Remedial Design Report and Remedial Action Work Plan for the 100-HR-3 Groundwater Operable Unit In Situ Redox Manipulation* (DOE-RL 2000). A 3-year, three-phase emplacement schedule was developed. The 680-m (2,231-ft)-long permeable reactive barrier was completed in the fall of 2004.

Seven compliance monitoring wells located between the barrier and the Columbia River shoreline are sampled quarterly to assess the performance of the ISRM treatment zone in the protection of aquatic receptors. As of fiscal year 2006 (FY06), the annual average hexavalent chromium concentrations in two of the seven compliance wells has met the RAO of 20 μg/L; two other compliance wells are near the RAO. Annual average concentrations decreased in four of the seven compliance wells and were stable in the other three compliance wells relative to FY05 values. The highest annual average chromium concentration in the seven compliance wells is 595 μg/L in well 199-D4-39.

Access controls continue to protect human health by restricting access to contaminants in the groundwater.

Monitoring groundwater contamination upgradient of and in the barrier provides information that will lead to the final remedy. The southwestern portion of the barrier appears to be effectively mitigating hexavalent chromium contamination. Some areas in the northeastern portion of the barrier have lost reductive capacity and are show increasing hexavalent chromium concentrations. Concentrations greater than 200 μg/L were measured in 14 to 15 of the 41 northeastern barrier wells in the first and second quarters of FY06, respectively.

Because previous attempts to re-establish reductive capacity in the barrier using the original ISRM chemicals have not been effective, other approaches are being pursued to mend the barrier. In addition, an effort is underway to identify the source(s) of the hexavalent chromium plume. Planning was completed in FY06 for these activities. In FY07, this work will include field testing the injection of miron-sized, zero-valent iron to mend the barrier; installing characterization wells and other investigations to locate the source(s) of the hexavalent chromium plume; and performing treatability testing of in situ biostimulation to reduce hexavalent chromium and nitrate in the plume.

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LIST OF TERMS

CERCLA	*Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
CFR	*Code of Federal Regulations*
DO	dissolved oxygen
DWS	"National Primary Drinking Water Standards" (40 CFR 141)
Eh	reduction/oxidation potential
EPA	U.S. Environmental Protection Agency
FH	Fluor Hanford, Inc.
FY	fiscal year
gpm	gallons per minute
HEIS	Hanford Environmental Information System
IAM	interim action monitoring
IC	ion chromatography
ICP	inductively coupled plasma
ISRM	In Situ Redox Manipulation
MCL	maximum contaminant level
NAVD88	North American Vertical Datum of 1988
OU	operable unit
QC	quality control
RAO	remedial action objective
RCRA	*Resource Conservation and Recovery Act of 1976*
RDR/RAWP	remedial design report/remedial action work plan
ROD	Record of Decision
RPD	relative percent difference
SDWS	"National Secondary Drinking Water Standards" (40 CFR 143)
WAC	*Washington Administrative Code*

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METRIC CONVERSION CHART

Into Metric Units			Out of Metric Units		
If You Know	*Multiply By*	*To Get*	*If You Know*	*Multiply By*	*To Get*
Length			**Length**		
inches	25.4	millimeters	Millimeters	0.039	inches
inches	2.54	centimeters	Centimeters	0.394	inches
feet	0.305	meters	Meters	3.281	feet
yards	0.914	meters	Meters	1.094	yards
miles	1.609	kilometers	Kilometers	0.621	miles
Area			**Area**		
sq. inches	6.452	sq. centimeters	sq. centimeters	0.155	sq. inches
sq. feet	0.093	sq. meters	sq. meters	10.76	sq. feet
sq. yards	0.836	sq. meters	sq. meters	1.196	sq. yards
sq. miles	2.6	sq. kilometers	sq. kilometers	0.4	sq. miles
acres	0.405	hectares	Hectares	2.47	acres
Mass (weight)			**Mass (weight)**		
ounces	28.35	grams	Grams	0.035	ounces
pounds	0.454	kilograms	Kilograms	2.205	pounds
ton	0.907	metric ton	metric ton	1.102	ton
Volume			**Volume**		
teaspoons	5	milliliters	Milliliters	0.033	fluid ounces
tablespoons	15	milliliters	Liters	2.1	pints
fluid ounces	30	milliliters	Liters	1.057	quarts
cups	0.24	liters	Liters	0.264	gallons
pints	0.47	liters	cubic meters	35.315	cubic feet
quarts	0.95	liters	cubic meters	1.308	cubic yards
gallons	3.8	liters			
cubic feet	0.028	cubic meters			
cubic yards	0.765	cubic meters			
Temperature			**Temperature**		
Fahrenheit	subtract 32, then multiply by 5/9	Celsius	Celsius	multiply by 9/5, then add 32	Fahrenheit
Radioactivity			**Radioactivity**		
picocuries	37	millibecquerel	Millibecquerels	0.027	picocuries

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1.0 INTRODUCTION

This annual progress and performance report discusses the In Situ Redox Manipulation (ISRM) interim remedial action at the 100-HR-3 Operable Unit (OU) from October 1, 2005, through September 30, 2006 (fiscal year 2006 [FY06]). This report specifically addresses remedial actions performed at the hexavalent chromium plume in the southwestern portion of the 100-D Area (Figure 1-1). Interim pump-and-treat remedial actions performed at the northeastern portion of the 100-D Area and in the 100-H Area are discussed in a separate annual summary report. This is the sixth annual summary report that specifically addresses the ISRM remediation technology, as presented in the *Remedial Design Report and Remedial Action Work Plan for the 100-HR-3 Groundwater Operable Unit In Situ Redox Manipulation* (RDR/RAWP) (DOE-RL 2000).

The ISRM technology involves creating a permeable subsurface treatment zone by injecting sodium dithionite into the aquifer, thus creating a chemically reduced environment. Hexavalent chromium passing through the treatment zone is reduced to less toxic and less mobile trivalent chromium.

Deployment of ISRM is specified in the *U.S. Department of Energy Hanford Site – 100 Area Benton County, Washington – Amended Record of Decision Summary and Responsiveness Summary (100-HR-3 Operable Unit)* (EPA et al. 1999) (hereinafter referred to as the ROD Amendment). The following remedial action objectives (RAOs) are identified in the *Declaration of the Record of Decision for the 100-HR-3 and 100-KR-4 Operable Units at the Hanford Site (Interim Remedial Actions)* (EPA et al. 1996) and the ROD Amendment:

- **RAO #1:** Protect aquatic receptors in the river bottom substrate from contaminants in groundwater entering the Columbia River.
- **RAO #2:** Protect human health by preventing exposure to contaminants in the groundwater.
- **RAO #3:** Provide information that will lead to the final remedy.

In addition to these RAOs, the ISRM system has been constructed in accordance with key design elements described in the RDR/RAWP (DOE-RL 2000).

1.1 PURPOSE

The purpose of this annual report is to provide the following:

- Document the progress toward achieving key design elements specified in the RDR/RAWP (DOE-RL 2000)
- Document groundwater remediation system performance and status
- Document general aquifer conditions and aquifer response to remedial actions
- Provide discussion on remediation efforts.

1.2 HISTORY OF OPERATIONS

The 100-HR-3 OU is located in the northern portion of the Hanford Site along the Columbia River. This OU includes the groundwater underlying the source OUs associated with the D/DR

and H Reactor areas and the property lying between the two areas. During operation of the D/DR Reactors between 1944 and 1967, large volumes of water were pumped from the Columbia River and used as reactor coolant. Sodium dichromate was added to the cooling water to inhibit corrosion of the reactor piping and subsequently leaked into the soil and contaminated the groundwater.

Following discovery of hexavalent chromium contamination in groundwater in 1995, an ISRM treatability test was conducted in the 100-D Area. The first ISRM treatment took place in well 199-D4-7 in September 1997, and four additional wells were treated between May and July 1998. The five treated wells created a reducing zone in the unconfined aquifer that was approximately 46 m (151 ft) long by 15 m (49 ft) wide (Figure 1-2).

During the fall of 1999, the treatment zone in the treatability test area was extended by the treatment of a sixth well (199-D4-21), resulting in hexavalent chromium concentrations being reduced from 1,050 µg/L to less than detection in that well. The success of these six treatment wells provided sufficient additional data to support advancing from treatability testing to emplacement of a large-scale treatment zone.

ISRM was identified in the ROD Amendment (EPA et al. 1999) as the selected alternative for hexavalent chromium treatment within the newly defined groundwater plume located to the west of the D/DR Reactor area. This alternative differed from the selected remedial action of pump-and-treat reinjection activities specified in the ROD for the 100-HR-3 OU (EPA et al. 1996). The ROD Amendment deferred the details of the full-scale design of the treatment zone to the RDR/RAWP (DOE-RL 2000). A 3-year emplacement schedule was developed in the RDR/RAWP to meet the ROD Amendment requirements. The three phases (Phases I, II, and III) coincide with FY00, FY01, and FY02, respectively. The ISRM treatment zone was constructed outward from the center of the most contaminated portion of the groundwater plume near the Columbia River shoreline. The treatment zone was to be expanded until the edge of the 20 µg/L hexavalent chromium groundwater plume was reached, as identified in the RDR/RAWP.

In FY00, Phase I of the large-scale deployment of the ISRM technology was initiated. Sixteen wells were installed (2 compliance wells and 14 treatment zone wells), and chemical treatment was performed in 10 wells. During this phase, the ISRM treatment zone was extended 60 m (197 ft) toward the northeast and 60 m (197 ft) toward the southwest.

In FY01, Phase II well construction and treatment zone emplacement activities began. Thirty-two wells were installed (4 compliance wells and 28 treatment zone wells), and chemical treatment was performed in 28 wells. These 28 treatment wells extended the ISRM treatment zone to a length of over 195 m (640 ft).

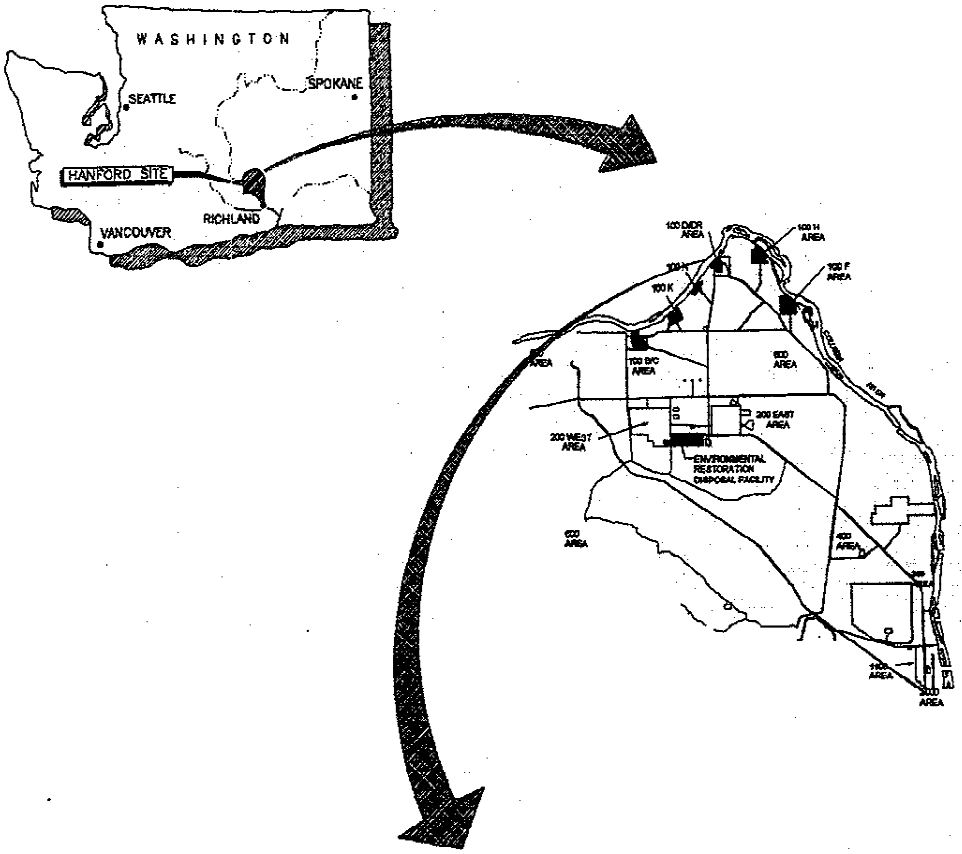
The ISRM barrier was extended to the west during Phase III drilling in FY02. Seventeen ISRM treatment wells and 3 characterization boreholes were drilled, and chemical treatment was performed in 12 of 17 treatment wells. Chemical treatment was subsequently completed in the last five wells during FY03, which extended the ISRM treatment zone to a length of 680 m (2,231 ft).

1.3 REPORT ORGANIZATION

This document consists of nine sections. Section 1.0 contains the introduction. Section 2.0 provides an overview and discussion of the ISRM technology and its development and demonstration at the Hanford Site. Section 3.0 discusses aquifer response in terms of both

hydraulic monitoring and contaminant monitoring. Section 4.0 provides a brief discussion of pending treatability tests and drilling. Section 5.0 discusses the quality assurance/ quality control (QC) for the samples analyzed in FY06, and Section 6.0 presents ISRM cost data. Section 7.0 provides conclusions, and Section 8.0 presents recommendations. A list of the references used to prepare this document is found in Section 9.0. Appendix A contains plots of flow direction and gradient solutions for groundwater, and Appendix B includes hexavalent chromium concentration trend plots.

Figure 1-1. In Situ Redox Manipulation Site Location Map.



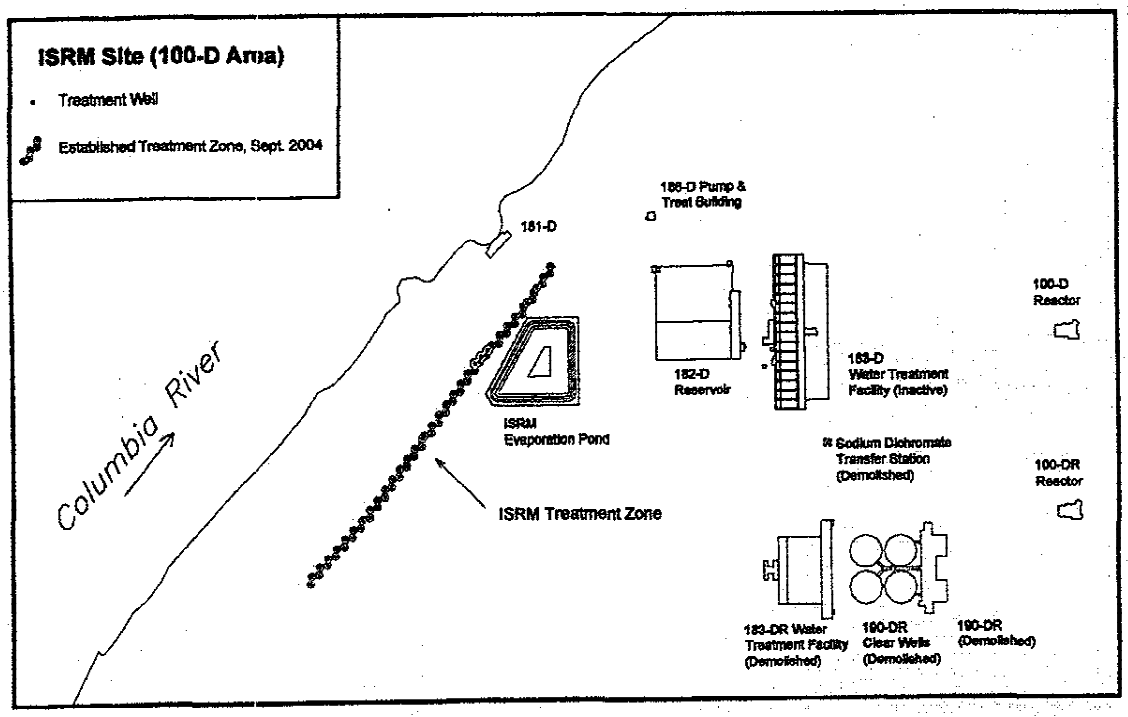
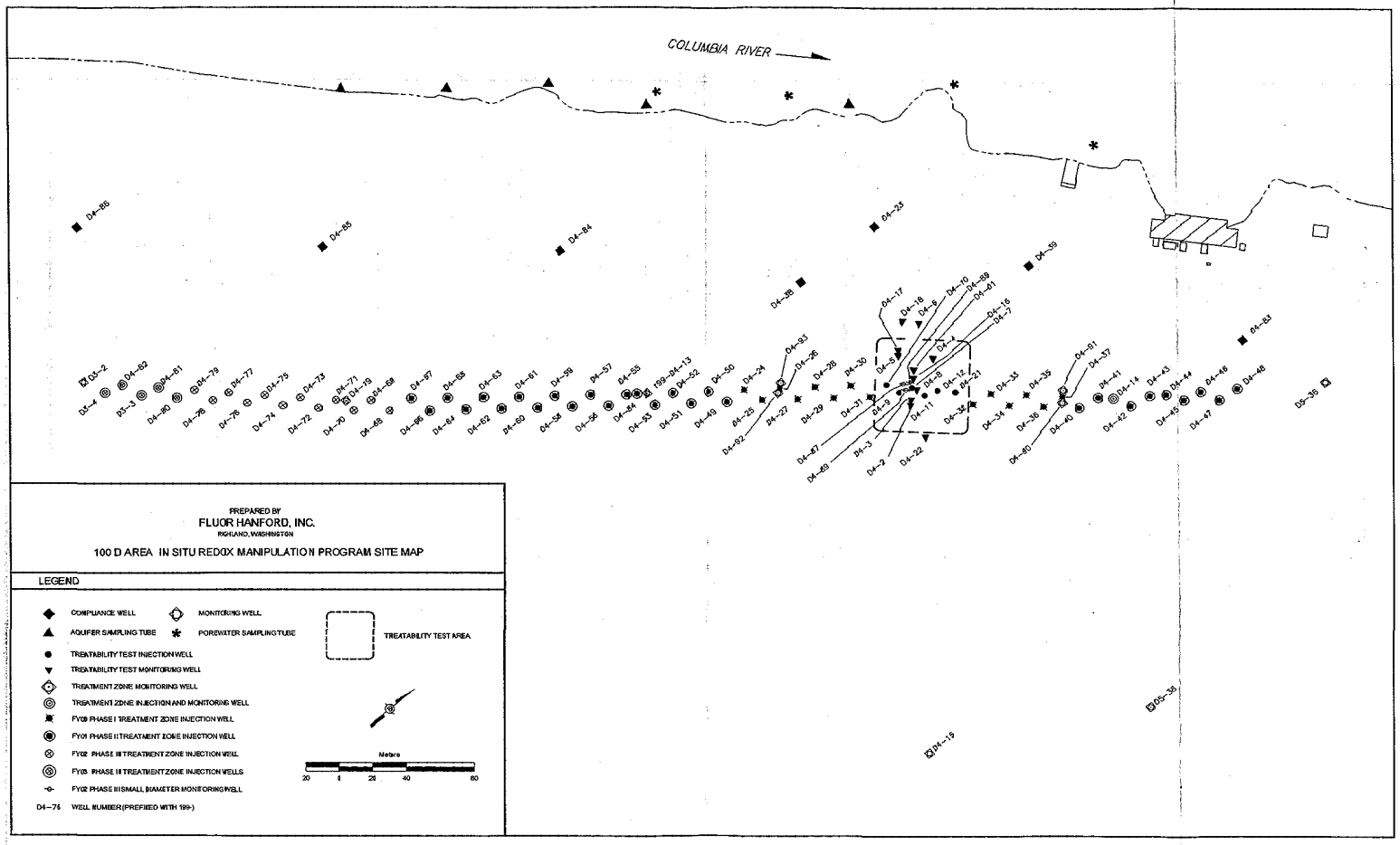


Figure 1-2. In Situ Redox Manipulation Treatment Zone Well Locations.



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2.0 IN SITU REDOX MANIPULATION TECHNOLOGY OVERVIEW

A plume of dissolved hexavalent chromium in the groundwater was discovered in 1995 during groundwater characterization activities along the Columbia River shoreline to the west of the D/DR Reactors in the 100-D Area. The source of the observed hexavalent chromium contamination is believed to be sodium dichromate. Sodium dichromate-dihydrate ($Na_2Cr_2O_7 \cdot 2H_2O$) was previously used for corrosion control in reactor cooling water. Chemical stock material or concentrated sodium dichromate solution may have been released near the reactor inlet cooling water treatment facilities. The geometry of the current groundwater plume indicates that the release(s) occurred near the facility where water was treated before it was used as cooling water in the reactors. The actual source has not been confirmed, and specific release point(s) of the chromium into the groundwater system have not been identified.

The ISRM technology creates a chemically reduced permeable treatment zone that reduces hexavalent chromium in groundwater to trivalent chromium, which is less mobile and less toxic than the hexavalent form. A diagram showing the chemical speciation of chromium at varying reduction/oxidation potential (Eh)/pH conditions is provided in Figure 2-1.

The aquifer treatment zone is created by injecting a solution of sodium dithionite ($Na_2S_2O_4$) into the aquifer through a series of groundwater wells (Figure 1-2). Sodium dithionite is a strong reducing agent that scavenges unbound dissolved oxygen (DO) from the aquifer and reduces numerous metallic elements and oxy-ions present in the aquifer in an oxidized state. Numerous reduction reactions occur in a groundwater system during the ISRM treatment process. In addition, numerous oxidation reactions occur on a continuous basis following establishment of the treatment zone. The principal reaction that provides the residual reduction capacity to treat chromate ions flowing through the treatment zone is the reduction of ferric iron (Fe^{+3}) to ferrous iron (Fe^{+2}). After the reduction treatment, ferrous iron is present in two forms: (1) dissolved ferrous iron in solution in the groundwater, and (2) structural ferrous iron associated with the geologic material forming the aquifer matrix. Some dissolved ferrous iron may migrate slowly downgradient with the groundwater flow, while structural ferrous iron provides residual reduction capacity that can react with the hexavalent chromium in incoming groundwater.

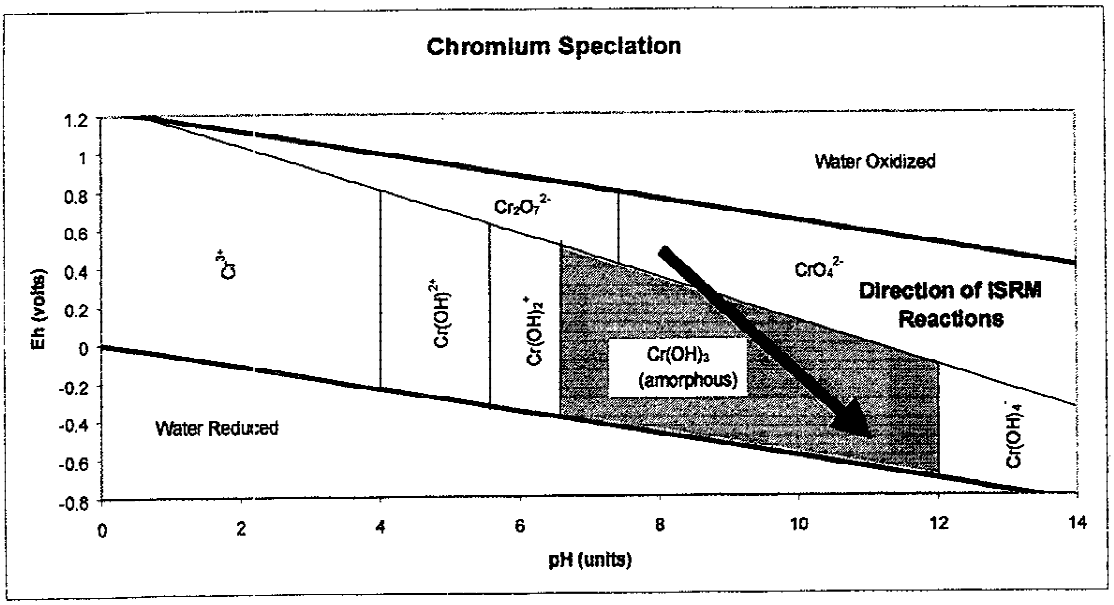
Hexavalent chromium in aqueous solution flows into and through the treatment zone at natural groundwater velocity. When dissolved hexavalent chromium (Cr^{+6}, in the form of the water-soluble chromate ion, CrO_4^{-2}) in the aquifer enters the reducing environment, it reacts with ferrous iron in the treatment zone and is reduced to trivalent, or chromic, chromium (Cr^{+3}). The resulting trivalent chromium ultimately precipitates from the groundwater as chromic hydroxide [$Cr(OH)_3$] or a chromic-ferric hydroxide complex. Both of these compounds have very low solubility in water and are less toxic than hexavalent chromium at typical groundwater pH and Eh conditions. As the treatment zone eventually becomes re-oxidized by the passage of naturally oxygenated groundwater through the treatment zone, the precipitated trivalent chromium is expected to remain insoluble. Dissolution of chromic hydroxide and re-oxidation of trivalent chromium may be facilitated by the presence of manganese oxide in the water. However, it is anticipated that hexavalent chromium concentrations will remain below levels of concern following complete treatment of the plume.

The results of the ISRM technology evaluation are presented in *100-D Area In Situ Redox Treatability Test for Chromate-Contaminated Groundwater, September 2000* (PNNL 2000). The year-end report provides additional information regarding the feasibility and apparent effectiveness of the ISRM technology.

The longevity of the treatment zone's capacity to reduce hexavalent chromium within the aquifer (estimated to be 23 years [PNNL 2000]) is a function of the combined effects of chemical and physical characteristics of the aquifer, including the following aspects:

- Quantity and distribution of residual ferrous iron within the aquifer matrix following the treatment process
- Flow rate of untreated groundwater into and through the treatment zone
- Concentration of oxidizing constituents in the incoming groundwater (e.g., DO, nitrate, and hexavalent chromium).

Figure 2-1. Chromium Speciation Diagram.[a]



[a] Source: "Chemical Reduction of Hexavalent Chromium in the Trinity Sand Aquifer," in *Groundwater*, Vol. 32, No. 3, May - June 1994 (Henderson 1994).

3.0 AQUIFER CONDITIONS

Plume movement, changes in contaminant concentrations, and hydraulic conditions in the aquifer were monitored in FY06 through the following activities:

- Observing changes in water levels (i.e., hydraulic monitoring) in monitoring wells surrounding the ISRM treatment zone (Section 3.1)
- Analyzing groundwater from monitoring and barrier wells at the site (Section 3.2).

3.1 HYDRAULIC MONITORING

Groundwater elevations in the unconfined aquifer were monitored in wells at the ISRM site. The water levels were measured using an automated recording system and also from quarterly manual measurements using an electric tape. The automated water-level monitoring system recorded data from pressure transducers on an hourly basis throughout the year at 15 groundwater monitoring wells at the site (Figure 3-1). The river-stage cycles and corresponding groundwater responses (i.e., hydrographs) for wells monitored by automated processes during part or all of FY06 (October 2005 through September 2006) are shown in Figure 3-2.

Both automated and manual depth-to-water measurements were used to calculate groundwater elevations through comparison with known survey elevations. The resulting groundwater elevation data were used to prepare contour maps of water levels at the site and to develop a detailed assessment of variations in groundwater flow direction and gradient across the ISRM site. A number of conclusions can be drawn from these assessments, including the following:

- During the first quarter of FY06 (October through December 2005), the Columbia River was at a low stage and groundwater was discharged to the river. A large groundwater mound resulted from the leakage of raw Columbia water from the 182-D reservoir at a rate of 386 L/min (102 gallons per minute [gpm]). The 182-D groundwater mound created a hydraulic divide separating the southwest ISRM hexavalent chromium plume and the north 100-D hexavalent chromium plume. A smaller groundwater mound was due to injection of treated groundwater from the DR-5 pump-and-treat operation. The injection rate was 159 L/min (42 gpm). A number of small groundwater depressions are related to the DR-5 and 100-D pump-and-treat extraction wells.
- During the second quarter of FY06 (January through March 2006), the Columbia River and groundwater were in approximate balance, with little recharge or discharge of groundwater. The groundwater mound resulting from the leakage from the 182-D reservoir was smaller, and leakage from the 182-D reservoir occurred at a lower rate (102.2 to 162.8 L/min [27 to 43 gpm]). The 182-D groundwater mound maintained the hydraulic divide separating the southwest ISRM hexavalent chromium plume and the north 100-D hexavalent chromium plume. The small mound centered on the DR-5 injection well and groundwater depressions (due to pump-and-treat extractions near the Columbia River) were also present.
- During the third quarter of FY06 (April through June 2006), the Columbia River was at a high stage, with the river recharging groundwater over a broad zone. The groundwater mound centered on the DR-5 injection well and a number of depressions near the river

and south of the 182-D reservoir (related to pump-and-treat extraction wells) were present. There was little evidence of leakage from the 182-D reservoir. The 182-D groundwater mound and the hydraulic divide separating the southwest ISRM hexavalent chromium plume and the north 100-D hexavalent chromium plume appreciably dissipated.

- During the fourth quarter of FY06 (July through September 2006), the river stage was generally low and groundwater discharged to the river with a relatively low gradient. The small groundwater mound remained centered on the DR-5 injection well, and a number of groundwater depressions related to DR-5 and 100-D extraction wells were present. Some of the depressions near the river shore were deep enough to allow gradient reversal and local aquifer recharge from the river. The 182-D reservoir showed little evidence of leakage during the quarter. The 182-D groundwater mound and the hydraulic divide separating the southwest ISRM hexavalent chromium plume and the north 100-D hexavalent chromium plume appreciably dissipated.

Additional detailed descriptions of groundwater conditions are presented in the following subsections.

3.1.1 Water Table Conditions

Water table conditions at the ISRM site are influenced by both natural and artificial conditions. The primary natural influence is the Columbia River, while artificial influences include ongoing leakage at the 182-D reservoir, as well as groundwater extraction and injection activities at the DR-5 and 100-D pump-and-treat operations. Seasonal variations in groundwater elevations in monitoring wells reflect changes in the stage and flow rate of the Columbia River and are generally lowest in the fall (September through November) and highest from mid-spring to mid-summer (mid-May through mid-August).

Data from the automated monitoring network indicate substantial seasonal and diurnal variations in water levels across the site (Figure 3-3). Well-defined seasonal variations are seen in all monitored wells and primarily reflect variations in river stage (Figure 3-3A). Wells located close to the Columbia River show diurnal fluctuations that are closely coupled to changes in the river stage. The magnitudes of diurnal fluctuations decrease in wells further from the river, and wells further from the river exhibit greater lag time in response to river fluctuations. The magnitudes of diurnal fluctuations can be seen in Figures 3-3B and 3-3C, each of which presents a week of data for two distinct flow regimes: reverse discharge and summer high flow. During the period of reverse discharge, flow volumes are intentionally kept low during daylight hours by the Grant County Public Utility District in order to encourage salmon to spawn in deeper water. Flows are greatest between sunset and sunrise, which is the opposite of normal flow patterns for generation of hydroelectric power. In FY06, reverse discharge occurred at three separate times: (1) between October 4 and October 12, 2005; (2) between November 15 and November 20, 2005 (Figure 3-3B); and (3) between November 27 and December 1, 2005.

Beginning with FY05, manual water-level measurements have been collected quarterly throughout the year. During FY06, water-level measurements were collected manually in November 2005 (first quarter of FY06), March 2006 (second quarter of FY06), June 2006 (third quarter of FY06), and August 2005 (fourth quarter of FY06) from most of the monitoring wells associated with the ISRM site. The groundwater elevation contours based on these water-level measurements are presented in Figures 3-4, 3-5, 3-6, and 3-7, respectively.

During FY06, there was uncertainty about the water elevation in the aquifer immediately surrounding well 199-D5-42 in relation to the measured water elevation. Measured water elevations were significantly higher (4.8 to 7.8 m [15.7 to 25.6 ft]) than the elevation of the top of the well screen (117.65 m [386 ft]). It was assumed that the actual water level was half the distance between the measured water level and the top of the screen (i.e., well screen efficiency is 50%). This approach assumed that the well screen is not capable of instantaneously transmitting all of the injected water to the groundwater. Until the second quarter of FY07, there were no wells near 199-D5-42 to provide water-elevation data to evaluate the well-efficiency assumption. Well 199-D5-106 is located 34 m (112 ft) and was completed during the second quarter of FY07. Water-elevation data from well 199-D5-106 (obtained during March 2007) have been used with FY06 water-elevation data from well 199-D5-93 to estimate water elevations proximal to well 199-D5-42 for contouring the groundwater elevations.

The water table map for the first quarter of FY06 (Figure 3-4 [FH 2006a]) shows a groundwater flow regime where the Columbia River was at a low stage and groundwater was discharging into the river. A relatively steep gradient towards the river was present within about 200 m (65.6 ft) of the shoreline. Further inland, the gradient was low and generally directed northeastward toward the Columbia River. A similar groundwater flow regime was present in the first quarter of FY05 (Figure 3-4 [DOE-RL 2006]). A groundwater mound was centered beneath the 182-D reservoir and was caused by leakage of raw Columbia River water from the reservoir. The reservoir leaked approximately 22 million L (5.8 million gal) of water at rate of 386 L/min (102 gpm) during the quarter (FH 2006a). The 182-D groundwater mound created a hydraulic divide separating the southwest ISRM hexavalent chromium plume and the north 100-D hexavalent chromium plume. A small groundwater mound was centered on injection well 199-D5-42. This groundwater mound was caused by the injection of treated groundwater from the DR-5 pump-and-treat operation at a rate of 159 L/min (42 gpm). Groundwater depressions located to the north-northeast of D Reactor, near the Columbia River, are related to pumping withdrawals by the 100-D pump-and-treat operation. A groundwater depression located north of well 199-D5-42, near the Columbia River, is related to groundwater withdrawals for the DR-5 pump-and-treat operation.

The water table map for the second quarter of FY06 (Figure 3-5 [FH 2006b]) represents a groundwater flow regime where the Columbia River and groundwater were approximately in balance, with little net discharge to or from the river. The regional groundwater gradient was low and directed generally northward. A groundwater mound was centered beneath the 182-D reservoir and was caused by leakage of raw Columbia River water from the reservoir at rates ranging from 100 to 163 L/min (27 to 43 gpm) (FH 2006b). The 182-D groundwater mound maintained the hydraulic divide separating the southwest ISRM hexavalent chromium plume and the north 100-D hexavalent chromium plume The groundwater mound related to injection of treated groundwater from the DR-5 pump-and-treat operation, and a groundwater depression due to groundwater extraction at the 100-HR-3 pump-and-treat operation were also present.

The water table map for the third quarter of FY06 (Figure 3-6 [FH 2006c]) represents a groundwater flow regime where the Columbia River was at a high stage and the gradient was reversed, with flows from the river to groundwater over a broad zone. Effects of the regional northward-directed groundwater gradient seen in the second quarter were not clearly evident during the third quarter. A groundwater mound centered at the 199-D5-42 injection well dominated the local water table, and a series of small depressions closer to the river and south of the 182-D reservoir were related to the operation of the DR-5 and 100-D extraction wells. The

182-D reservoir showed little evidence of leakage during the third quarter and little effect was seen in proximal monitoring wells. The 182-D groundwater mound and the hydraulic divide separating the southwest ISRM hexavalent chromium plume and the north 100-D hexavalent chromium plume appreciably dissipated. Relatively low water levels were maintained in the reservoir from May 1 through September 30, 2006 (Figure 3-2).

The water table map for the fourth quarter of FY06 (Figure 3-7) represents the latter portion of the annual spring and summer high for the Columbia River (Figure 3-3A), where the river stage was considerably lower than levels seen earlier in the summer. Groundwater flows generally discharged towards the Columbia River with a relatively low overall gradient. The local water table was dominated by a groundwater mound and several depressions related to pump-and-treat operations. A groundwater mound was centered on injection well 199-D5-42. Ongoing pumping from the 100-D extraction wells continued to produce well-defined groundwater depressions near the Columbia River north of D Reactor. The groundwater surface near these extraction wells was pumped to an elevation lower than the Columbia River, resulting in locally reversed flow from the Columbia River to groundwater. Groundwater depressions were also associated with DR-5 extraction wells. Little evidence was seen for continued leakage at the 182-D reservoir. The 182-D groundwater mound and the hydraulic divide separating the southwest ISRM hexavalent chromium plume and the north 100-D hexavalent chromium plume appreciably dissipated.

Table 3-1 compares FY05 and FY06 semi-annual water-level measurements for spring (June) and fall (November). These measurements were made manually, and a comparison indicates that FY06 elevations were 0.935 m (3.068 ft) higher in the spring and 0.113 m (0.371 ft) higher in the fall than the corresponding elevations in FY05. Table 3-2 summarizes water-level measurements in FY05 and FY06 from remotely monitored stations at the Columba River and at 16 wells located from 92 m to 665 m (300 to 2,180 ft) from the river. These data were recorded hourly and represent continuous water-level profiles for wells and the river station. Average water elevations recorded from wells during FY06 were generally higher than those recorded in FY05. The average Columbia River stages were also generally higher in FY06. The maximum river stage was 0.845 m (2.773 ft) higher in FY06 than in FY05, while the minimum level was the same in both years. Overall, the average Columbia River stage was 0.163 m (0.535 ft) higher in FY06 than it was in FY05.

3.1.2 Groundwater Flow Direction

For optimal treatment, the ISRM treatment zone was oriented to be as close as possible to perpendicular to the groundwater flow direction and plume axis. Because annual groundwater flow direction perturbations have been identified, the net flow direction is calculated each year in order to evaluate the position of the treatment zone. The optimal groundwater flow direction towards the treatment barrier is modeled to be perpendicular to the barrier at an azimuth of 307 degrees (±30 degrees).

At the ISRM site, automated water-level data were collected hourly from 11 wells and were used to solve a series of three-point problems. Wells 199-D4-38 and 199-D4-85 are located between the Columbia River and the ISRM barrier. Wells 199-D3-2, 199-D4-19, 199-D4-13, and 199-D5-36 are collinear with the treatment zone, toward the southwest and northeast, respectively. The other five wells (199-D4-20, 199-D5-33, 199-D5-34, 199-D5-38, and 199-D5-43) are located further inland from the barrier, with well 199-D5-43 being the farthest from the Columbia River (Figure 3-8).

The principle behind the three-point problem is that, given the hydraulic head at three unique locations, it is possible to calculate geometrically the azimuth of the flow direction based on the relative magnitude of each head measurement at any one time. The hourly water-level data allow for a large number of calculations throughout the entire year (e.g., 8,737 sets of data were used for the calculations for Triangle 1). A net flow vector (magnitude and azimuth) can then be calculated from these data. A more detailed discussion of the three-point problem method is presented in *Fiscal Year 2002 Annual Summary Report for the In Situ Redox Manipulation Operations* (DOE-RL 2003a).

Data collected from nine groupings of three wells (i.e., nine triangles) were evaluated in FY06. Figure 3-8 shows the well locations and the nine sets of three-point triangles used and includes a summary table of the triangle solutions for FY06. Table 3-3 presents a summary of the solutions of the nine triangles, and Appendix A contains the flow direction and gradient graphs for the nine sets of triangles.

The optimal groundwater flow direction towards the treatment barrier is an azimuth of 307 degrees (±30 degrees). Flow directions for Triangles 2, 3, 4, and 9 are within these limits. These four triangles are closest to the barrier. Net flow directions for Triangles 1, 5, 6, 7, and 8 are not within the optimal flow direction limits. The net flow directions for Triangles 1, 5, and 7 are to the north, while flow directions for Triangles 6 and 8 are to the southwest and west, respectively.

Changes in flow direction appear to be closely related to the river stage, although leakage at the 182-D reservoir, pump-and-treat extraction at well 199-D5-39, and pump-and-treat injection at well 199-D5-42 also influence flow. The treatment zone (Triangles 1, 2, 3, 4, 7, and 9) intercepted groundwater in the optimal flow direction for 47% to 68% of the year. The optimal time of plume interception was fall through winter, coinciding with lower river stage. The least optimal time was mid-April through June, coinciding with higher river stage. Consequently, the hexavalent chromium contaminant plume is not expected to be effectively treated during this period. However, flux to the river would also be relatively low at this time.

Triangles 1 and 7 have flow directions of 2.9 and 365.5 degrees, respectively, and are most likely affected by responses of wells near the river to relatively rapid changes in river level and the inland wells that comprise the these two triangles. Triangles 6 and 8 have flow directions of 257.6 and 218.7 degrees, respectively. It is likely that the flow directions have been affected by leakage from the 182-D reservoir and the injection well east of the reservoir. Triangle 5 has a flow direction of 17.3 degrees that may reflect flow less influenced by river stage effects.

Leakage from the 182-D reservoir during the first and second quarters of FY06 influenced the flow direction at Triangles 2, 3, 5, 6, 7,and 8 (Appendix A). The effect was most pronounced in the first quarter and most obvious at Triangle 8 where the flow direction rotated south approximately 65 degrees; from 270 to 205 degrees. The changes in flow directions at Triangles 2, 3, 5, 6, and 7 ranged from 15 to 85 degrees; the flow directions rotated generally to the south.

3.2 CONTAMINANT MONITORING

Groundwater at the ISRM site is sampled as part of *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) interim action monitoring (IAM). The contaminant of concern is hexavalent chromium. The DO is also monitored because groundwater with depleted DO levels may harm aquatic receptors. Other groundwater

constituents and properties are also monitored in order to understand plume chemical characteristics.

The IAM is controlled by the *Sampling and Analysis Plan for In Situ Redox Manipulation Projects* (DOE-RL 2003b) and includes wells that have been completed since 1999. The sampling and analysis plan contains the long-term monitoring approach for the ISRM treatment zone and also addresses sampling of near-shore aquifer sampling tubes and porewater sampling tubes.

The IAM sampling occurs predominantly on a quarterly schedule to assess compliance with RAOs and performance of the ISRM barrier, specifically including the following:

- Compliance wells are sampled to identify when the hexavalent chromium concentrations are 20 µg/L or less in order to achieve 10 µg/L at the Columbia River.
- Treatment zone wells, including both aquifer treatment wells (i.e., wells previously used to treat the aquifer) and treatment zone monitoring wells (i.e., monitoring wells within the treatment zone that were not previously used to treat the aquifer), are sampled to monitor changes in hexavalent chromium concentrations within the ISRM barrier and to assess the performance of the ISRM treatment zone.
- Plume monitoring wells are sampled to monitor changes in plume concentrations and plume movement.

Depending on the quarter in which wells were sampled, between 41 and 46 wells were sampled each quarter for IAM purposes. Between five and six of these wells were also sampled on a monthly schedule. Table 3-4 identifies the type of well (i.e., compliance, plume monitoring, treatment zone monitoring, or aquifer treatment), the sampling frequency, and whether each well is sampled for CERCLA IAM or supplemental operational monitoring of the treatment zone. Data from IAM samples are controlled by and maintained in the Hanford Environmental Information System (HEIS) database.

Supplemental operational monitoring of the treatment zone is directed by Fluor Hanford, Inc. (FH) project personnel. This sampling helps to provide more detailed information regarding the distribution of hexavalent chromium within the ISRM treatment zone and aids in assessing treatment zone performance. Groundwater samples from 65 aquifer treatment wells and 5 monitoring wells located in and near the treatment zone are analyzed for hexavalent chromium on a quarterly basis. Seven wells sampled every month during the FY, and an additional 12 wells were sampled more frequently than on a quarterly basis. Data from the supplemental operational monitoring are controlled and maintained by FH project personnel and are not included in the HEIS database.

The results from IAM and supplemental operational monitoring are summarized in the following subsections.

3.2.1 Interim Action Monitoring

During FY06, 41 to 46 compliance, treatment zone, and monitoring wells were sampled during each quarter (Table 3-5 lists these wells by type and indicates whether each well was sampled during each quarter). During individual quarters, five to six of these wells were also sampled monthly. Four monitoring/extraction wells were sampled during the first quarter of FY06, five were sampled during the second quarter, two were sampled during the third quarter, and two were sampled during the fourth quarter.

Groundwater samples were analyzed for hexavalent chromium, total chromium, other metals (including aluminum, arsenic, barium, cadmium, cobalt, iron, magnesium, manganese, silver, sodium, uranium, and zinc), anions (including chloride, fluoride, nitrite, nitrate, and sulfate), and tritium, as well as the field parameters of DO, pH, specific conductance, temperature, and turbidity. Sampling and analysis for total chromium and other metals, including arsenic, were conducted during the first quarter of FY06. Sampling and analysis for sulfate took place in all four quarters, and sampling and analysis for nitrate took place in the first quarter of FY06.

Concentration trends are considered stable if percentage changes in concentration are ≤20%. Decreasing (negative) trends indicate that the percentage change in concentration is greater than -20%, and increasing (positive) trends indicate that the percentage change in concentration is greater than +20%.

Results of monitoring for chromium, DO, sulfate, nitrate, and tritium are addressed in the subsections below. None of the wells sampled during the first quarter of FY06 exceeded the maximum contaminant level (MCL) of 10 µg/L for arsenic.

3.2.1.1 Hexavalent Chromium. Table 3-5 summarizes the chromium and hexavalent chromium results and significant trends for each of the compliance, treatment zone, and monitoring wells sampled for IAM. The table includes annual averages for FY04, FY05, and FY06, as well as percentage change values and trends based on comparisons of FY05 and FY06 annual and fourth quarter data. Trend plots of chromium and hexavalent chromium in the compliance wells from October 2001 through October 2006 are shown in Figure 3-9. Figures 3-10, 3-11, 3-12, and 3-13 show contoured plots of the hexavalent chromium results for the first, second, third, and fourth quarters of FY06, respectively. Key results from IAM during FY06 are summarized as follows:

- On an annual basis, 13 wells show increasing trends, 12 wells show decreasing trends, and 15 wells are stable.
- During the fourth quarter (fourth quarter FY06 versus fourth quarter FY05), 15 wells show increasing trends, 11 wells show decreasing trends, and 14 wells are stable.
- Loss of reductive capacity in the barrier is present in the northeastern portion of the treatment zone, where generally elevated chromium analyses extend over a width of 215 m (705 ft).

Annual average FY06 trends are calculated for 40 wells (Table 3-5). Of these wells, 13 wells show increasing annual trends, 12 wells show decreasing trends, and 15 wells show stable trends on an annual basis. Annual trends cannot be calculated for eight wells because of incomplete data for either FY05 or FY06. These wells include three pump-and-treat extraction wells and one pump-and-treat injection well. Trend plots for IAM wells are provided in Appendix B. Overall, the majority of the annual increases were seen in treatment zone monitoring wells, where increases ranged from 25% to 113%.

Fourth quarter trends are calculated for 41 wells (Table 3-5). Of these wells, 15 wells show increasing trends, 12 wells show decreasing trends, and 14 wells show stable trends when the fourth quarter of FY06 is compared to the fourth quarter of FY05. The majority of the increases seen during the fourth quarter were within or proximally downgradient of the treatment barrier, where increases ranged from 26% to 940%. In addition, significant increases were seen in some upgradient monitoring wells, including monitoring well 199-D5-34 (+33,300%). The large increase at this well may be due to plume movements related to pumping in nearby extraction

well 199-D5-39 and is consistent with increasing hexavalent chromium concentration throughout the year.

Figure 3-14 provides a detailed contour map covering the area of the treatment barrier, as well as nearby compliance and monitoring wells, and presents data for the fourth quarter of FY06. Both IAM data and operational monitoring data in the proximity of the treatment barrier are presented on this map in order to provide a basis for more detailed interpretation of this area. Both sets of data were merged for contouring purposes, although it is recognized that different analytical methods and standards may play a role in precision and accuracy of these results. Contouring shows two discrete areas where there has been a loss of reductive capacity along the treatment barrier where hexavalent chromium exceeding 100 µg/L is seen both upgradient and downgradient of the barrier. The area toward the southwest is approximately 25 m (82 ft) in width and is centered on well 199-D4-26, while the area toward the northeast is approximately 25 m (82 ft) in width and is centered between wells 199-D4-40 and 199-D4-41.

3.2.1.1.1 Compliance Monitoring Wells. Compliance monitoring wells were installed and sampled to meet the following criteria:

- Establish whether the 20 µg/L hexavalent chromium RAO has been achieved in groundwater that has passed through the ISRM treatment barrier
- Define the boundaries of the plume so compliance with the RAO can be verified for groundwater beyond the limits of the ISRM treatment barrier
- Detect and allow assessment of hexavalent chromium breakthrough in the ISRM treatment barrier.

When considered on an annual basis, chromium concentrations meet the RAO of 20 µg/L in two compliance wells (199-D4-23 and 199-D4-86), which show increasing or stable annual trends. Annual chromium concentrations for the remaining five wells (199-D4-38, 199-D4-39, 199-D4-83, 199-D4-84, and 199-D5-85), which exceed the RAO, showed declining or stable trends for the year.

High annual chromium concentrations (Table 3-5) in compliance wells 199-D4-38 (189 µg/L) and 199-D4-39 (595 µg/L), as well as in upgradient treatment zone wells, indicate that portions of the northeastern part of the treatment zone have lost some reductive capacity.

On a quarterly basis, hexavalent chromium concentrations exceeded the RAO of 20 µg/L in five compliance wells during the first, third, and fourth quarters of FY06 and in three wells during the second quarter of FY06.

3.2.1.1.2 Treatment Zone and Proximal Monitoring Wells. Seventeen wells within and proximal to the treatment zone were sampled on a quarterly basis as part of IAM to monitor concentrations within the ISRM barrier and to assess the effectiveness and performance of the ISRM treatment zone. These wells (see Table 3-5 and Figures 3-10 through 3-13) consist of nine treatment zone injection wells (aquifer treatment wells), two treatment zone monitoring wells, and six proximal monitoring wells (see well types "Ti," "Tm," and "PM" in Table 3-5). The following general conclusions can be drawn from these data:

- Average annual concentrations for FY06 relative to FY05 show increasing trends in eight wells, decreasing trends in five wells, and stable trends in four wells.
- Barrier reductive capacity is the most compromised in two relatively narrow channels flanking the original treatability test site in the northeastern portion of the barrier.

- Overall, barrier performance in FY06 was similar to that seen in FY05.

Wells with increasing annual trends are found throughout much of the treatment zone. The wells with the highest annual increases (199-D4-36 [+113%] and 199-D4-32 [+103%]) are found in the northeastern portion of the treatment barrier, where loss of reductive capacity is the greatest. This area coincides with the highest concentration portion of the groundwater plume. The immediately upgradient portion of the plume is monitored by proximal monitoring well 199-D4-22, which displayed a stable trend for FY06 relative to FY05. The treatment zone well (199-D4-7) that is immediately downgradient of monitoring well 199-D4-22 showed an increasing annual trend for FY06 (+98%).

On a quarterly basis, 10 wells display increasing hexavalent chromium trends when comparing the fourth quarter of FY06 to the fourth quarter of FY05 (Table 3-5), 5 wells display decreasing trends, and 2 wells display stable hexavalent chromium trends.

3.2.1.1.3 Plume Monitoring Wells. During FY06, 13 plume monitoring wells were sampled on a quarterly basis and 5 wells were sampled on a monthly basis as part of IAM in order to monitor changes in plume concentrations and plume movement (Table 3-5). These 18 wells do not include the proximal monitoring wells discussed above, nor do they include the 5 pump-and-treat extraction or injection wells that were sampled during at least part of the year.

Significant observations regarding plume configuration in FY06 include the following:

- Overall, plume size and configuration remained similar to FY05 observations.
- Groundwater flow (see Section 3.1.2) through the treatment barrier was nearly perpendicular to the barrier axis for much of the year. Plume movement inland from the barrier appears to have been impacted by leakage from the 182-D reservoir and the DR-5 groundwater injection well. The northeastern third of the barrier continues to intercept the high-concentration hexavalent chromium in the groundwater plume.
- Two wells show significant annual increases: one well located near the 182-D reservoir, and one well located north of D Reactor. There were no significant annual decreases.

When considered on an annual basis, average FY06 concentrations are calculated for 15 of 18 monitoring wells (well type "M" in Table 3-5) that are located inland or northeast of the ISRM treatment zone. Significant increases in the average FY06 chromium concentrations relative to average FY05 values are seen in two wells. Well 199-D5-34 (+8,589%) is located approximately 150 m (492 ft) to the northeast of an extraction well (199-D5-39), which is located within the hexavalent chromium plume that impacts the treatment barrier. The large increase in the hexavalent chromium concentration during the year may be related to groundwater extraction activities. Well 199-D4-15 (+58%) is located a short distance to the north of D Reactor. Annual decreases in plume monitoring wells are generally small.

3.2.1.1.4 Aquifer Sampling Tubes. The FY06 data from aquifer sampling tubes and porewater sampling tubes show that groundwater in excess 20 µg/L hexavalent chromium is entering the Columbia River at several sites. Key elements of aquifer tube and porewater sampling can be summarized as follows:

- Hexavalent chromium concentrations in excess of 20 µg/L were found at 8 of 11 aquifer tube sites sampled during the year, with concentrations ranging from 25 to 200 µg/L.

- Hexavalent chromium concentrations in excess of 20 µg/L were found at all four porewater tubes (samples from river bottom substrate) sampled during the year, with concentrations ranging from 41 to 394 µg/L.
- Analytical data from aquifer and porewater tube sites downgradient of the northeastern portion of the ISRM treatment barrier define a length of Columbia River shoreline approximately 380 m (1,247 ft) in length where hexavalent chromium exceeding 100 µg/L is found in at least one depth-discrete interval in five of eight aquifer tube and porewater tube sites.

Water samples were collected from 11 aquifer sampling tube and 4 porewater sampling tube locations during the second quarter of FY06. No samples were collected during other quarters during the year. One to four aquifer or porewater sampling tubes were sampled at each location, and the results are shown in Table 3-6. The maximum hexavalent chromium concentrations recorded at each location during the second quarter of FY06 are shown in Figure 3-11.

Hexavalent chromium concentrations exceeding 20 µg/L were found at all locations during sampling in the second quarter, with the exception of aquifer sampling tubes DD-49 (located upstream of the ISRM treatment barrier), AT-D-2 and AT-D-4 (located downstream of the ISRM treatment barrier), and AT-36 (not sampled during FY06). Hexavalent chromium concentrations ranged from 2 to 200 µg/L.

Hexavalent chromium concentrations in excess of 100 µg/L were found at porewater tube site 166-D-3 (Redox-3-3.3 [394 µg/L] and Redox-3-4.6 [375 µg/L]) and at porewater tube site 166-D-1 (Redox-1-3.3 [124 µg/L] and Redox-1.6.0 [109 µg/L]), as well at aquifer tube sites DD-43 (DD-43-3 [114 µg/L]), DD-39 (DD-39-2 [129 µg/L]), and DD-42 (DD-42-4 [200 µg/L]). These five sites are all located downgradient of the ISRM treatment barrier, and the data indicates that a portion of the groundwater contaminant plume may not be effectively treated by the ISRM barrier.

3.2.1.2 Dissolved Oxygen. The DO concentrations are monitored as required by the ROD Amendment (EPA et al. 1999), the RDR/RAWP (DOE-RL 2000), and the sampling and analysis plan (DOE-RL 2003b). The sodium-dithionite injection process effectively reduces DO in the groundwater removed from the injected wells to near zero. However, the results of the treatability test indicate that after treatment, DO concentrations are expected to increase to about 75% saturation by the time the treated groundwater reaches the river. Because levels of DO that are less than 60% saturation (approximately 6 mg/L) may be harmful to aquatic receptors, concentrations are closely monitored. In addition, there is an RAO specifying that DO levels at the compliance wells be at least 75% of saturation levels (DOE-RL 2000).

The DO content of groundwater varies directly with water temperature. As shown in Table 3-7, the temperature of groundwater for most samples collected from ISRM wells was between 16.0°C and 27.6°C (60.8°F and 81.7°F). The DO saturation concentration for water in this temperature range is approximately 9.7 to 7.7 mg/L, assuming that other chemical constituents in groundwater do not interfere with the saturation concentration.

Results from DO sampling during the fourth quarter of FY06 are summarized as follows:

- DO concentrations in wells upgradient of the treatment zone were near saturation levels, ranging from 4.93 to 9.25 mg/L.

- DO concentrations from wells within the treatment barrier showed the effects of a strong reducing environment, ranging from 0.25 to 5.94 mg/L.
- DO concentrations in compliance wells ranged from 2.40 to 6.83 mg/L in compliance wells immediately downgradient of the treatment zone, while DO concentrations in two wells located slightly beyond the limits of the treatment zone ranged from 6.47 to 7.19 μg/L. The DO concentrations reach 60% of saturation level in only one downgradient compliance well, and none of the downgradient compliance wells reach 75% of saturation (when saturation is considered to be 9.7 mg/L). Both compliance wells located slightly beyond the limits of the treatment zone have DO concentrations exceeding 60% of saturation.

Figure 3-15 shows the DO concentrations in wells in the ISRM area for the fourth quarter of FY06. The intersection of the 6 mg/L contour line and the Columbia River shoreline in Figure 3-15 delineates approximately 300 m (984 ft) of shoreline where concentrations of DO are less than the 60% saturation criteria. The DO concentrations upgradient of the ISRM treatment zone (i.e., in untreated groundwater) ranged from 4.93 to 9.25 mg/L. The DO concentrations in two treatment zone wells were less than 1 mg/L, reflecting a strongly reducing environment. The DO concentrations in an additional six treatment zone wells ranged from 1.57 to 4.74 mg/L, with increasing trends in five of these wells (a trend could not be calculated for one well because no data are available for the corresponding quarter of FY05). In seven downgradient compliance wells, DO concentrations ranged from 2.40 to 7.19 mg/L during the fourth quarter of FY06. The lowest DO concentration in compliance wells was seen in well 199-D4-84 (2.40 mg/L), located downgradient of the southeastern portion of the treatment barrier. Relatively low concentrations were also seen in compliance wells 199-D4-39 (3.31 mg/L) and 199-D4-23 (4.03 mg/L), both located downgradient of the core of the contaminant plume. In general, most compliance wells displayed DO concentrations that were lower than the concentrations found in upgradient monitoring wells. Both compliance wells located beyond the limits of the treatment zone (199-D4-83 and 199-D4-86) had DO concentrations similar to untreated groundwater (7.19 and 6.47 mg/L, respectively). One compliance well (199-D4-23) showed an increase from 1.76 to 4.03 mg/L, indicating that the influence of the treatment zone had decreased at this well over the period. The remaining six compliance wells had stable or decreasing DO levels over the period. None of the compliance wells had DO concentrations exceeding 75% of the saturation level.

Table 3-6 includes DO and temperature data for the aquifer sampling tubes that were measured in the second quarter of FY06. The DO and temperature values ranged from 4.8 mg/L at 6.5°C (43.7°F) (at Redox-3-4.6) to 11.1 mg/L at 10.8°C (51.4 F) (at DD-42-2). The DO values less than the 60% saturation criteria were found at DD-44-4, DD-41-3, Redox-3-4.6, Redox-2-6.0, AT-4-D-D, AT-D-2-S, AT-36-M, AT-D-3-S, and AT-D-3-M.

3.2.1.3 Sulfate. Sulfate is a byproduct of the sodium dithionite reaction that established the ISRM treatment zone. It is also listed as a groundwater contaminant with a "National Secondary Drinking Water Standards" (SDWS) (40 *Code of Federal Regulations* [CFR] 143) MCL of 250 mg/L. Table 3-8 provides a summary of annual average sulfate concentrations, a comparison of FY05 averages versus FY06 averages, and quarterly FY06 sulfate concentrations.

Results from sampling during FY06 include the following:

- Sulfate concentrations and distribution in FY06 were very comparable to those seen in FY05.
- Ten wells had average annual sulfate concentrations exceeding the secondary MCL of 250 mg/L, including two downgradient compliance wells, four proximal downgradient monitoring wells, and four treatment zone injection/monitoring wells.
- Sampling during the fourth quarter of FY06 showed eight wells with sulfate concentrations exceeding the secondary MCL, including one downgradient compliance well, four proximal downgradient monitoring wells, and three treatment zone injection/monitoring wells.

During FY06, average annual sulfate concentrations in 36 wells ranged from 15.5 to 533.8 mg/L. Ten wells had average FY06 concentrations greater than the 250 mg/L secondary MCL. Compliance wells 199-D4-23 (293.3 mg/L) and 199-D4-84 (427 mg/L) exceeded the 250 mg/L secondary MCL. Four proximal downgradient monitoring wells and four treatment zone wells also had average FY06 concentrations exceeding the secondary MCL. Only one of these wells (compliance well 199-D4-84) showed an increasing trend. The increasing trend in compliance well 199-D4-84 is likely a consequence of treatment of the aquifer and is consistent with an increasing trend previously noted at this well in FY05.

Sulfate was measured in 33 wells during the fourth quarter of FY06, ranging from 25 to 500 µg/L. Concentrations were above the 250 mg/L secondary MCL level in eight wells, including downgradient compliance well 199-D4-84 (410 µg/L), in addition to four proximal monitoring wells and three treatment zone injection/monitoring wells. The fourth quarter FY06 sulfate contour map (Figure 3-16) indicates that sulfate concentrations may have exceeded the MCL along the Columbia River shoreline in two areas: one downgradient of well 199-D4-84, and another downgradient of compliance well 199-D4-23.

3.2.1.4 Nitrate. During the first quarter of FY06, nitrate levels in three monitoring wells (199-D2-6, 199-D4-22, and 199-D5-43) exceeded the U.S. Environmental Protection Agency's (EPA's) drinking water MCL of 45 mg/L. Two of these wells are located within the upgradient portion of the contaminant plume that impacts the ISRM treatment barrier, and one well is a proximal monitoring well located downgradient of the original treatability test. Nitrate analyses at these three wells range from 52.3 to 59.9 mg/L.

3.2.1.5 Tritium. Samples from four wells exceeded the MCL of 20,000 pCi/L for tritium ("National Primary Drinking Water Standards" [40 CFR 141 and 40 CFR 142]) during sampling during the first quarter of FY06. Wells 199-D4-19 (26,400 pCi/L) and 199-D4-78 (32,500 pCi/L) are treatment zone monitoring wells located within the southwestern portion of the ISRM treatment barrier, and well 199-D4-85 (29,800 pCi/L) is a compliance well located downgradient of these two treatment zone monitoring wells. Well 199-D5-17 (20,200 pCi/L) is a cross-gradient monitoring well located near DR Reactor.

3.2.2 Supplemental Operational Monitoring

Supplemental operational monitoring was implemented to provide additional information about the performance of the ISRM treatment zone. More frequent monitoring (i.e., monthly rather than quarterly) is used for barrier wells where increasing hexavalent chromium concentrations imply a reduction in barrier reductive capacity in order to help characterize and monitor these

unanticipated changes. Key elements of supplemental operational monitoring for FY06 include the following:

- Seventy wells were sampled quarterly or monthly.
- For the fourth quarter of FY06, 12 wells showed increasing concentrations, 34 wells showed decreasing concentrations, and 24 wells showed stable concentrations.
- Barrier reductive capacity is the most compromised in the northeastern portion of the barrier, where 53% of the wells sampled exceeded 20 μg/L hexavalent chromium in the fourth quarter. Five wells (12%) exceeded 100 μg/L.
- In the southwestern portion of the barrier, 24% of the wells sampled exceeded 20 μg/L. The wells with values above 20 μg/L are found near the southwestern limit of the barrier, where a zone of increasing concentrations appears to be becoming better established.

Seventy wells, including 65 aquifer treatment wells and 5 monitoring wells located in or near the treatment zone, were sampled either quarterly or monthly as part of this monitoring activity. The samples are analyzed for hexavalent chromium. Several aquifer treatment wells were sampled on a monthly basis, which is generally required when hexavalent chromium concentrations are greater than 30 μg/L (DOE-RL 2003b). High hexavalent chromium concentrations are presumed to indicate a loss of reductive capacity in the treatment zone. These data are shown in Table 3-9.

Figure 3-17 shows the operational monitoring results for each quarter of FY06. The histograms (one for each quarter) show the areas with reduced reductive capacity (as indicated by wells with high concentrations of hexavalent chromium). The histograms also indicate the variability in concentrations during the year.

Comparison of hexavalent chromium concentrations between the fourth quarter of FY05 and the fourth quarter of FY06 (Table 3-9) indicates that concentrations have remained stable in 24 wells, increased in 12 wells, and decreased in 34 wells. However, significant short-term (i.e., monthly or quarterly) variation of up to three orders of magnitude may be present in operational monitoring results from wells within the ISRM treatment zone, as shown in Table 3-9. This is due, at least in part, to seasonal groundwater gradient reversal in the treatment zone that is coupled to river stage. Consequently, relatively small-scale increases or decreases in hexavalent chromium concentration, particularly those at or near the detection limit, are not considered to be significant. Only one well (199-D4-21) shows a potentially significant increase (exceeding 30 μg/L) when the fourth quarter of FY05 and fourth quarter of FY06 are compared. The maximum hexavalent chromium concentration recorded during the fourth quarter of FY06 was 380 μg/L in well 199-D4-26 for a sample collected in August 2006. Generally, lower overall concentrations in the fourth quarter of FY06 compared to the fourth quarter of FY05 are most likely related to elevated river elevation throughout much of FY06.

Supplemental operational monitoring results for the ISRM treatment zone (65 aquifer treatment wells and 5 proximal monitoring wells) during the fourth quarter of FY06 are summarized below:

- 39% (27 wells): no detectable hexavalent chromium (0 μg/L)
- 21% (15 wells): 10 μg/L hexavalent chromium
- 9% (6 wells): 20 μg/L hexavalent chromium
- 14% (10 wells): 30 to 40 μg/L hexavalent chromium
- 10% (7 wells): 50 to 100 μg/L hexavalent chromium
- 7% (5 wells): >100 μg/L hexavalent chromium.

A significant difference in overall hexavalent chromium levels seen in the southwestern and northeastern portions of the treatment barrier continues to be evident. As shown on Figure 3-14, the main portion of the contaminant plume directly impacts the northeastern portion of the barrier, while the southeastern portion is impacted by relatively low-concentration contamination. Hexavalent chromium analyses exceed 20 µg/L near the southwestern limit of the barrier, where analyses across a six-well zone are generally elevated (Figure 3-14). The results from the southwestern portion of the barrier for the fourth quarter of FY06, including wells 199-D3-4 through 199-D4-56 (29 wells), are summarized as follows:

- 62% (18 wells): no detectable hexavalent chromium (0 µg/L)
- 14% (4 wells): 10 µg/L hexavalent chromium
- 7% (2 wells): 20 µg/L hexavalent chromium
- 17% (5 wells): 30 to 40 µg/L hexavalent chromium
- 0% (0 wells): 50 to 100 µg/L hexavalent chromium
- 0% (0 wells): >100 µg/L hexavalent chromium.

The northeastern portion of the ISRM treatment barrier includes wells 199-D4-55 through 199-D4-48 (41 wells) and is more directly impacted by the higher concentration portion of the hexavalent chromium groundwater plume. In the fourth quarter of FY06, hexavalent chromium levels in excess of 100 µg/L were detected in five of these wells. The results from northeastern half of the barrier for the fourth quarter of FY06 are summarized as follows:

- 22% (9 wells): no detectable hexavalent chromium (0 µg/L)
- 24% (10 wells): 10 µg/L hexavalent chromium
- 12% (5 wells): 20 µg/L hexavalent chromium
- 12% (5 wells): 30 to 40 µg/L hexavalent chromium
- 17% (7 wells): 50 to 100 µg/L hexavalent chromium
- 12% (5 wells): >100 µg/L hexavalent chromium.

Figure 3-1. Automated Water-Level Monitoring Network

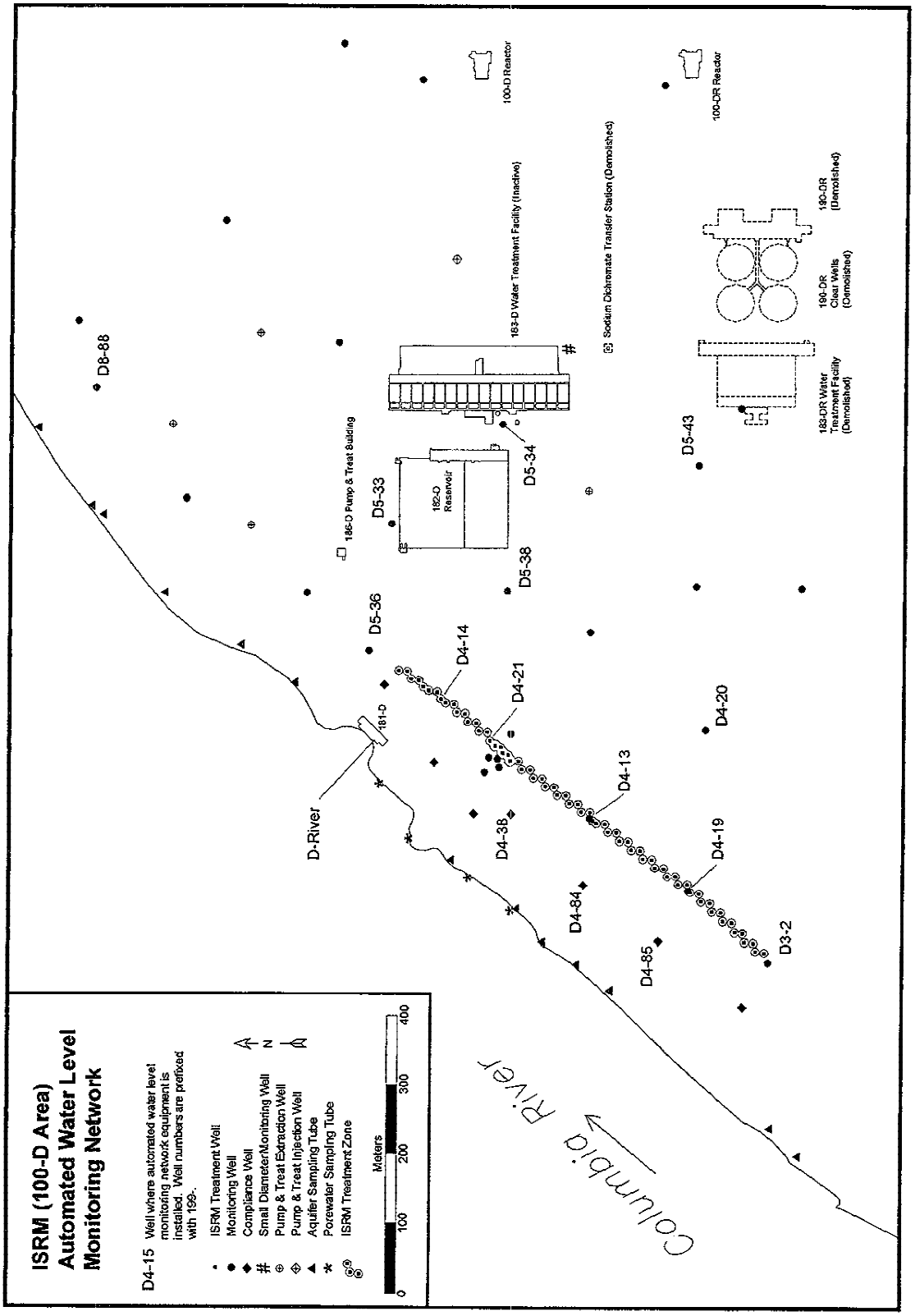


Figure 3-2. Comparison of Seasonal Water-Level Fluctuations at the In Situ Redox Manipulation Site. (3 sheets)

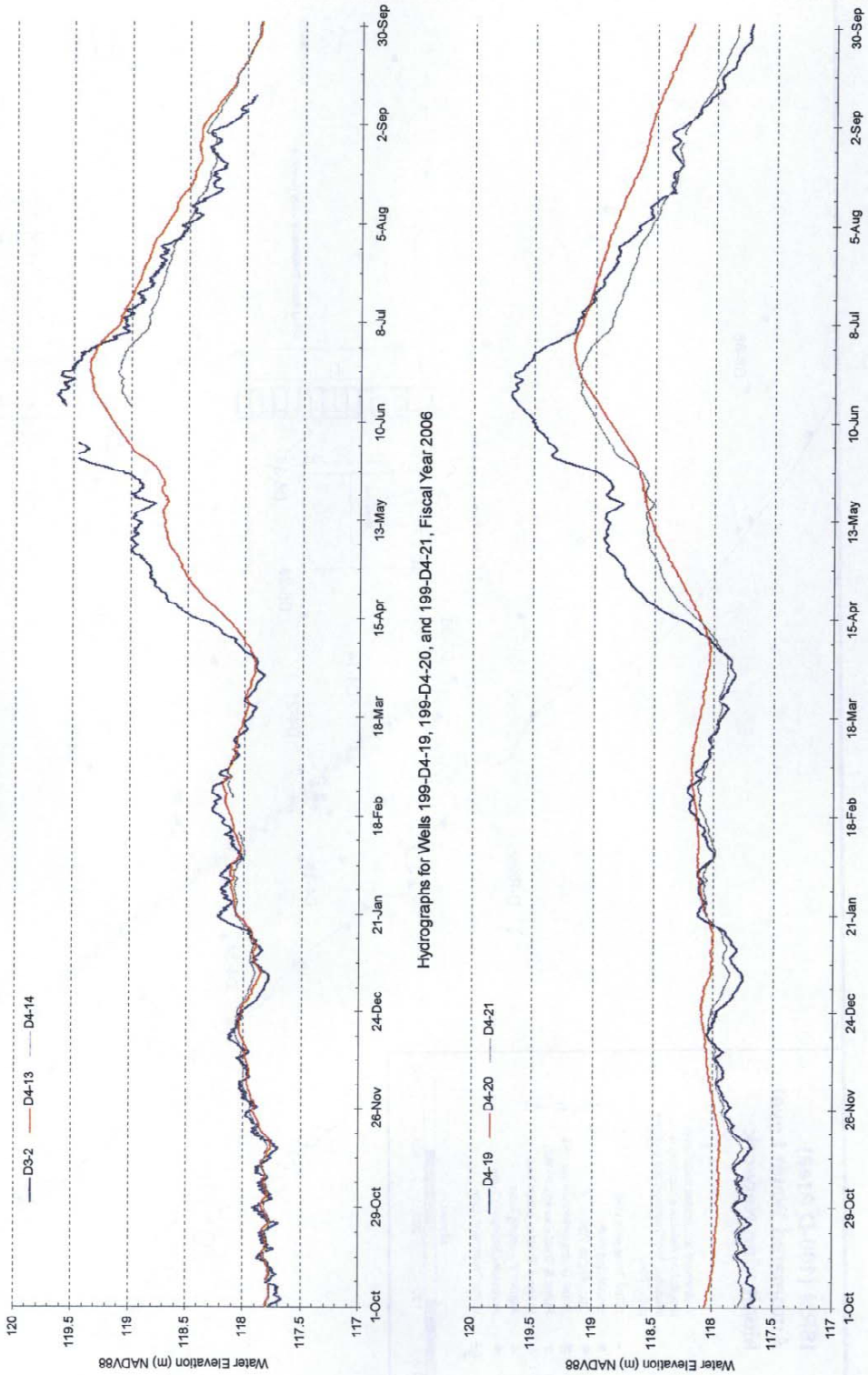


Figure 3-2. Comparison of Seasonal Water-Level Fluctuations at the In Situ Redox Manipulation Site. (3 sheets)

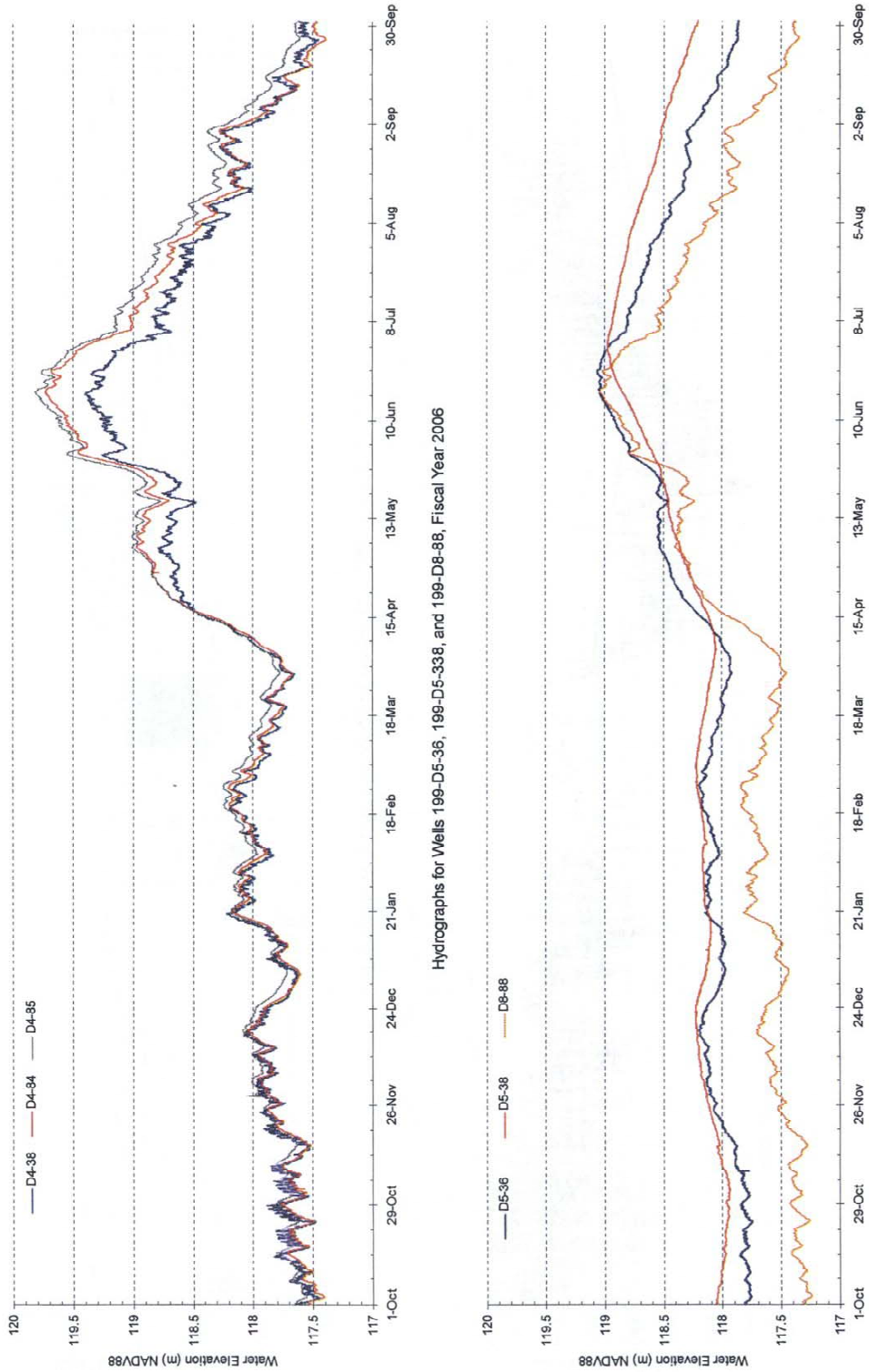


Figure 3-2. Comparison of Seasonal Water-Level Fluctuations at the In Situ Redox Manipulation Site. (3 sheets)

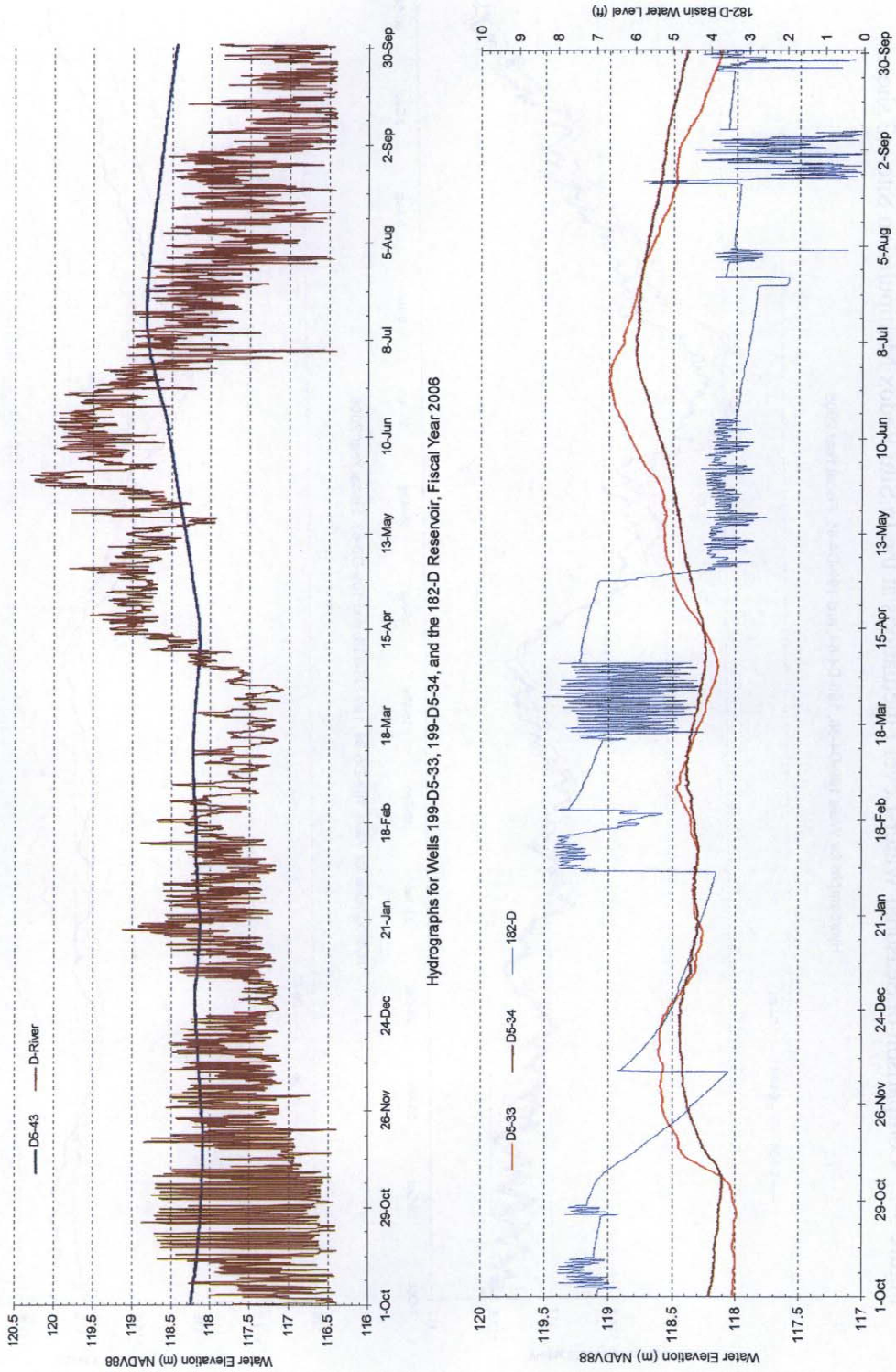
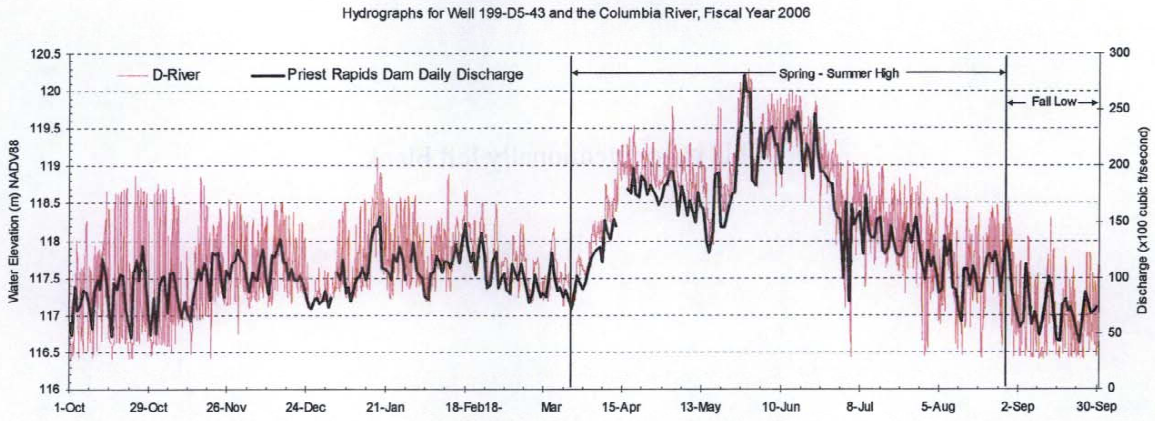
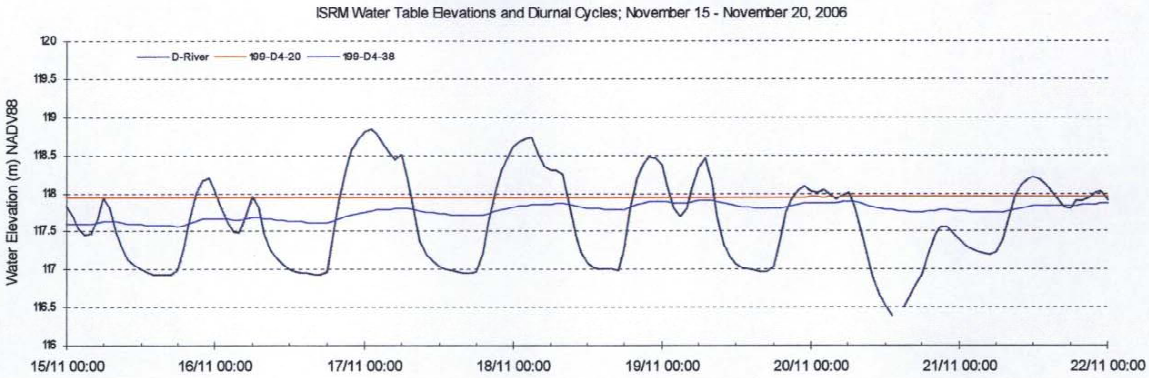


Figure 3-3. Seasonal and Diurnal Cycles at the In Situ Redox Manipulation Site.

(A) Seasonal Cycles



(B) Diurnal Cycles - Reverse Discharge Flow Regime



(C) Diurnal Cycles - Summer High-Flow Regime

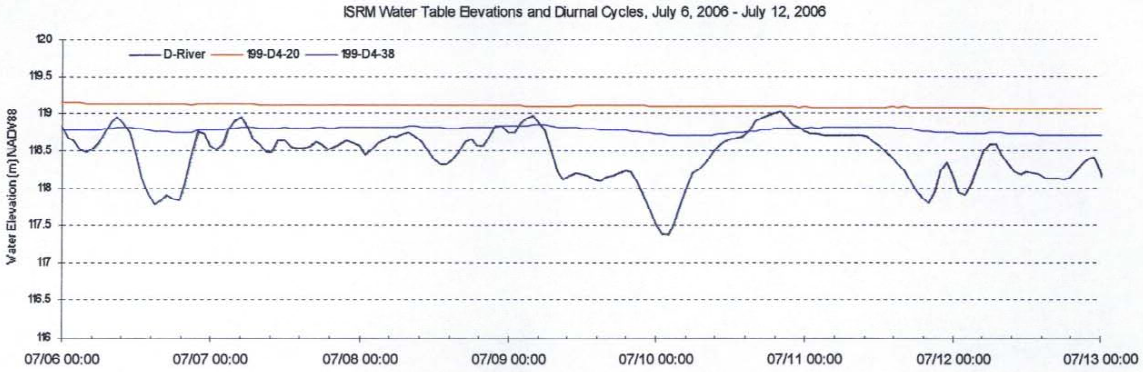


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Figure 3-4. 100-D Area Water Table Map, November 2005.

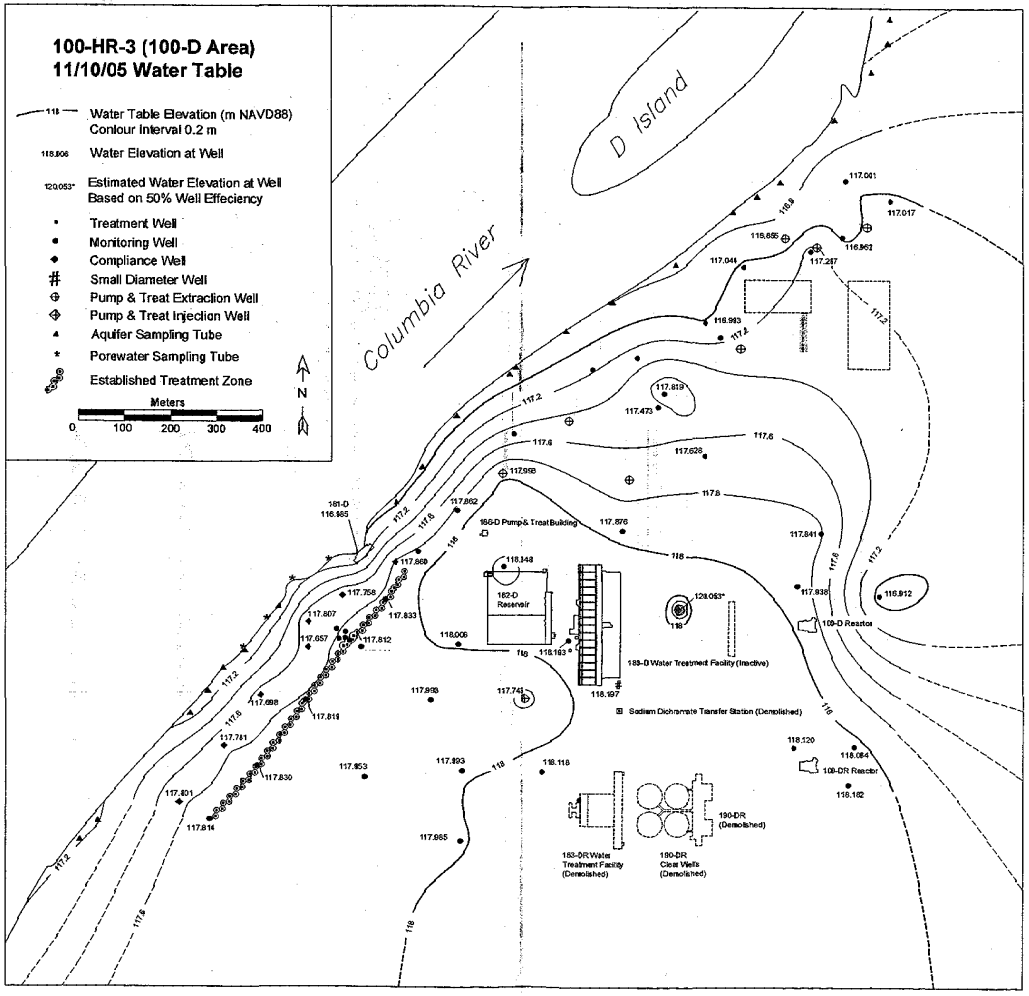

Figure 3-5. 100-D Area Water Table Map, March 2006.

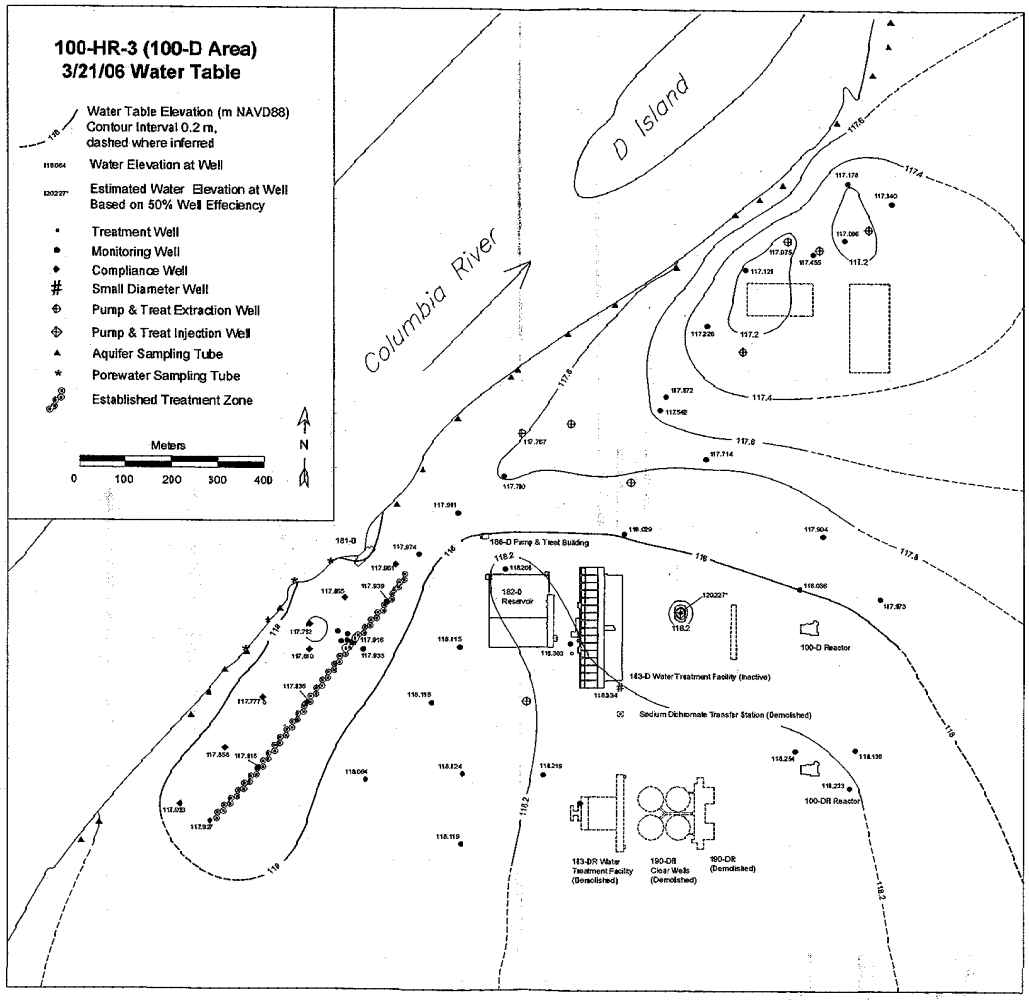

Figure 3-6. 100-D Area Water Table Map, June 2006.

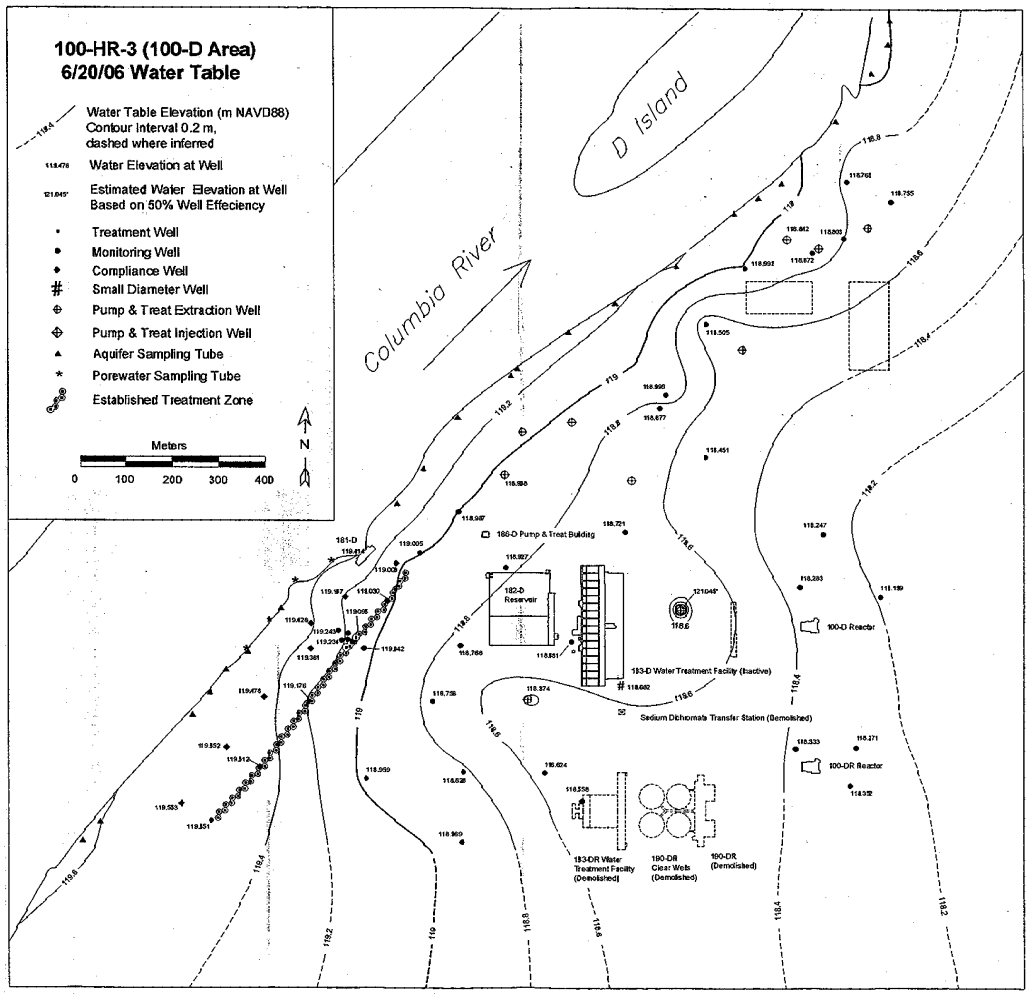

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Figure 3-7. 100-D Area Water Table Map, August 2006.

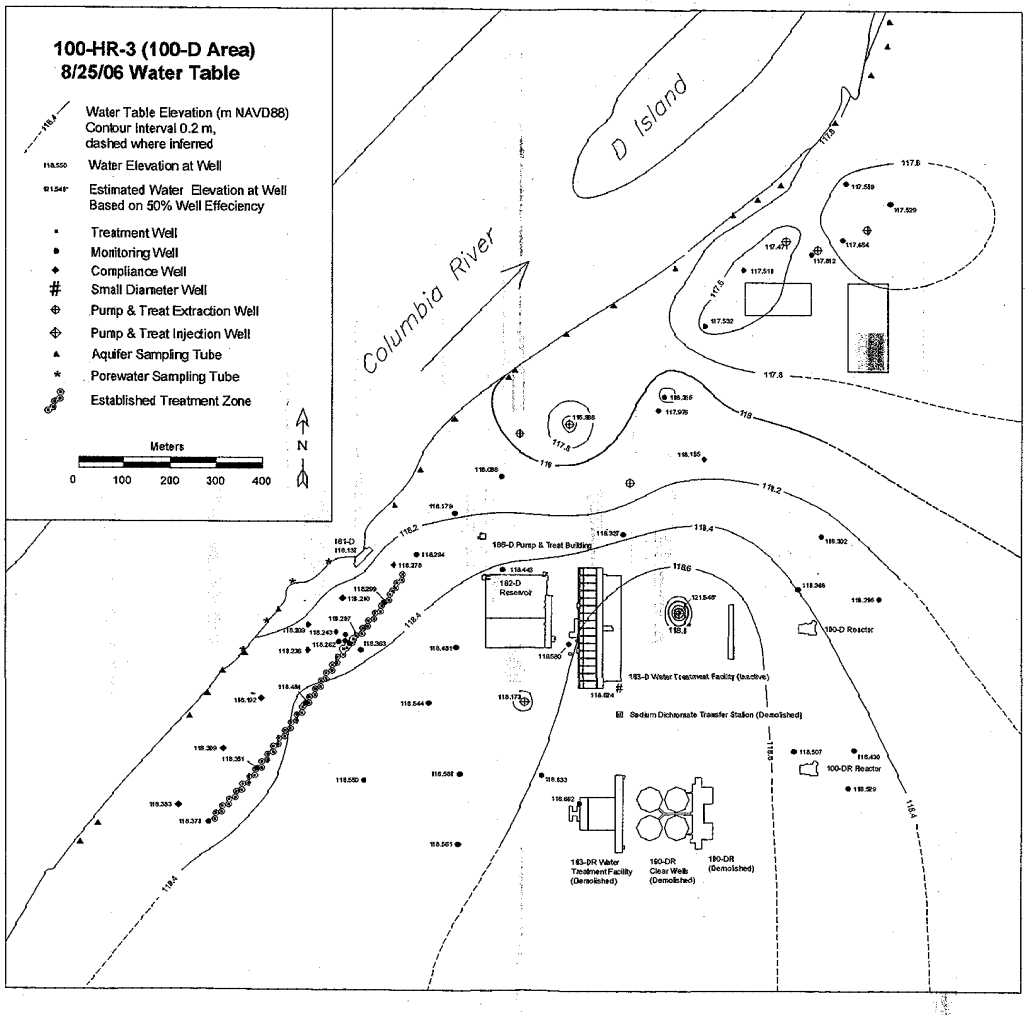

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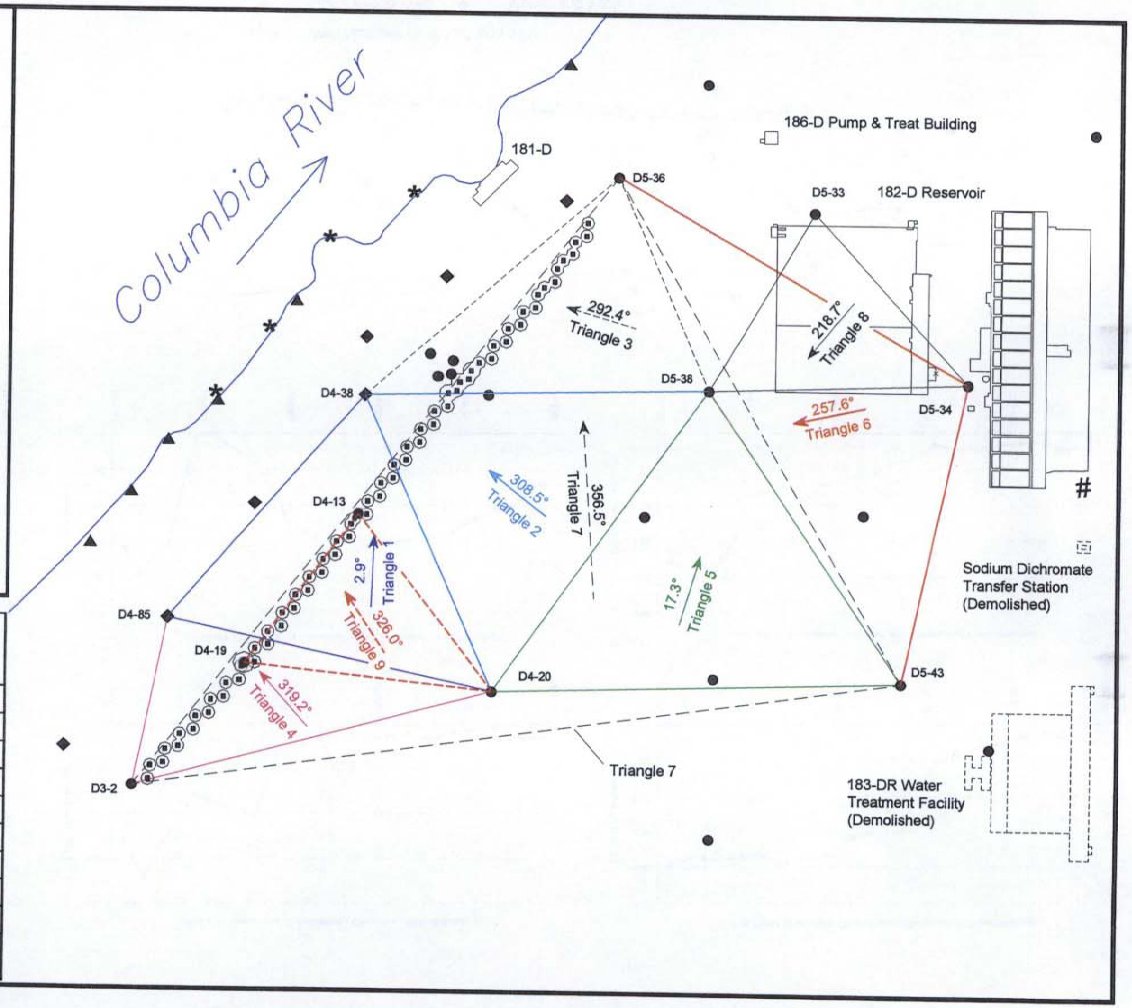
Figure 3-8. Three-Point Problem Triangles and Net Flow Directions.



Triangle	% Optimal	Total Distance (m)	Net Flow Direction (°a)	Average Gradient
1	61	11.98	2.9	0.0012
2	68	11.18	308.5	0.0011
3	57	9.53	292.4	0.0010
4	47	1.13	319.2	0.0008
5	35	0.73	17.3	0.0004
6	31	8.35	257.6	0.0006
7	52	2.39	356.5	0.0005
8	17	10.48	218.7	0.0010
9	61	15.37	326.0	0.0010

K = 25 ft/d (hydraulic conductivity), Θ = 15% (porosity)

Figure 3-9. Hexavalent Chromium Trends in Compliance Wells, Fiscal Year 2006.

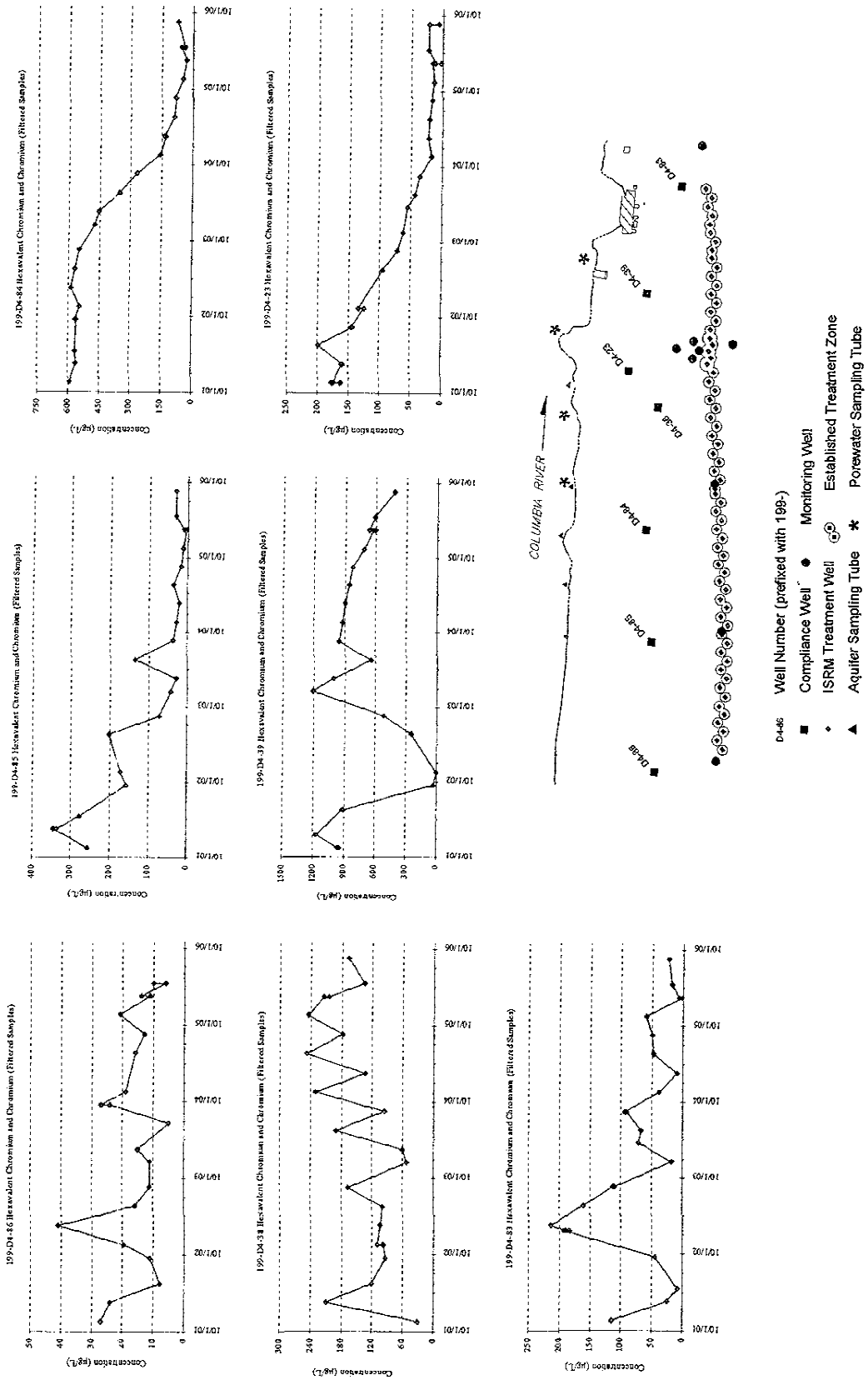


Figure 3-10. 100-D Area Hexavalent Chromium Plume Map, First Quarter of Fiscal Year 2006.

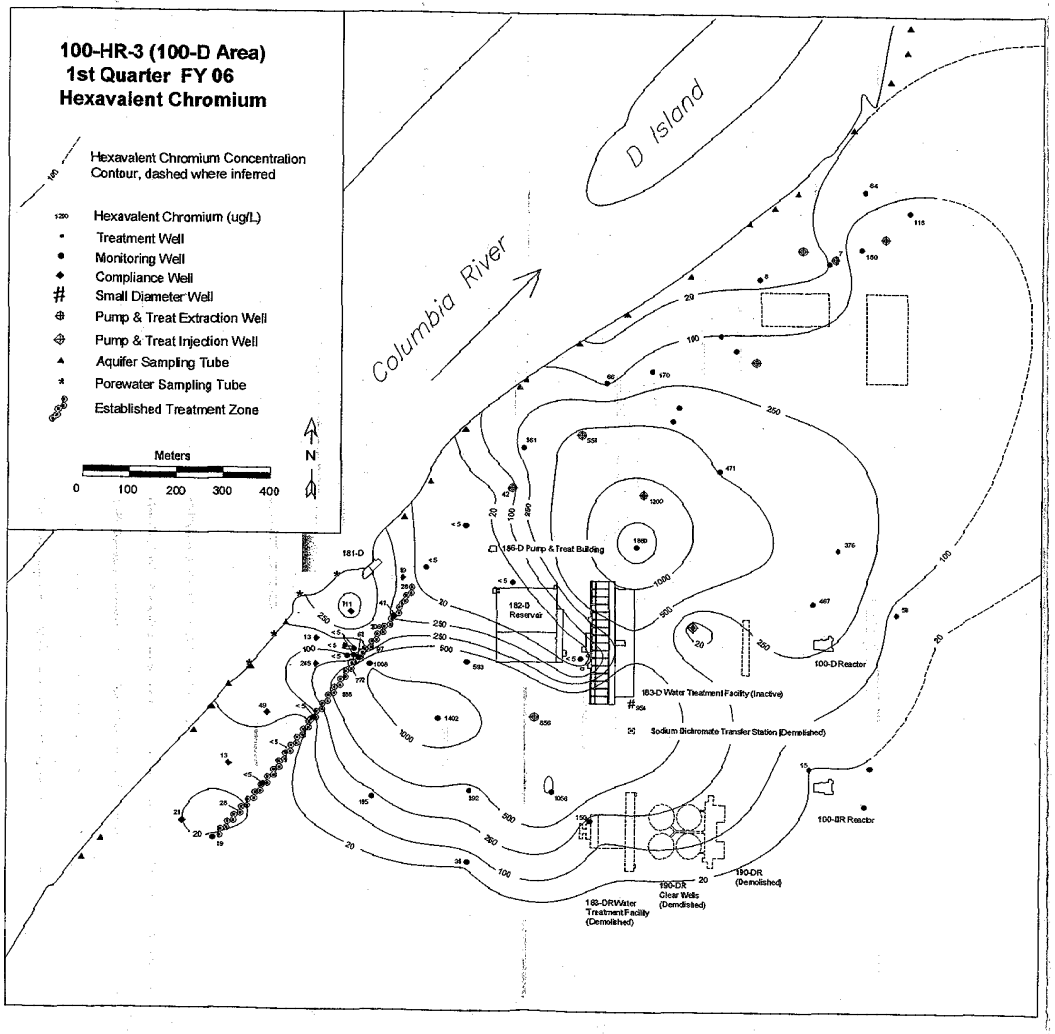


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Figure 3-11. 100-D Area Hexavalent Chromium Plume Map, Second Quarter of Fiscal Year 2006.

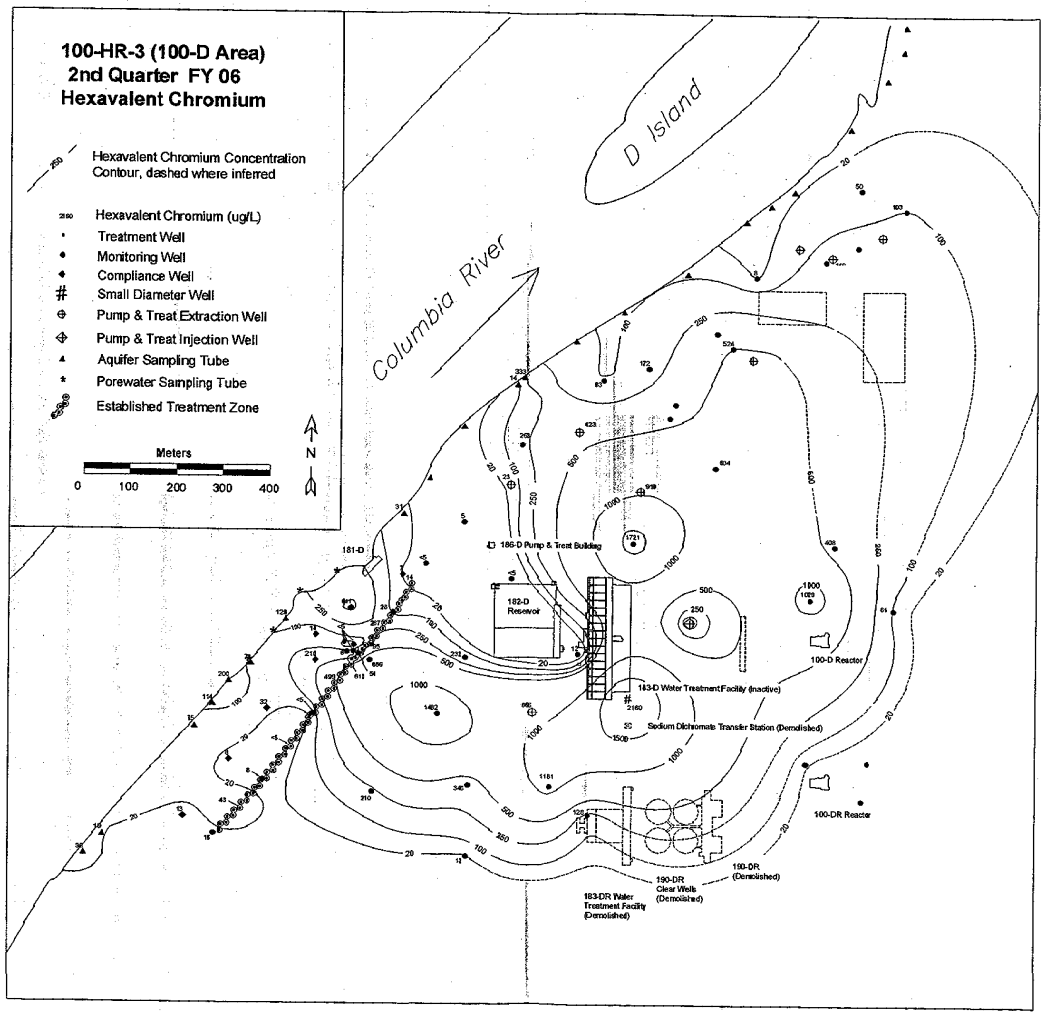

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Figure 3-12. 100-D Area Hexavalent Chromium Plume Map, Third Quarter of Fiscal Year 2006.

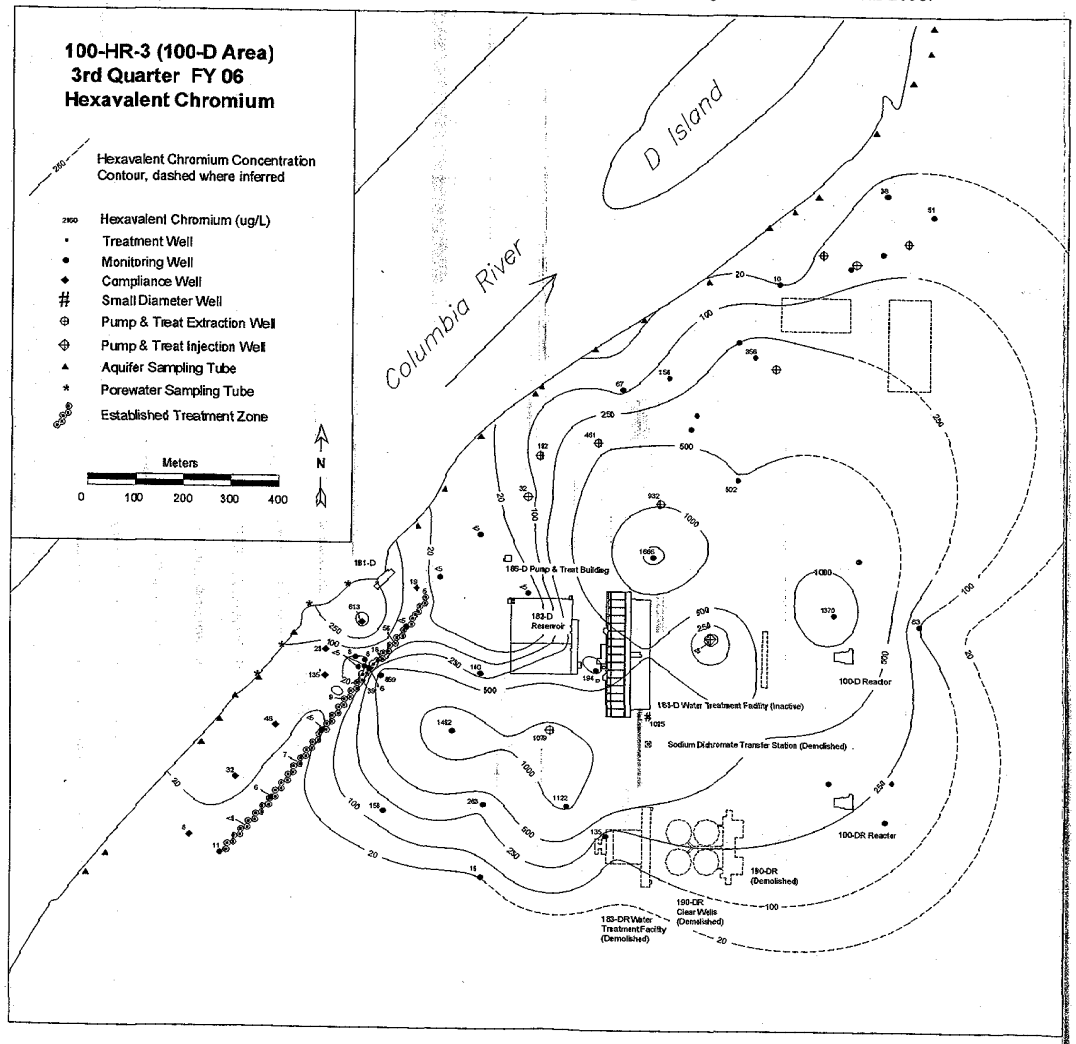

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Figure 3-13. 100-D Area Hexavalent Chromium Plume Map, Fourth Quarter of Fiscal Year 2006.

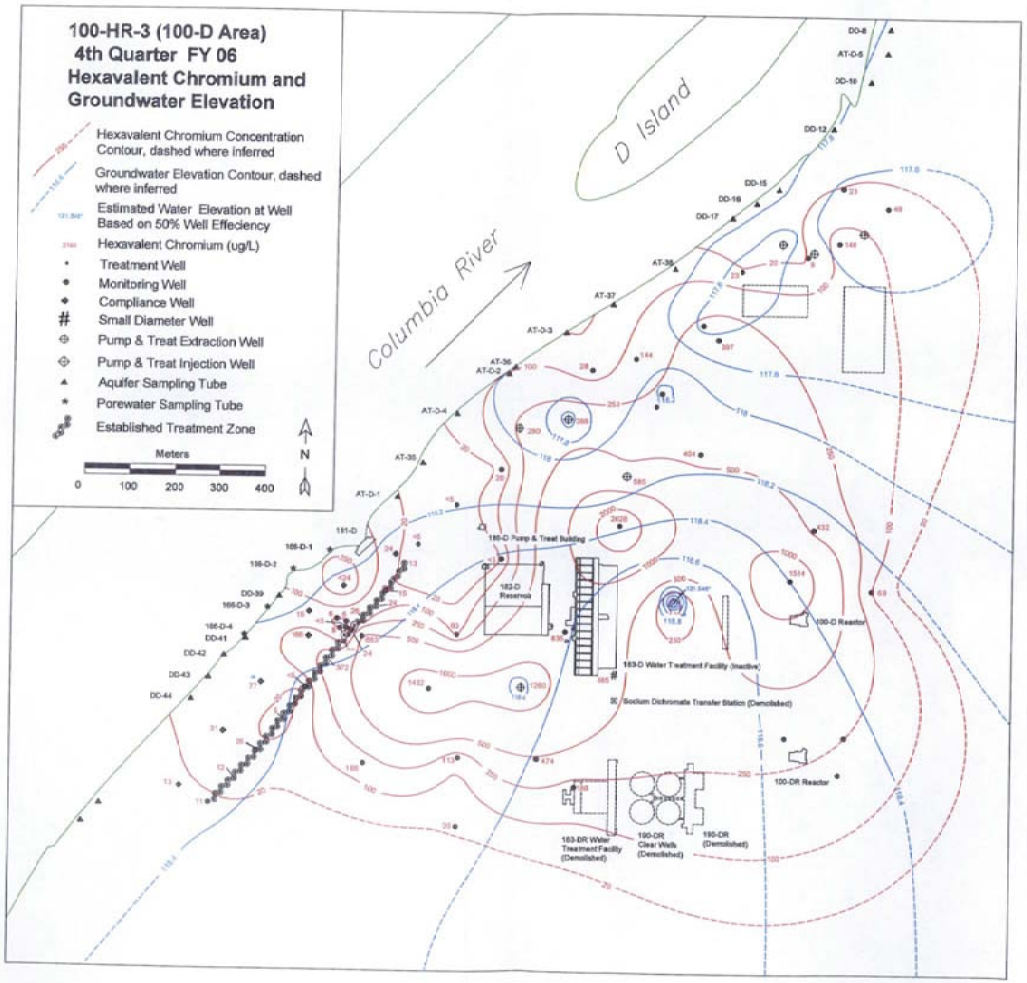
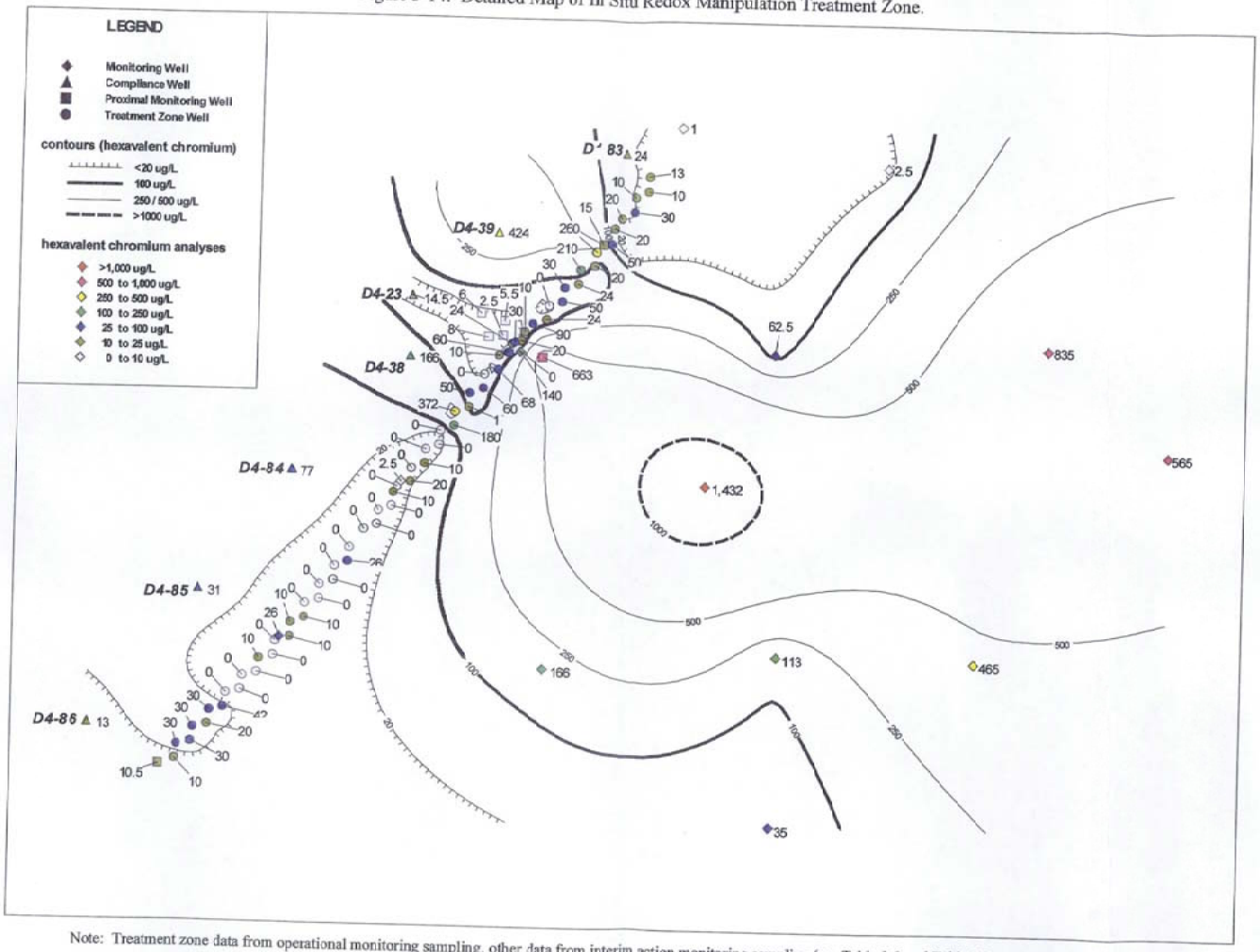


Figure 3-14. Detailed Map of In Situ Redox Manipulation Treatment Zone.



Note: Treatment zone data from operational monitoring sampling, other data from interim action monitoring sampling (see Table 3-9 and Table 3-5, respectively).

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Figure 3-15. In Situ Redox Manipulation Dissolved Oxygen Concentrations, Fourth Quarter Fiscal Year 2006.

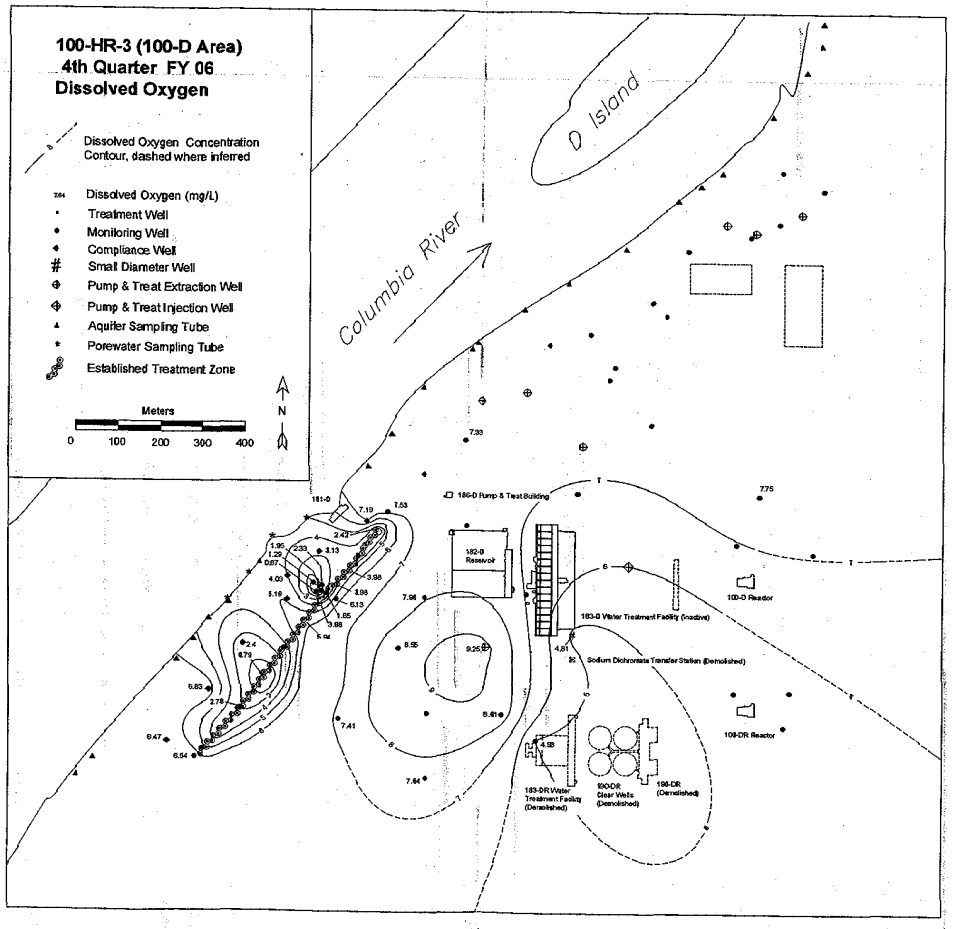

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Figure 3-16. In Situ Redox Manipulation Sulfate Plume Map, Fourth Quarter Fiscal Year 2006.

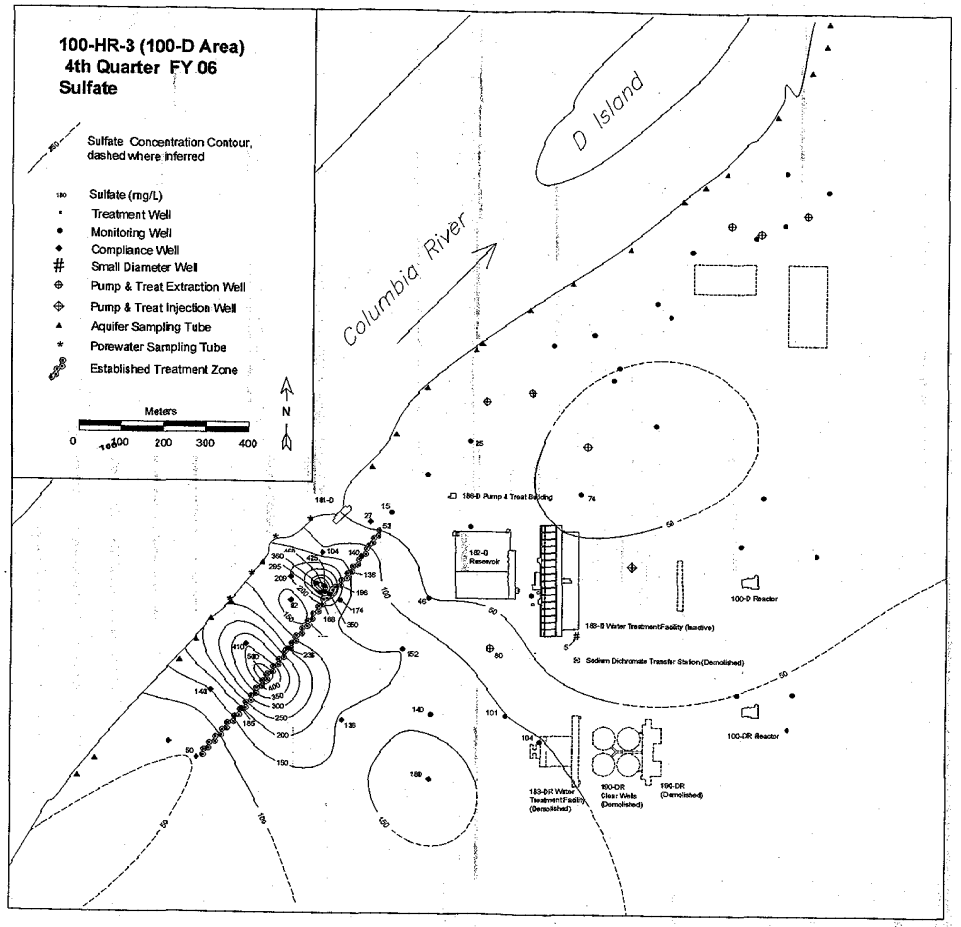


Figure 3-17. In Situ Redox Manipulation Operational Monitoring – Quarterly Hexavalent Chromium Concentrations, Fiscal Year 2006.

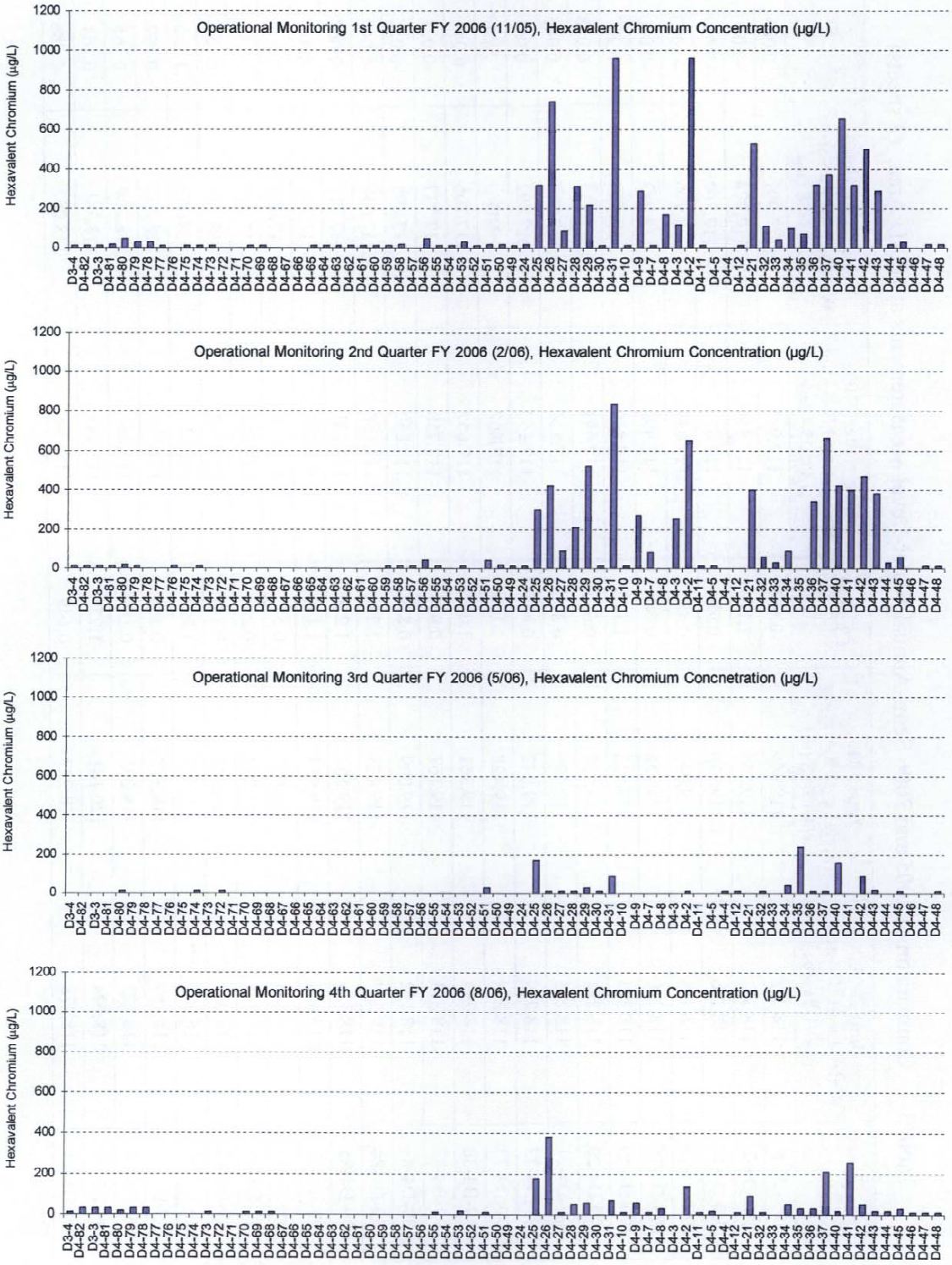


Table 3-1. Comparison of 2005 and 2006 Semi-Annual Water-Level Measurements at 100-D Area. (2 sheets)

Well Name	June 2005 Water-Level Elevation NAVD88 (m)	June 2006 Water-Level Elevation NAVD88 (m)	Change (m)	November 2005 Water-Level Elevation NAVD88 (m)	November 2006 Water-Level Elevation NAVD88 (m)	Change (m)
199-D2-6	118.308	118.969	-0.661	117.985	117.991	0.006
199-D3-2	118.381	119.551	1.170	117.814	117.774	-0.040
199-D4-13	118.246	119.176	0.930	117.819	117.762	-0.057
199-D4-14	118.198	119.049	0.851	117.833	117.790	-0.043
199-D4-15	118.270	118.758	0.488	117.993	117.983	-0.010
199-D4-19	118.333	119.512	1.179	117.830	117.763	-0.067
199-D4-20	118.294	118.959	0.665	117.953	117.935	-0.018
199-D4-21	118.205	119.095	0.890	117.812	117.766	-0.046
199-D4-22	118.219	119.042	0.823	117.863	117.802	-0.061
199-D4-23	118.298	119.428	1.130	117.807	ND	N/A
199-D4-38	118.294	119.361	1.067	117.657	117.706	0.049
199-D4-39	118.213	119.167	0.954	117.758	117.737	-0.021
199-D4-83	118.192	119.009	0.817	117.860	117.808	-0.052
199-D4-84	118.237	119.478	1.241	117.698	117.658	-0.040
199-D4-85	118.336	119.552	1.216	117.781	117.714	-0.067
199-D4-86	118.413	119.553	1.140	117.801	117.782	-0.019
199-D5-13	117.868	118.451	0.583	117.628	117.695	0.067
199-D5-14	117.963	118.247	0.284	117.841	117.994	0.153
199-D5-15	118.039	118.283	0.244	117.938	118.103	0.165
199-D5-16	116.979	118.199	1.220	116.912	118.062	1.150
199-D5-17	118.169	118.333	0.164	118.120	118.297	0.177
199-D5-18	118.122	118.271	0.149	118.064	118.229	0.165
199-D5-19	118.224	120.181	1.957	118.182	118.346	0.164
199-D5-33	118.278	118.927	0.649	118.348	118.062	-0.286

Table 3-1. Comparison of 2005 and 2006 Semi-Annual Water-Level Measurements at 100-D Area. (2 sheets)

Well Name	June 2005 Water-Level Elevation NAVD88 (m)	June 2006 Water-Level Elevation NAVD88 (m)	Change (m)	November 2005 Water-Level Elevation NAVD88 (m)	November 2006 Water-Level Elevation NAVD88 (m)	Change (m)
199-D5-34	118.309	118.681	0.372	118.193	118.217	0.024
199-D5-36	118.194	119.005	0.811	ND	117.822	N/A
199-D5-37	118.203	119.245	1.042	117.993	117.944	-0.049
199-D5-38	118.250	118.768	0.518	118.006	117.972	-0.034
199-D5-39	118.295	118.374	0.079	117.743	117.798	0.055
199-D5-40	118.295	118.828	0.533	117.993	117.996	0.003
199-D5-41	118.301	118.721	0.420	117.876	117.943	0.067
199-D5-42	118.090	124.440	6.350	122.456	124.776	2.320
199-D5-43	118.310	118.624	0.314	118.118	118.185	0.067
199-D5-44	118.094	118.987	0.893	117.862	117.761	-0.101
		Average Change	**0.935**		**Average Change**	**0.113**

N/A = not applicable
NAVD88 = *North American Vertical Datum of 1988*
ND = not measured

Table 3-2. Comparison of Fiscal Year 2005 and Fiscal Year 2006 Water-Level Monitoring Data.

Well	Distance from River (m)	Average Water-Level Elevation (m)			Maximum Water-Level Elevation (m)			Minimum Water-Level Elevation (m)		
		FY05	FY06	Change[a]	FY05	FY06	Change[a]	FY05	FY06	Change[a]
Columbia River	0	117.807	117.970	0.163	119.454	120.299	0.845	116.402	116.402	0
199-D4-84	92	118.015	118.225	0.210	118.664	119.725	1.061	116.868	117.388	0.520
199-D4-85	92	118.092	118.313	0.221	118.589	119.813	1.224	117.563	117.559	-0.004
199-D4-38	95	117.988	118.163	0.175	118.589	119.396	0.807	117.434	117.446	0.012
199-D4-14	112	118.101	118.187	0.086	118.431	119.116	0.685	117.747	117.757	0.010
199-D5-36	114	118.103	118.242	0.139	118.410	119.060	0.650	117.716	117.746	0.030
199-D4-21	145	118.077	118.216	0.139	118.427	119.137	0.710	117.722	117.748	0.026
199-D4-13	165	118.109	118.293	0.184	118.541	119.362	0.821	117.730	117.756	0.026
199-D4-19	191	118.104	118.310	0.206	118.673	119.693	1.020	117.633	117.640	0.007
199-D3-2	195	118.155	118.291	0.136	118.775	119.651	0.876	117.662	117.662	0
199-D5-33	269	118.346	118.447	0.101	118.786	118.996	0.210	117.925	117.987	0.062
199-D5-38	320	118.220	118.332	0.112	118.441	118.975	0.534	117.667	117.936	0.269
199-D4-20	370	118.201	118.345	0.144	118.531	119.179	0.648	117.783	117.725	-0.058
199-D5-34	483	118.312	118.426	0.114	118.529	118.791	0.262	118.066	118.103	0.037
199-D5-43	665	118.276	118.343	0.067	118.454	118.822	0.368	117.882	117.867	-0.015

[a] Difference between FY05 and FY06 values.
FY = fiscal year
NA = not applicable
ND = no remote water-level monitoring data available

Table 3-3. Groundwater Flow Summary.

Triangle	% Optimal	Well "A"	Well "B"	Well "C"	Total Distance (m)	Net Flow Direction (°a)	Average Gradient
1	61	199-D4-20	199-D4-38	199-D4-85	11.98	2.9	0.0012
2	68	199-D4-20	199-D4-38	199-D5-38	11.18	308.5	0.0011
3	57	199-D4-38	199-D5-38	199-D5-36	9.53	292.4	0.0010
4	47	199-D4-20	199-D3-2	199-D5-85	1.13	319.2	0.0008
5	35	199-D5-43	199-D4-20	199-D5-38	0.73	17.3	0.0004
6	31	199-D5-34	199-D5-43	199-D5-36	8.35	257.6	0.0006
7	52	199-D5-43	199-D3-2	199-D5-36	2.39	356.5	0.0005
8	17	199-D5-34	199-D5-38	199-D5-33	10.48	218.7	0.0010
9	61	199-D4-20	199-D4-13	199-D4-19	15.37	326.0	0.0010

°a = degrees azimuth

Table 3-4. In Situ Redox Manipulation Aquifer Treatment, Compliance, and Monitoring Wells. (3 sheets)

Well			Sampling	
Name	Type	Location	Frequency	Type
199-D4-23	Compliance	Downgradient	A/Q	IAM
199-D4-38	Compliance	Downgradient	A/M	IAM
199-D4-39	Compliance	Downgradient	A/M	IAM
199-D4-83	Compliance	Downgradient	A/Q	IAM
199-D4-84	Compliance	Downgradient	A/Q	IAM
199-D4-85	Compliance	Downgradient	A/Q	IAM
199-D4-86	Compliance	Downgradient	A/Q	IAM
199-D3-2	Proximal monitoring	Cross-gradient	A/Q	IAM
199-D4-1	Proximal monitoring	Downgradient	A/Q	IAM
199-D4-4	Proximal monitoring	Downgradient	A/Q	IAM/operational monitoring
199-D4-5	Proximal monitoring	Downgradient	A/Q	IAM/operational monitoring
199-D4-6	Proximal monitoring	Downgradient	A/Q	IAM
199-D4-22	Proximal monitoring	Upgradient	A/Q	IAM
199-D4-7	Aquifer treatment	Treatment zone	A/Q	IAM/operational monitoring
199-D4-13	Monitoring	Treatment zone	A/Q	IAM
199-D4-14	Aquifer treatment/ monitoring	Treatment zone	A/Q	IAM
199-D4-19	Monitoring	Treatment zone	A/Q	IAM
199-D4-26	Aquifer treatment	Treatment zone	A/Q/m	IAM/operational monitoring
199-D4-31	Aquifer treatment	Treatment zone	A/Q/m	IAM/operational monitoring
199-D4-32	Aquifer treatment	Treatment zone	A/Q	IAM/operational monitoring
199-D4-36	Aquifer treatment	Treatment zone	A/Q	IAM/operational monitoring
199-D4-48	Aquifer treatment	Treatment zone	A/Q	IAM/operational monitoring
199-D4-62	Aquifer treatment	Treatment zone	A/Q	IAM/operational monitoring
199-D4-78	Aquifer treatment	Treatment zone	A/Q	IAM/operational monitoring
199-D2-6	Monitoring	Upgradient	A/Q	IAM
199-D2-8	Monitoring	Upgradient	A/Q	IAM

Table 3-4. In Situ Redox Manipulation Aquifer Treatment, Compliance, and Monitoring Wells. (3 sheets)

Well			Sampling	
Name	Type	Location	Frequency	Type
199-D4-15	Monitoring	Upgradient	A/Q	IAM
199-D4-20	Monitoring	Upgradient	A/Q	IAM
199-D5-13	Monitoring	Upgradient	A/Q	IAM
199-D5-14	Monitoring	Upgradient	A/Q	IAM
199-D5-15	Monitoring	Upgradient	A/Q	IAM
199-D5-20	Monitoring/P&T EW	Cross-gradient	A/Q	IAM
199-D5-32	Monitoring/P&T EW	Cross-gradient	A/Q	IAM
199-D5-33	Monitoring	Upgradient	A/Q	IAM
199-D5-34	Monitoring	Upgradient	A/Q	IAM
199-D5-36	Monitoring	Cross-gradient	A/Q	IAM
199-D5-37	Monitoring/P&T EW	Cross-gradient	A/Q	IAM
199-D5-38	Monitoring	Upgradient	A/Q	IAM
199-D5-39	Monitoring/P&T EW	Upgradient	A/Q	IAM
199-D5-40	Monitoring	Upgradient	A/Q	IAM
199-D5-41	Monitoring	Upgradient	A/Q	IAM
199-D5-42	Monitoring/P&T IW	Upgradient	A/Q	IAM
199-D5-43	Monitoring	Upgradient	A/M	IAM
199-D5-44	Monitoring	Cross-gradient	A/Q	IAM
199-D5-92	Monitoring/P&T EW	Cross-gradient	A/Q	IAM
199-D8-73	Monitoring	Cross-gradient	A/Q	IAM
199-D8-88	Monitoring	Cross-gradient	A/Q	IAM
199-D4-47	Aquifer treatment	Treatment zone	A/Q	Operational monitoring
199-D4-46	Aquifer treatment	Treatment zone	A/Q	Operational monitoring
199-D4-45	Aquifer treatment	Treatment zone	A/Q	Operational monitoring
199-D4-44	Aquifer treatment	Treatment zone	A/Q	Operational monitoring
199-D4-43	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-42	Aquifer treatment	Treatment zone	Q/m	Operational monitoring
199-D4-41	Aquifer treatment	Treatment zone	Q/m	Operational monitoring
199-D4-37	Aquifer treatment	Treatment zone	Q/m	Operational monitoring
199-D4-35	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-34	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-33	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-21	Aquifer treatment	Treatment zone	Q/m	Operational monitoring
199-D4-12	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-11	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-2	Monitoring	Upgradient	Q	Operational monitoring
199-D4-3	Monitoring	Upgradient	Q	Operational monitoring
199-D4-8	Monitoring	Treatment zone	Q	Operational monitoring
199-D4-9	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-10	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-30	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-29	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-28	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-27	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-25	Aquifer treatment	Treatment zone	Q/m	Operational monitoring
199-D4-24	Aquifer treatment	Treatment zone	Q	Operational monitoring

Table 3-4. In Situ Redox Manipulation Aquifer Treatment, Compliance, and Monitoring Wells. (3 sheets)

Well			Sampling	
Name	Type	Location	Frequency	Type
199-D4-49	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-50	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-51	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-52	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-53	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-54	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-55	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-56	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-57	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-58	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-59	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-60	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-61	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-63	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-64	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-65	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-66	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-67	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-68	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-69	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-70	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-71	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-72	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-73	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-74	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-75	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-76	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-77	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-79	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-80	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-81	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D3-3	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-82	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D3-4	Aquifer treatment	Treatment zone	Q	Operational monitoring
199-D4-40	Aquifer treatment	Treatment zone	Q/m	Operational monitoring

NOTE: Locations are relative to the long axis of the ISRM treatment zone. "Upgradient," "downgradient," and "cross-gradient" locations assume a typical groundwater gradient for the fall when there are low-flow conditions in the Columbia River.

A = annual sampling schedule
IAM = interim action monitoring
ISRM = In Situ Redox Manipulation
M = monthly sampling schedule for supplemental operational monitoring
M = monthly sampling schedule for IAM sampling
Q = quarterly sampling schedule
P&T EW = pump-and-treat extraction well (DR-5 pump-and-treat operation)
P&T IW = pump-and-treat injection well (DR-5 pump-and-treat operation)

Table 3-5. Total Chromium and Hexavalent Chromium Concentrations, In Situ Redox Manipulation Monitoring and Compliance Wells. (3 sheets)

Well		Total Chromium[a]/Hexavalent Chromium Concentration (µg/L) – Filtered Samples													
		Annual FY Averages					Quarterly Samples					Quarterly Average			
					FY05 vs. FY06		FY05	FY06				FY05	FY06		
Name	Type	2004	2005	2006	% Change	Trend	4th Qtr.	1st Qtr.	2nd Qtr.	3rd Qtr.	4th Qtr.	4th Qtr.	4th Qtr.	% Change	Trend
199-D4-23	C	49	20	16	-20	Decreasing	17	(12.6|12.9)	(16|2(U)); (12)	23	(23|6)	17	14.5	-15	Stable
199-D4-38	C	100	197	189	-4	Stable	178	245	(214|205)	135	166	178	166	-7	Stable
199-D4-39	C	953	873	595	-32	Decreasing	826	711	629|607(D); (664(D))	613	424	826	424	-49	Decreasing
199-D4-83	C	62	36	22	-39	Decreasing	50	59	3;7	19	24	50	24	-52	Decreasing
199-D4-84	C	388	116	51	-56	Decreasing	82	49.1	(31|32)	57|38	77	82	77	-6	Stable
199-D4-85	C	60	25	21	-16	Stable	17	13	(11|5)	32	31	17	31	82	Increasing
199-D4-86	C	14	17	14	-18	Stable	13	20.9	(14|11)	10	13	13	13	0	Stable
199-D4-7	Ti	2	11	22	98	Increasing	17	62.3	(58|50)	6	24	17	24	41	Increasing
199-D4-13	Tm	2	3	2	-30	Decreasing	(5(U)|5(U))	1.9(U)	5(U)	5(U)	5(U)	2.5	2.5	0	Stable
199-D4-14	Ti	17	22	11	-48	Decreasing	21	40.7	28	5(U)	15	21	15	-29	Decreasing
199-D4-19	Tm	3	8	10	28	Increasing	5(U)	1.9(U)	8	6	26	2.5	26	940	Increasing
199-D4-26	Ti	366	345	372	8	Stable	279	608	499	9	372	279	372	33	Increasing
199-D4-31	Ti	299	272	372	37	Increasing	54	772	610	39	68	54	68	26	Increasing
199-D4-32	Ti	11	29	59	103	Increasing	5(U)	97	95	18	24	2.5	24	860	Increasing
199-D4-36	Ti	15	65	138	113	Increasing	(11|11)	206	267	(56|56)	24	11	24	118	Increasing
199-D4-48	Ti	10	12	15	25	Increasing	17	28.2	14	5	13	17	13	-24	Decreasing
199-D4-62	Ti	4	2	3	62	Increasing	(5(U)|5(U))	1.9(U)	5(U)|5(U)	7	26	2.5	26	940	Increasing
199-D4-78	Ti	6	16	29	81	Increasing	25	(25|24.1); 31.8	43	5(U)	42	25	42	68	Increasing
199-D3-2	PM	9	12	12	1	Stable	16	18.6	(16|2(U))	11	10|11	16	10.5	-34	Decreasing
199-D4-1	PM	3	3	2	-30	Decreasing	(5(U)|5(U))	1.9(U)	5(U)	5(U)	5(U)	2.5	2.5	0	Stable
199-D4-4	PM	3	10	4	-56	Decreasing	12	1.9(B)	(5(U)|2)	8	6|5	12	5.5	-54	Decreasing
199-D4-5	PM	3	6	5	-13	Stable	6	2.4(B)	(7|9)	5(U)	8	6	8	33	Increasing
199-D4-6	PM	9	7	5	-36	Decreasing	5(U)	5(U); 4.2(B)	(5(U)|2)	8	6	2.5	6	140	Increasing
199-D4-22	PM	1,043	929	854	-8	Stable	934	(986|1030)	886	859	658|668	934	663	-29	Decreasing
199-D2-6	M	39	32	24	-24	Decreasing	35	(33.7|35.7)	(10|13)	15	35	35	35	0	Stable
199-D2-8	M	--	146	150	3	Stable	144	150	128	135	186	144	186	29	Increasing

Table 3-5. Total Chromium and Hexavalent Chromium Concentrations, In Situ Redox Manipulation Monitoring and Compliance Wells. (3 sheets)

Well		Total Chromium[a]/Hexavalent Chromium Concentration (µg/L) – Filtered Samples													
		Annual FY Averages					Quarterly Samples					Quarterly Average			
					FY05 vs. FY06		FY05	FY06				FY05	FY06		
Name	Type	2004	2005	2006	% Change	Trend	4th Qtr.	1st Qtr.	2nd Qtr.	3rd Qtr.	4th Qtr.	4th Qtr.	4th Qtr.	% Change	Trend
199-D4-15	M	1,259	1,354	1,443	7	Stable	1,416; 1,436; 870	1,384|1,488; (1,400|1,390), 1,312|1,436	(1,332|1,590); 1,516; 1,468	(1,436|1,448); 1,464|1,520; 1,434	1,450; 1,408; 1,438	1,241	1,432	15	Stable
199-D4-20	M	178	218	182	-17	Stable	192	195	210	(156|156)	166	192	166	-14	Stable
199-D5-13	M	705	583	495	-15	Stable.	602	471	604	502	404	602	404	-33	Decreasing
199-D5-14	M	297	389	405	4	Stable	(361|362)	376	408	--	432	361.5	432	20	Increasing
199-D5-15	M	503	673	1,064	58	Increasing	1,082	467	1,034|1,024	1,370|1,370	1,514	1,082	1,514	40	Increasing
199-D5-20	M/E	1,369	--	--	N/A	N/A	--	557	423(D)	--	--	--	--	--	N/A
199-D5-32	M/E	843	--	--	N/A	N/A	--	1,200(N)	919(D)	913;975;980; 928;963;895; 933;938;862; 930	--	--	--	--	N/A
199-D5-33	M	4	3	2	-23	Decreasing	(5(U)|5(U))	1.9(U), 5(U)	5(U)	5(U)	5(U)	2.5	2.5	0	Stable
199-D5-34	M	5	3	261	8,589	Increasing	5(U)	1.9(U), 5(U)	12	194	835	2.5	835	33,300	Increasing
199-D5-36	M	7	4	2	-55	Decreasing	5(U)	2.1(B)	(0.1(U)|2(U)); (5(U))	(5(U)|5(U))	2(U)	2.5	1	-60	Stable
199-D5-37	M/E	224	30	29	-2	Stable	5|31	39|38; 46	23; 25	30; 33	24|15	18	19.5	8	Stable
199-D5-38	M	254	332	329	-1	Stable	295; 361; (530|533)	(586|600);(605| 596), 584|588	305|299; (257|247); 141	223|220; 176|171: (23|24)	45; 80	396	62.5	-84	Decreasing
199-D5-39[b]	M/E	1,493	--	1,280	N/A	N/A	--	693; 937, (958|982)|870	792; 912|918; (817); (914|968)	--	(960|998); 1,352; 1,506|1,514	--	1,280	--	N/A
199-D5-40	M	187	--	279	N/A	N/A	--	392	346	263	113	--	113	--	N/A
199-D5-41	M	2,269	--	1,819	N/A	N/A	--	1,860	1,650(D)|1,792	1,666	2,028	--	2,028	--	N/A
199-D5-42	M/I	31	--	--	N/A	N/A	--	--	--	--	--	--	--	--	N/A

Table 3-5. Total Chromium and Hexavalent Chromium Concentrations, In Situ Redox Manipulation Monitoring and Compliance Wells. (3 sheets)

Well		Total Chromium[a]/Hexavalent Chromium Concentration (µg/L) – Filtered Samples													
		Annual FY Averages					Quarterly Samples					Quarterly Average			
					FY05 vs. FY06		FY05	FY06				FY05	FY06		
Name	Type	2004	2005	2006	% Change	Trend	4th Qtr.	1st Qtr.	2nd Qtr.	3rd Qtr.	4th Qtr.	4th Qtr.	4th Qtr.	% Change	Trend
199-D5-43	M	1,063	1,186	958	-19	Stable	(1,056|1,240); 1,114; 994	1,046; (954|1,040), (1,000|1,030); 1,170	1,164; (1,200(D)| 1,216); 1,178|1,162	1,216; (1,212|1,210); 939	(460|478); 461	1,085	465	-57	Decreasing
199-D5-44	M	4	2	3	37	Increasing	5(U)	1.9(U)	5	5(U)	5(U)	2.5	2.5	0	Stable
199-D5-92	M/E	--	--	--	N/A	N/A	--	--	(256|270)	--	--	--	--	--	N/A
199-D5-93	M	--	1,013	1,138	12	Stable	873|845	920; 980; 2,360	1,600; 2,160; 1,360	1,010; 1,040; 930	740; 390	859	565	-34	Decreasing
199-D8-73	M	--	173	161	-7	Stable	160; (161|160); 164	171;170	174|173; 171; 171|172	169; 136; 164	(141|128); (159|148); 152|153	162	146.8	-9	Stable
199-D8-88	M	--	49.5	61	22	Increasing	69; 58; 88	(51|50); 78.5	78; 88|86; 84	(69|69); 88; 45	17; 19; 47	72	27.7	-62	Decreasing

[a] Concentrations are total chromium from filtered inductively coupled plasma metals analysis and can be assumed to be entirely hexavalent chromium.
[b] Well converted to pump-and-treat extraction well in third quarter of FY05.
% change = (Average 4th quarter FY06 – average 4th quarter FY05) / (average 4th quarter FY05) X 100%. Wells are considered stable if there is less than a 20% change in concentration from FY05 to FY06. Where a (U) qualifier is involved in the % change or average calculation, one-half of the listed detection limit is used in the calculation.
(132|131) = Indicates sample results from splits. 172|152 = Indicates sample results from replicates.
– = no data available
(B) = detected at concentration less than the contract-required detection limit but greater than the instrument or method detection limit
(N) = spike sample recovery outside control limits
C = compliance well
(F) = result flagged as suspect; not used
FY = fiscal year
M = monitoring well
E = pump-and-treat extraction well
I = pump-and-treat injection well
(N) = spike sample recovery outside the control limits
N/A = not applicable
PM = proximal monitoring well located near the treatment zone
Ti = treatment zone injection well; well has been used to treat the aquifer
Tm = treatment zone monitoring well; well has not been used to treat the aquifer
(U) = analyzed but not detected; value shown is analysis detection limit; one-half of the detection limit is used to calculate average or % change values

Table 3-6. Aquifer Sampling Tubes and Porewater Sampling Tubes, Hexavalent Chromium and Specific Conductance, Dissolved Oxygen and Temperature. (2 sheets)

Tube Site*	Tube Name	Sample Depth (ft)	Cr^{+6} Concentration (µg/L) and Specific Conductance (µS/cm)				FY06 DO and Temperature
			FY03	FY04	FY05	FY06	
DD-50	DD-50-1	15.0	NS	NS	23:241.1	18:223.9	10.3 mg/L @ 12.7°C
	DD-50-2	20.0	24:245	18:278	23: 280.9	25:256.2	10.0 mg/L @ 13.3°C
	DD-50-3	24.7	NS	24:299	23:247.3	38:271.5	9.4 mg/L @ 13.0°C
	DD-50-4	31.0	28: –	23: –	32:250.4	30:246.1	9.8 mg/L @ 13.2°C
DD-49	DD-49-1	12.0	10:184	12: –	29:292	6:190.4	11.1 mg/L @ 10.1°C
	DD-49-2	21.8	NS	18:319	NS	NS	NS
	DD-49-3	25.0	20:252	20:237	16:231.3	18:263.2	10.2 mg/L @ 13.0°C
	DD-49-4	31.0	17:263|25:25	21:258	23:267.3	19:264.1	9.8 mg/L @ 12.9°C
DD-44	DD-44-3	12.0	46:202	216:534	13:183.4	65:527.6	10.8 mg/L @ 10.1°C
	DD-44-4	18.0	247:577	217: –	NS	75:707.3	**6.4 mg/L @ 10.1°C**
DD-43	DD-43-2	10.0	NS	293: –	3:133.3	38:310	10.5 mg/L @ 9.9°C
	DD-43-3	13.9	144:281	347:581	35:214.6	114:688.4	8.6 mg/L @ 10.0°C
DD-42	DD-42-2	10.2	295: –	270:304	2:131.2	4:140.8	11.1 mg/L @ 10.8°C
	DD-42-3	15.2	NS	383:–	NS	NS	NS
	DD-42-4	18.2	NS	357: –	NS	200:597.6	8.4 mg/L @ 12.6°C
DD-41	DD-41-1	8.1	1.5:124	14:141	<1.5:128.8	2:123.6	8.0 mg/L @ 9.5°C
	DD-41-2	13.6	176:295	186:936	119:739.9	73:727.7	7.4 mg/L @ 11.8°C
	DD-41-3	18.6	143:260	153:401	53:452.8	57:497	**6.3 mg/L @ 11.2°C**
166-D-4	Redox-4-3.0	3.0	NS	157: 991	79:541.2	81:687.5	9.9 mg/L @ 8.9°C
	Redox-4-6.0	6.0	NS	181:952	85:593.7	76:686.4	7.6 mg/L @ 8.6°C
166-D-3	Redox-3-3.3	3.3	172:611	163:828	223: –	394:622.6	9.9 mg/L @ 7.4°C
	Redox-3-4.6	4.6	166:585	160:824	233|233: –	375:619.2	**6.8 mg/L @ 8.3°C**
DD-39	DD-39-1	5.5	12|13:182	42:330	{17.4:}	NS	NS
	DD-39-2	10.5	104:532	55:499	95:800	129:564.8	6.6 mg/L @ 10.7°C
	DD-39-3	15.0	NS	62:102	NS	NS	NS
166-D-2	Redox-2-3.0	3.0	41:227	39:728	42:322.7	6:265.5	10.1 mg/L @ 6.4°C
	Redox-2-6.0	6.0	30:297	13:478	38:490.2	41:496.8	**4.8 mg/L @ 6.5°C**

Table 3-6. Aquifer Sampling Tubes and Porewater Sampling Tubes, Hexavalent Chromium and Specific Conductance, Dissolved Oxygen and Temperature. (2 sheets)

Tube Site[a]	Tube Name	Sample Depth (ft)	Cr^{+6} Concentration (µg/L) and Specific Conductance (µS/cm)				FY06 DO and Temperature
			FY03	FY04	FY05	FY06	
166-D-1	Redox-1-3.3	3.3	NS	780:656	19:137.7	124:196.7	10.7 mg/L @ 5.3°C
	Redox-1-6.0	6.0	NS	581:642	123:185	109:193.7	9.0 mg/L @ 6.9°C
AT-D-1	AT-D-1-S	7.0	NS	8:224	4:279.2	10:131.2	9.1 mg/L @ 7.9°C
	AT-D-1-M	10.8	NS	4:53	20:240	31:253.9	10.3 mg/L @ 8.2°C
	AT-D-1-D	13.3	NS	10:268	25:241.8	20:266.8	8.3 mg/L @ 10.6°C
AT-D-4	AT-D-4-S	12.4	NS	20:153	27:160.8	2:150	8.4 mg/L @ 7.5°C
	AT-D-4-M	13.8	NS	23:153	27:161.3	3:150.5	7.7 mg/L @ 7.2°C
	AT-4-D-D	15.7	NS	33:169	23:158.4	2:152.1	**7.0 mg/L @ 7.7°C.0**
AT-D-2	AT-D-2-S	14.3	NS	91:282	26:189.9	11:234.1	**4.5 mg/L @ 12.4°C**
	AT-D-2-M	16.3	NS	78:287	25:181.9	14:192.9	8.5 mg/L @ 10.2°C
AT-36	36-S	8.0	NS	NA	NS	37:275.2	8.5 mg/L @ 12.7°C
	36-M	14.0	NS	NA	NS	120:251.9	**5.9 mg/L @ 12.3°C**
	36-D	21.0	NS	NA	NS	333:286	7.9 mg/L @ 12.9°C
AT-D-3	AT-D-3-S	7.3	NS	290:339	NS	30:223	**5.7 mg/L @ 13.0°C**
	AT-D-3-M	8.8	NS	316:37	NS	32:223.2	**5.7 mg/L @ 13.8°C**
	AT-D-3-D	11.8	NS	233:321.5	134:235.4	34:221.4	6.6 mg/L @ 13.8°C

NOTE: The "166-" prefix sites are porewater sampling tubes installed in river substrate.
[a] Tube sites are listed from southwest to northeast.
28:278 = hexavalent chromium concentration in µg/L : specific conductance in µS/cm
17:263|25:256 = replicate sample, value separated by "|"
– = specific conductance value not listed in the Hanford Environmental Information System
DO = dissolved oxygen
FY = fiscal year
NA = not available
NS = not sampled
{123}= hexavalent chromium from automated system installed on July 20, 2004 (averaged value)
6.4 mg/L @ 10.1°C = bold text indicates DO concentration is less than the 60% saturation value

Table 3-7. Dissolved Oxygen Concentrations and Temperature, In Situ Redox Manipulation Monitoring, Compliance and Treatment Wells. (2 sheets)

Well		DO (mg/L) and Temperature (°C) – Unfiltered Samples					
		Quarterly Samples		4th Quarter Average DO			
Name	Type	FY05 4th Qtr.	FY06 4th Qtr.	FY05 (mg/L)	FY06 (mg/L)	% Change	Trend
199-D2-6	M	--	7.64 mg/L @ 24.8°C	--	7.64	NA	NA
199-D2-8	M	6.11 mg/L @ 17.7°C	4.93 mg/L @ 19.1°C	6.11	4.93	-19	Stable
199-D3-2	PM	7.26 mg/L @ 17.3°C	6.54 mg/L @ 17.7°C	7.26	6.54	-10	Stable
199-D4-1	PM	0.15 mg/L @ 17.6°C	1.95 mg/L @ 19.3°C	0.15	1.95	1,200	Increasing
199-D4-4	PM	2.05 mg/L @ 20.4°C	2.33 mg/L@ 18.7°C; 1.83 mg/L@ 27.3°C	2.05	2.08	1	Stable
199-D4-5	PM	1.03 mg/L @ 19.3°C	0.67 mg/L@ 18.6°C	1.03	-.67	-165	Decreasing
199-D4-6	PM	--	--	--	--	NA	NA
199-D4-7	Ti	0.47 mg/L @ 18.4°C	1.65 mg/L @ 24.3°C; 0.27 mg/L @ 19.2°C	0.47	0.96	104	Increasing
199-D4-14	Ti	0.35 mg/L @ 17.0°C	1.29 mg/L @ 17.2°C	0.35	1.29	269	Increasing
199-D4-15	M	8.38 mg/L @ 17.7°C; 9.20 mg/L @ 17.0°C; 7.95 mg/L @ 17.2°C	8.30 @ 17.5°C; 8.55 @ 17.7°C, 8.48 @ 17.7°C	8.51	8.44	-1	Stable
199-D4-20	M	6.72 mg/L @ 17.6°C	7.41 @ 17.5°C	6.72	6.72	0	Stable
199-D4-22	PM	7.54 mg/L @ 17.6°C	6.13 mg/L @ 18.0°C	7.54	6.13	-19	Stable
199-D4-23	C	1.76 mg/L @ 16.9°C	4.03 mg/L @ 17.2°C	1.76	4.03	129	Increasing
199-D4-26	Ti	3.00 mg/L @ 17.9°C	4.31 mg/L @ 18.6°C; 5.94 mg/L @ 17.9°C; 3.96 mg/L @ 16.4°C	3.00	4.74	58	Increasing
199-D4-31	Ti	0.47 mg/L @ 18.3°C	1.34 mg/L @ 22.5°C; 1.63 mg/L @ 20.0°C; 3.98 mg/L @ 28.1°C; 4.08 mg/L @ 16.0 °C	0.47	2.76	487	Increasing
199-D4-32	Ti	0.62 mg/L @ 18.7°C	3.17 mg/L @ 24.6°C; 1.00 mg/L @ 19.5°C	0.62	2.09	237	Increasing
199-D4-36	Ti	0.92 mg/L @ 18.2°C	0.92 mg/L @ 22.7°C; 0.92 mg/L @ 24.3°C; 1.07 mg/L @ 17.7°C; 3.36 mg/L @ 19.0°C	0.92	2.09	127	Increasing
199-D4-38	C	4.36 mg/L @ 17.7°C	5.19 mg/L @ 17.8°C	4.36	5.19	19	Stable
199-D4-39	C	3.93 mg/L @ 17.0°C	3.13 mg/L @ 17.2°C	3.93	3.13	-20	Decreasing
199-D4-48	Ti	1.05 mg/L @ 16.7°C	2.42 mg/L @ 20.9°C; 1.51 mg/L @ 21.1°C	1.05	1.97	88	Increasing
199-D4-62	Ti	0.10 mg/L @ 18.0°C	0.79 mg/L @ 25.2°C; 0.25 mg/L @ 18.7°C	0.10	0.52	420	Increasing
199-D4-78	Ti	--	2.78 mg/L @ 27.6°C; 2.72 mg/L @ 18.1°C	--	2.75	NA	NA
199-D4-83	C	7.77 mg/L @ 15.9°C	7.19 mg/L @ 16.3°C	7.77	7.19	-7	Stable
199-D4-84	C	2.94 mg/L @ 16.9°C	2.40 mg/L @ 17.6°C	2.94	2.40	-18	Stable
199-D4-85	C	6.22 mg/L @ 16.8°C	6.83 mg/L @ 17.9°C	6.22	6.83	10	Stable
199-D4-86	C	6.39 mg/L @ 17.2°C	6.47 mg/L @ 17.6°C	6.39	6.47	1	Stable

Table 3-7. Dissolved Oxygen Concentrations and Temperature, In Situ Redox Manipulation Monitoring, Compliance and Treatment Wells. (2 sheets)

Well		DO (mg/L) and Temperature (°C) – Unfiltered Samples					
		Quarterly Samples		4th Quarter Average DO			
Name	Type	FY05 4th Qtr.	FY06 4th Qtr.	FY05 (mg/L)	FY06 (mg/L)	% Change	Trend
199-D5-20	M	--	--	--	--	NA	NA
199-D5-33	M	9.53 m/L @ 12.8°C	--	9.53	--	NA	NA
199-D5-34	M	8.10 mg/L @ 14.9°C	--	8.10	--	NA	NA
199-D5-36	M	7.51 mg/L @ 15.9°C	7.53 mg/L @ 16.0°C	7.51	7.53	0	Stable
199-D5-37	M	--	7.33 mg/L @ 18.5°C	--	7.33	NA	NA
199-D5-38	M	8.11 mg/L @ 16.2°C; 9.15 mg/L @ 15.8°C; 8.66 mg/L @ 15.9°C	7.43 mg/L @ 16.3°C; 7.96 mg/L @ 16.3°C; 7.49 mg/L @ 16.4°C	8.64	7.63	-12	Stable
199-D5-39	M	--	8.59 mg/L @ 16.2°C; 9.25 mg/L @ 16.0°C; 8.03 mg/L @ 16.4°C	--	8.62	NA	NA
199-D5-40	M	--	--	--	--	NA	NA
199-D5-41	M	--	--	--	--	NA	NA
199-D5-43	M	7.60 mg/L @ 17.9°C; 7.57 mg/L @ 16.9°C; 6.78 mg/L @ 17.1°C	8.61 mg/L @ 18.1°C; 8.28 mg/L @ 17.2°C	7.32	8.45	15	Stable
199-D8-88	M	8.19 mg/L @ 18.2°C	--	8.19	--	NA	N/A

% change = (Average 4th quarter FY06 – average 4th quarter FY05) / (average 4th quarter FY05) X 100%. Wells are considered stable if there is less than a 20% change in concentration from FY05 to FY06.

-- = no data available
C = compliance well
DO = dissolved oxygen
FY = fiscal year
M = monitoring well
PM = proximal monitoring well located near the treatment zone
NA = not available
Ti = treatment zone injection well; well has been used to treat the aquifer
Tm = treatment zone monitoring well; well has not been used to treat the aquifer

Table 3-8. Sulfate Concentrations, In Situ Redox Manipulation Monitoring and Compliance Wells. (3 sheets)

Well		Sulfate Concentration (mg/L) – Unfiltered Samples													
		Annual FY Averages					Quarterly Samples					Quarterly Average			
							FY05	FY06				FY05	FY06		
Name	Type	2004	2005	2006	% Change	Trend	4th Qtr.	1st Qtr.	2nd Qtr.	3rd Qtr.	4th Qtr.	4th Qtr.	4th Qtr.	% Change	Trend
199-D2-6	M	131	122	136	11	Stable	140	(126|118)	108|112	132	180	140	180	29	Increasing
199-D2-8	M	--	187	102.8	-45	Decreasing	110	101	102	104	104	110	104	-5	Stable
199-D3-2	PM	119	101	67.2	-33	Decreasing	70	81.5	(74|81.5)	60	46|53	70	49.5	-29	Decreasing
199-D4-1	PM	561	421	278.3	-34	Decreasing	(460|460)	311	320	330	460	460	460	0	Stable
199-D4-4	PM	513	414	381.5	-8	Stable	410	431	310	360	420|430	410	425	4	Stable
199-D4-5	PM	769	376	304	-19	Stable	200	336	330	255	295	200	295	48	Increasing
199-D4-6	PM	527	409	416	2	Stable	--	480; 368	400	480	360	--	360	--	NA
199-D4-7	Ti	381	290	257.8	-11	Stable	380	216	210	255	350	380	350	-8	Stable
199-D4-13	Tm	186	174	187.5	8	Stable	(196|176)	158	184	172	236	186	236	27	Increasing
199-D4-14	Ti	117	123	112.8	-8	Stable	124	109	90	112	140	124	140	13	Stable
199-D4-15	M	139	142	139.8	-2	Stable	140; 144	140|148; (128|144); (184|130)	(152|140); 84; 120	152|152; (123|164); (138|152)	148; 152	142	150	6	Stable
199-D4-19	Tm	796	800	533.8	-33	Decreasing	340	1050	590	310	185	340	185	-46	Decreasing
199-D4-20	M	141	130	126.5	-3	Stable	126	121	126	122|124	136	126	136	8	Stable
199-D4-22	PM	225	145	145.9	1	Stable	156	(133|126)	128	152	176|172	156	174	12	Stable
199-D4-23	C	404	398	293.3	-26	Decreasing	340	349|351	(305|303)	310	(208|210)	340	209	-39	Decreasing
199-D4-26	Ti	152	147	148.5	1	Stable	160	126	180	140	148	160	148	-8	Stable
199-D4-31	Ti	195	166	175.5	6	Stable	208	142	192	180	188	208	188	-10	Stable
199-D4-32	Ti	157	172	162.5	-6	Stable	168	142	168	144	196	168	196	17	Stable
199-D4-36	Ti	98	117	124.5	6	Stable	(130|128)	126	120	116	136	129	136	5	Stable
199-D4-38	C	239	143	123.3	-14	Stable	70	153	164	84	92	70	92	31	Increasing
199-D4-39	C	123	101	91.3	-10	Stable	110	85.3	86	90	104	110	104	-5	Stable
199-D4-48	Ti	81	57	44.7	-22	Decreasing	51	42.8	45	39	52	51	52	2	Stable

Table 3-8. Sulfate Concentrations, In Situ Redox Manipulation Monitoring and Compliance Wells. (3 sheets)

Well		Sulfate Concentration (mg/L) – Unfiltered Samples													
		Annual FY Averages					Quarterly Samples					Quarterly Average			
							FY05	FY06				FY05	FY06		
Name	Type	2004	2005	2006	% Change	Trend	4th Qtr.	1st Qtr.	2nd Qtr.	3rd Qtr.	4th Qtr.	4th Qtr.	4th Qtr.	% Change	Trend
199-D4-62	Ti	376	252	286.8	14	Stable	250|310	187	(240|260)	210	500	280	500	79	Increasing
199-D4-78	Ti	823	418	443.3	6	Stable	--	680; 510	345	390	--	--	--	--	NA
199-D4-83	C	26	23	23.6	3	Stable	28	26.2	19	22	27	28	27	-4	Stable
199-D4-84	C	182	348	427	23	Increasing	300	388	410	500	410	300	410	37	Increasing
199-D4-85	C	256	149	173.8	17	Stable	152	167	156	232	140	152	140	-8	Stable
199-D4-86	C	88	77	68.7	-11	Stable	64	80.1	71	55	--	64	--	--	NA
199-D5-13	M	--	99	--	--	NA	--	102	--	--	--	--	--	--	NA
199-D5-14	M	--	123	--	--	NA	--	125	--	--	--	--	--	--	NA
199-D5-15	M	--	110	--	--	NA	--	111	--	--	--	--	--	--	NA
199-D5-17	M	--	110	--	--	NA	--	104	--	--	--	--	--	--	NA
199-D5-20	M/E	63	41	--	--	NA	--	38.6	--	--	--	--	--	--	NA
199-D5-32	M/E	--	59	--	--	NA	--	66	--	--	--	--	--	--	NA
199-D5-33	M	--	13	--	--	NA	--	9.7	--	--	--	--	--	--	NA
199-D5-34	M	--	58	--	--	NA	--	65.8	--	--	--	--	--	--	NA
199-D5-36	M	16	15	16.9	13	Stable	14	14.5	(19|15.6)	21|20	15.3	14	15.3	9	Stable
199-D5-37	M/E	27	20	22.1	11	Stable	20	19.3	--	22	25	20	25	25	Increasing
199-D5-38	M	85	116	100.4	-13	Stable	92; (100|94)	(68.2|86); 86|92(90); 116	142|144; 114; 110	(88|91.7); (96|93.7); 40|42; 46	46	94.5	46	-51	Decreasing
199-D5-39	M/E	90	56	79.6	42	Increasing	--	80; 110|114(82.2); 100|100	76; 78; (74|66.7)	78; 78; 76	(61.2|68); 80	--	72.3	--	NA
199-D5-40	M	76	112	117.8	5	Stable	--	105	108	118	140	--	140	--	NA
199-D5-41	M	69	59	69.2	17	Stable	--	56.6	72	74	74	--	74	--	NA

Table 3-8. Sulfate Concentrations, In Situ Redox Manipulation Monitoring and Compliance Wells. (3 sheets)

Well		Sulfate Concentration (mg/L) – Unfiltered Samples													
		Annual FY Averages					Quarterly Samples					Quarterly Average			
							FY05	FY06				FY05	FY06		
Name	Type	2004	2005	2006	% Change	Trend	4th Qtr.	1st Qtr.	2nd Qtr.	3rd Qtr.	4th Qtr.	4th Qtr.	4th Qtr.	% Change	Trend
199-D5-42	M/I	147	--	--	--	NA	--	--		--	--	--	--	--	NA
199-D5-43	M	110	116	144.8	25	Increasing	(115|110); 116: 120	146; (101|115), (136|138); (148|120)	146; 126; (124|124)	104; 116|118; 100	(104|97.5); 99.1	116.2	99.9	-14	Stable
199-D5-44	M	14	14	15.5	11	Stable	13	13.5	16	17	--	13	--	--	NA

% change = (Average 4th quarter FY06 – average 4th quarter FY05) / (average 4th quarter FY05) X 100%.
(132|131) = Indicates sample results from splits. 172|152 = Indicates sample results from replicates.
– = no data available
C = compliance well
FY = fiscal year
M = monitoring well, M/I = monitoring/injection well, M/E = monitoring/extraction well
NA = not available
PM = proximal monitoring well located near the treatment zone
Ti = treatment zone injection well; well has been used to treat the aquifer
Tm = treatment zone monitoring well; well has not been used to treat the aquifer

Table 3-9. In Situ Manipulation Treatment Zone Operational Sampling – Hexavalent Chromium. (3 sheets)

Well Name[a]	Injection Date(s)	Hexavalent Chromium Concentrations in Treatment Zone Wells (µg/L)														
		July 2005	Aug. 2005	Sept. 2005	Oct. 2005	Nov. 2005	Dec. 2005	Jan. 2006	Feb. 2006	Mar. 2006	Apr. 2006	May 2006	June 2006	July 2006	Aug. 2006	Sept. 2006
199-D3-4	2003	--	10	--	--	10	--	--	10	--	--	0	--	--	10	--
199-D3-3	2003	--	20	--	--	10	--	--	10	--	--	0	--	--	30	--
199-D4-82	2003	--	20	--	--	10	--	--	10	--	--	0	--	--	30	--
199-D4-81	2003	--	40	--	--	20	--	--	10	--	--	0	--	--	30	--
199-D4-80	2003	--	10	--	--	50	--	--	20	--	--	10	--	--	20	--
199-D4-79	2002	--	0	--	--	30	--	--	10	--	--	0	--	--	30	--
199-D4-78	2002	--	30	--	--	30	--	--	0	--	--	0	--	--	30	--
199-D4-77	2002	--	10	--	--	10	--	--	0	--	--	0	--	--	0	--
199-D4-76	2002	--	10	--	--	0	--	--	10	--	--	0	--	--	0	--
199-D4-75	2002	--	10	--	--	10	--	--	0	--	--	0	--	--	0	--
199-D4-74	2002	--	0	--	--	10	--	--	10	--	--	10	--	--	0	--
199-D4-73	2002	--	10	--	--	10	--	--	0	--	--	0	--	--	10	--
199-D4-72	2002	--	0	--	--	0	--	--	0	--	--	10	--	--	0	--
199-D4-71	2002	--	10	--	--	0	--	--	0	--	--	0	--	--	0	--
199-D4-70	2002	--	10	--	--	10	--	--	0	--	--	0	--	--	10	--
199-D4-69	2002	--	10	--	--	10	--	--	0	--	--	0	--	--	10	--
199-D4-68	2002	--	10	--	--	0	--	--	0	--	--	0	--	--	10	--
199-D4-67	2002	--	0	--	--	0	--	--	0	--	--	0	--	--	0	--
199-D4-66	2002	--	10	--	--	0	--	--	0	--	--	0	--	--	0	--
199-D4-65	2002	--	10	--	--	10	--	--	0	--	--	0	--	--	0	--
199-D4-64	2002	--	0	--	--	10	--	--	0	--	--	0	--	--	0	--
199-D4-63	2002	--	0	--	--	10	--	--	0	--	--	0	--	--	0	--
199-D4-62	2001	--	10	--	--	10	--	--	0	--	--	0	--	--	0	--
199-D4-61	2001	--	10	--	--	10	--	--	0	--	--	0	--	--	0	--
199-D4-60	2001	--	10	--	--	10	--	--	0	--	--	0	--	--	0	--
199-D4-59	2001	--	0	--	--	10	--	--	10	--	--	0	--	--	0	--
199-D4-58	2001	--	10	--	--	20	--	--	10	--	--	0	--	--	0	--
199-D4-57	2001	--	10	--	--	0	--	--	10	--	--	0	--	--	0	--
199-D4-56	2001	--	30	--	--	50	60	40	40	50	10	0	--	--	0	--

Table 3-9. In Situ Manipulation Treatment Zone Operational Sampling – Hexavalent Chromium. (3 sheets)

Well Name[a]	Injection Date(s)	Hexavalent Chromium Concentrations in Treatment Zone Wells (µg/L)														
		July 2005	Aug. 2005	Sept. 2005	Oct. 2005	Nov. 2005	Dec. 2005	Jan. 2006	Feb. 2006	Mar. 2006	Apr. 2006	May 2006	June 2006	July 2006	Aug. 2006	Sept. 2006
199-D4-55	2001	--	10	--	--	10	--	--	10	--	0	0	--	--	10	--
199-D4-54	2001	--	30	--	--	10	--	--	0	--	20	0	--	--	0	--
199-D4-53	2001	--	0	--	--	30	--	--	10	--	0	0	--	--	20	--
199-D4-52	2001	--	10	--	--	10	--	--	0	--	0	0	--	--	0	--
199-D4-51	2001	--	50	--	--	20	--	--	40	110	20	30	--	--	10	--
199-D4-50	2001	--	10	--	--	20	--	--	20	--	20	0	--	--	0	--
199-D4-49	2001	--	0	--	--	10	--	--	10	--	0	0	--	--	0	--
199-D4-24	2001	-	0	-	-	20	--	--	10	--	10	0	-	-	0	-
199-D4-25	2001	180	210	580	480	320	550	280	300	580	210	170	150	50	180	640
199-D4-26	2000	360	510	700	600	740	500	330	420	760	10	10	--	--	380	530
199-D4-27	2000	10	20	70	350	90	150	10	90	160	20	10	--	--	10	
199-D4-28	2000	20	210	240	390	310	10	90	210	300	0	10	--	--	50	60
199-D4-29	2000	--	170	440	580	220	40	90	520	510	0	30	--	--	60	150
199-D4-30	2000	--	10	--	--	10	--	--	10	--	0	10	--	--	0	
199-D4-31	2000	70	380	720	1090	960	450	840	840	980	140	90	30	60	70	470
199-D4-10	1998, 2002	--	10	20	--	10	--	--	10	--	10	0	--	--	10	--
199-D4-9	1998, 2002	10	80	390	400	290	250	220	270	400	300	0	--	--	60	250
199-D4-7	1997, 2002	--	10	--	--	10	--	--	80	80	0	0	--	--	30	--
199-D4-8[b]	Not treated	--	10	--	--	170	0	10	0	--	0	0	--	--	30	--
199-D4-3[b]	Not treated	--	10	--	--	120	30	60	250	130	0	0	--	--	0	--
199-D4-2[b]	Not treated	10	540	1020	960	960	1020	460	650	760	0	10	--	--	140	530
199-D4-11	1998, 2002	--	10	--	--	10	--	--	10	--	0	0	--	--	10	
199-D4-5[b]	Not treated	--	10	--	--	10	--	--	0	--	0	0	--	--	20	--

Table 3-9. In Situ Manipulation Treatment Zone Operational Sampling – Hexavalent Chromium. (3 sheets)

Well Name[a]	Injection Date(s)	Hexavalent Chromium Concentrations in Treatment Zone Wells (µg/L)														
		July 2005	Aug. 2005	Sept. 2005	Oct. 2005	Nov. 2005	Dec. 2005	Jan. 2006	Feb. 2006	Mar. 2006	Apr. 2006	May 2006	June 2006	July 2006	Aug. 2006	Sept. 2006
199-D4-4[b]	Not treated	--	30	0	10	0	--	--	0	--	0	10	--	--	0	--
199-D4-12	1998, 2002	--	10	--	--	10	--	--	0	--	10	10	--	--	10	--
199-D4-21	1999	10	40	500	540	530	570	500	400	520	50	0	--	--	90	480
199-D4-32	2000	--	0	--	--	110	80	70	60	60	40	10	--	--	10	--
199-D4-33	2000	--	0	--	--	40	40	30	30	60	20	0	--	--	0	--
199-D4-34	2000	40	40	160	130	10	210	40	90	160	10	40	--	--	50	150
199-D4-35	2000, 2002	150	30	0	10	70	0	190	0	10	560	240	490	50	30	40
199-D4-36	2000	10	0	--	--	320	390	410	340	380	130	10	0	20	30	170
199-D4-37	2001	270	400	380	230	370	720	680	660	650	460	10	0	150	210	520
199-D4-40	2001	120	160	640	460	650	460	600	420	500	690	160	270	140	20	330
199-D4-41	2001	40	570	390	310	320	440	310	400	420	110	0	--	--	260	280
199-D4-42	2001	10	170	430	570	500	570	490	470	700	290	90	10	130	50	320
199-D4-43	2001	10	170	310	320	290	390	240	380	380	30	20	--	--	20	--
199-D4-44	2001	--	50	--	--	20	--	--	30	50	10	0	--	--	20	--
199-D4-45	2001	--	10	--	--	30	--	--	60	120	0	10	--	--	30	--
199-D4-46	2001	--	0	--	--	0	--	--	0	--	--	0	--	--	10	--
199-D4-47	2001	--	0	--	--	20	--	--	10	--	--	0	--	--	10	--
199-D4-48	2001	--	20	--	--	20	--	--	10	--	--	10	--	--	10	--

[a] Wells are listed from southwest to northeast.
[b] Monitoring wells in the original treatability test zone.
– = well not sampled during this time interval

4.0 PLANNED REMEDIATION AND CHROMIUM SOURCE STUDIES

Two remediation technology studies and one chromium source study are scheduled for FY07 and are summarized in this section.

4.1 BARRIER AMENDMENT WITH MICRON-SIZE, ZERO-VALENT IRON

As described in an unpublished FH document, *Statement of Work for Testing Micron-Size Iron Injection for Mending an Existing Permeable Reactive Barrier* (FH 2006d), and in a Pacific Northwest National Laboratory study, *Experimental Study of Micron-Size Zero-Valent Iron Emplacement in Permeable Porous Media Using Polymer-Enhanced Fluids* (PNNL 2005), a remediation test is planned for FY07 that will involve injection of micron-size, zero-valent iron into two wells within the ISRM barrier.

The ISRM barrier in the 100-D Area was constructed between 1999 and 2002 and consists of a network of 65 wells creating a reducing barrier across the width of a groundwater plume contaminated with hexavalent chromium. Laboratory tests carried out prior to barrier construction indicated that sodium dithionite would effectively reduce naturally occurring ferric iron (Fe^{+3}) to ferrous iron (Fe^{+2}). The ferrous iron would serve to convert hexavalent chromium (Cr^{+6}) in groundwater to trivalent chromium (Cr^{+3}), which is relatively immobile (insoluble) in water and has low toxicity. These laboratory tests suggested that the barrier would be effective for about 20 years, but in some areas of the barrier a loss of reductive capacity was noted after periods as short as 18 months. Recent work has indicated that ongoing loss of reductive capacity is related to the presence of zones within the barrier that have high permeability and low iron content.

Reinjection of wells with sodium dithionite is not an effective long-term solution because reinjected wells have shown loss of reductive capacity within 2 years of secondary treatment. At the present time, approximately 20 wells within the barrier have lost a significant portion the reductive capacity that was present after treatment with sodium dithionite.

An alternative technology, which does not include periodic reinjection of the wells with sodium dithionite, is currently scheduled for field testing in the fourth quarter of FY07. This test involves injection of micron-size, zero-valent iron suspended in a polymer-based, shear-thinning fluid. The proposed fluid is expected to be sufficiently viscous to keep the iron in suspension for extended periods of time, allowing movement of the micron-size, zero-valent iron into the sediments surrounding injected wells. Zero-valent iron (Fe^{0}) is an extremely strong chemical reductant and has been shown effective in reducing hexavalent chromium in bench-scale laboratory testing. Following laboratory testing and numerical modeling, micron-size, zero-valent iron will be injected into two wells (199-D4-26 and 199-D4-37) located in high-permeability zones where significant loss of effectiveness is present. Some of the goals of the test include determining the distance that injected iron will be transported, the concentration of iron at a point 7 m (23 ft) from the injection point (a distance equivalent to about half the distance between adjacent treatment zone wells), and the degree of dilution of the polymer under field conditions. One borehole will be drilled after injection and characterization sampling in order to evaluate the distribution and concentration of micron-size, zero-valent iron in sediments near an injection well.

4.2 CHROMIUM SOURCE IDENTIFICATION STUDY

A drilling program is scheduled for FY07 as part of a study to identify the source(s) of hexavalent chromium in the groundwater plume that impacts the ISRM treatment barrier. Part of this study will include installing between 7 and 10 groundwater monitoring wells. Wells will be drilled to the top of the Ringold Upper Mud Unit (i.e., the bottom of the unconfined aquifer), and the completed wells will be screened across the saturated interval. Completion will be with 10.2-cm (4-in.)-diameter polyvinyl chloride slotted-screen and riser pipe. The seven wells that have been completed as of May 1, 2007, are shown in Figure 4-1. The total number of wells ultimately drilled will depend upon the vadose zone and groundwater characterization data acquired during drilling and subsequent monitoring activities.

4.3 IN SITU BIOSTIMULATION STUDY

As described in *Hanford 100-D Area Treatability Demonstration: In Situ Biostimulation for a Reducing Barrier* (PNNL 2006), a treatability test is scheduled for FY07. It has recently become evident that the chromium plume currently impacting the ISRM treatment barrier is coupled to a continuing source of hexavalent chromium. Even if the source of the contamination can be identified (see Section 4.1) and undergoes successful remediation, the contaminant plume will continue to present a threat to the Columbia River. Modeling predicts that hexavalent chromium concentrations within the contaminant plume will remain above 20 µg/L for at least 40 years. This period exceeds the 20-year design life of the treatment barrier that was predicted based on the initial treatability test and greatly exceeds the estimated 10-year reductive capacity of the barrier if 60 mg/L of nitrate is present in the groundwater (Szecsody et al. 2005).

The in situ biostimulation study will test the feasibility of injection of an organic substrate as a means of stimulating indigenous micro-organisms to reduce chromate and nitrate in the contaminated aquifer. If chromate and nitrate levels (as well as DO levels) can be significantly reduced upgradient of the ISRM treatment barrier, the longevity of the barrier can be greatly enhanced. In situ reduction of hexavalent chromium to insoluble trivalent chromium can be carried out through injection of a dissolved organic substrate (e.g., molasses), and nitrate can be reduced to nitrogen gas using an immiscible substrate (e.g., vegetable oil). Increased bacterial activity due to the presence of organic substrates should lead to enhanced reduction of DO.

The treatability test will demonstrate field-scale reduction of chromate, nitrate, and DO and will provide information about the longevity of the treatment. The test will also provide information about the implementability of the method and optimum design criteria. The field test will include construction of two test cells, each consisting of an injection well and five monitoring wells, as shown in Figure 4-2. The test cells will be 200 to 300 m (650 to 985 ft) upgradient of the treatment barrier. Injection of a dissolved substrate (e.g., molasses) and an immiscible substrate (e.g., vegetable oil) will allow for the evaluation of substrate performance under field conditions.

Figure 4-1. Location Map for 100-D Area Chromium Source Identification Wells.

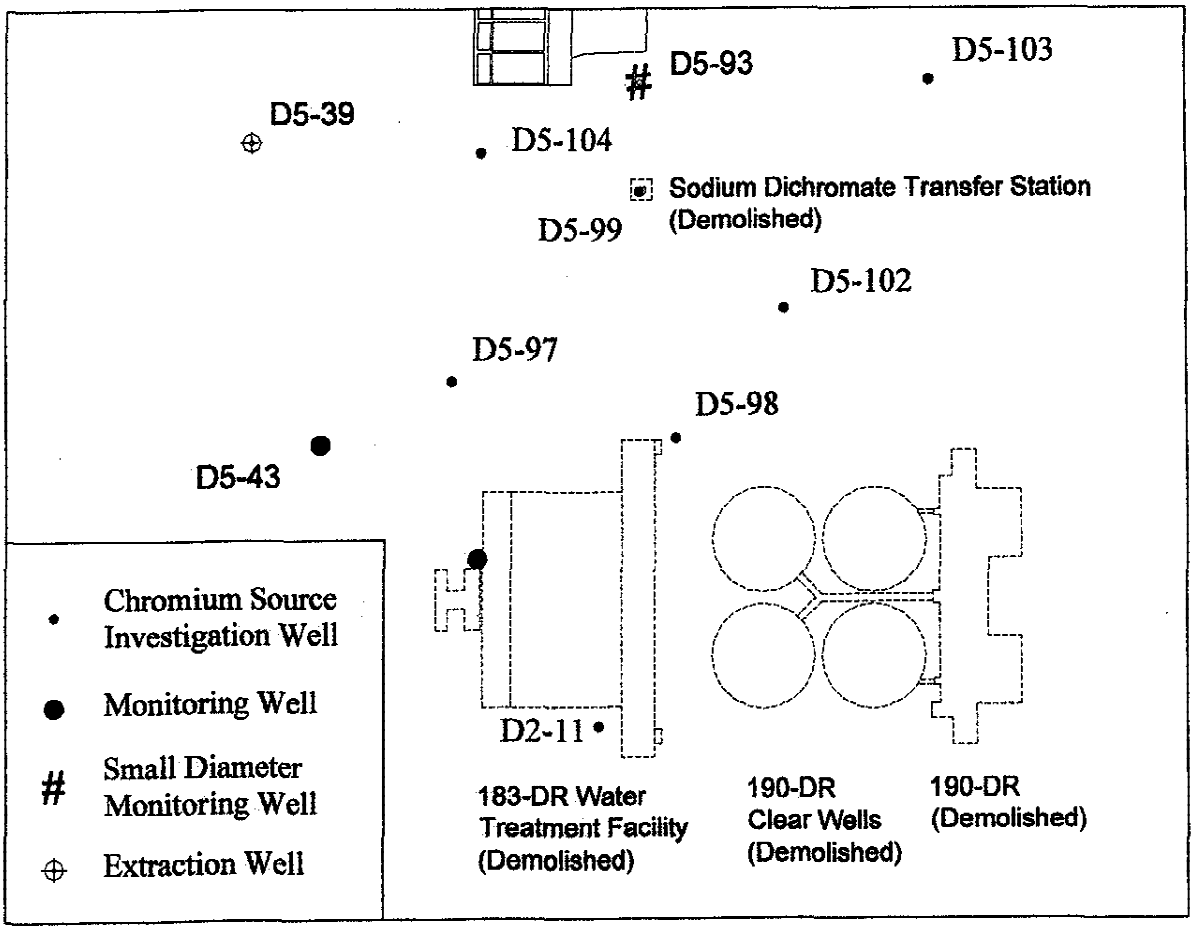
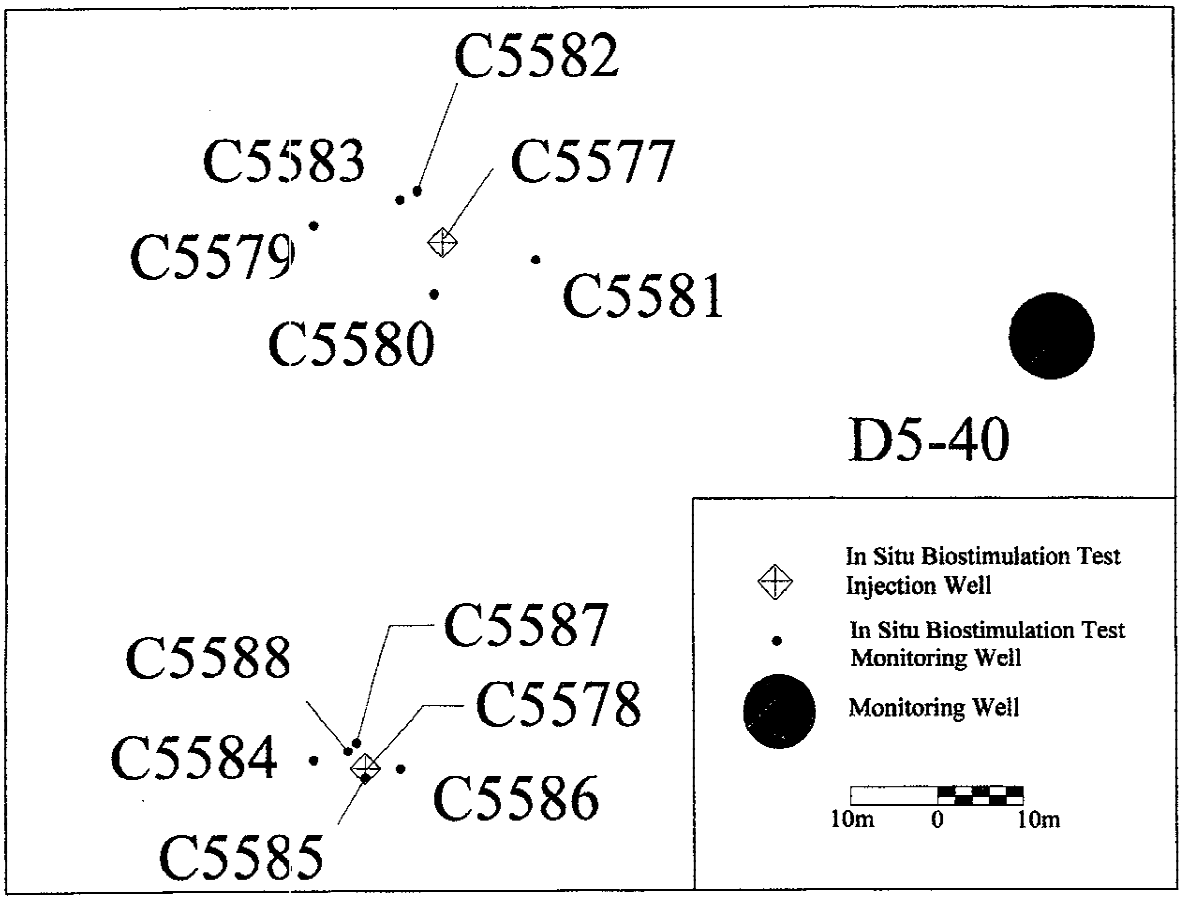


Figure 4-2. 100-D Area In Situ Biostimulation Test Cells.



5.0 QUALITY ASSURANCE/QUALITY CONTROL

Field replicates, offsite laboratory replicates, and field/offsite laboratory splits are QC samples used to assess the precision of chemical analyses. Establishing the precision of analyses by field screening consisted of comparing analyses for field replicates and field/offsite laboratory splits and calculating the relative percent difference (RPD), as follows:

$$\text{RPD} = \frac{(c1 - c2)}{(c1 + c2)/2} \text{ x } 100\%$$

where $c1$ and $c2$ are replicate or split concentrations.

The EPA's functional guideline is ±20% for these types of analyses (EPA 1998). The RPD values that are <±20% are acceptable. The QC samples analyzed in FY06 indicate that there was acceptable data quality for most analyses, as discussed below. A total of 21% of samples split and analyzed in the field and in an offsite laboratory had unacceptable data quality.

5.1 CHROMIUM

The results of the QC analyses performed for hexavalent chromium and total chromium during FY06 are included in Table 5-1 and are listed by well number, sample date, sample number, result, and RPD.

Twenty-three field replicates were analyzed for hexavalent chromium using the using field method COLOR_TK_CR6_FLD[1]. The RPD calculation for two sample pairs was not conducted because the analytical data included results that were less than the detection limit. The RPD values for the remaining 21 sample pairs ranged from 0% to 26.1%. The EPA's functional guideline is ±20% for these types of analyses (EPA 1998). One sample pair (4%) exceeded the EPA guideline.

Thirty-eight samples were split and analyzed in the field for hexavalent chromium using method COLOR_TK_CR6_FLD[1] and then in an offsite laboratory using method 7196_CR6[1]. The RPD calculation for four sample pairs was not conducted because the analytical data included results that were less than the detection limit. The RPD values for the remaining 34 sample pairs ranged from 0% to 117.2%. Eight sample pairs (21%) exceed the EPA function guideline of ±20%.

Twenty replicate sample pairs were collected and analyzed for total chromium in offsite laboratories using method 6010_METALS_ICP[1]. Filtered samples were used for 3 sample pairs, unfiltered samples were used for 3 sample pairs, and 14 sample pairs had one sample that was filtered and one that was not filtered. The RPD values for these 20 sample pairs ranged from 0% to 42.7%. Two sample pairs (10%) exceeded the EPA guideline.

Finally, seven sample pairs were split and analyzed for total chromium in offsite laboratories using method 6010_METALS_ICP[1]. Three chromium sample pairs were filtered, three were unfiltered, and one sample pair consisted of a filtered sample and an unfiltered sample. The RPD values for sample pairs ranged from 0.7% to 13.1%, with all RPD values falling below the EPA guideline.

[1] Methods are taken from the HEIS database.

5.2 SULFATE

The results of the QC analyses for sulfate performed during FY06 are included in Table 5-2 and are listed by well number, sample date, sample number, result, and RPD.

Eighteen field replicates were analyzed for sulfate using field method COLOR_TK_FIELD[1]. The RPD values of these nine field replicates ranged from 0% to 24.4%. One sample (6%) exceeded the EPA functional guideline of ±20% for these types of analyses (EPA 1998).

Sixteen samples were split and analyzed in the field using field method COLOR_TK_FIELD[1] and then in an offsite laboratory using method 300_ANIONS_IC[1]. The RPD values for these replicate samples ranged from 0% to 29.5%. Four samples (25%) exceeded the EPA functional guideline of ±20%.

Two replicate sample pairs were collected and analyzed for sulfate in an offsite laboratory using method 300.0_ANIONS_IC[1]. The RPD value for these samples ranged from 1.1% to 1.6%, both below the EPA functional guideline.

Finally, one sample pair was split and analyzed in two offsite laboratories using method 300.0_ANIONS_IC[1]. The RPD value for this sample was 6.6%, which is below the EPA functional guideline.

Table 5-1. Hexavalent Chromium and Chromium Quarterly Quality Control Results. (4 sheets)

Well Name	Sample Date	Constituent	Reported Value #1 (µg/L)	Sample Number	Reported Value #2 (µg/L)	Sample Number	RPD (%)	Filtered
Field Replicates (COLOR_TK_FLD)								
199-D2-6	02/01/2006	Hexavalent chromium	13	B1HH61	10	B1HJ59	26.1	Yes
199-D3-2	08/09/2006	Hexavalent chromium	11	BiK6D6	10	B1K6D4	9.5	Yes
199-D4-15	10/10/2005	Hexavalent chromium	1,488	B1F3H2	1,384	B1F3H4	7.2	Yes
199-D4-15	11/07/2004	Hexavalent chromium	1,436	B1F8V5	1,312	B1F8V4	9.0	Yes
199-D4-15	04/04/2006	Hexavalent chromium	1,448	B1HY04	1,436	B1HY02	0.8	Yes
199-D4-20	04/26/2006	Hexavalent chromium	156	B1J5V6	156	B1J5V4	0	Yes
199-D4-22	08/10/2006	Hexavalent chromium	668	B1K6H0	658	B1K6F8	1.5	Yes
199-D4-39	02/07/2006	Hexavalent chromium	629	B1HF11	607	B1HF12	3.6	Yes
199-D4-4	08/15/2006	Hexavalent chromium	6	B1K6K1	5	B1K6K3	18.2	Yes
199-D4-62	08/24/2005	Hexavalent chromium	5(U)	B1HJC1	5(U)	B1HJB9	N/A	Yes
199-D5-15	02/07/2006	Hexavalent chromium	1,034	B1HFD3	1,024	B1HFD4	1.0	Yes
199-D5-36	05/03/2006	Hexavalent chromium	5(U)	B1J3K9	5(U)	B1K3K7	N/A	Yes
199-D5-37	10/10/2005	Hexavalent chromium	39	B1F3D7	38	B1F3D8	2.6	Yes
199-D5-38	11/07/2005	Hexavalent chromium	588	B1F904	584	B1F903	0.7	Yes
199-D5-38	01/09/2006	Hexavalent chromium	305	B1H7T1	299	B1H7T3	2.0	Yes
199-D5-38	06/06/2006	Hexavalent chromium	24	B1JD38	23	B1JD36	4.3	Yes
199-D5-39	11/09/2005	Hexavalent chromium	982	BIFB95	958	B1F911	2.5	Yes
199-D5-39	12/02/2005	Hexavalent chromium	768	B1FY11	756	B1FY09	1.6	Yes
199-D5-43	03/07/2006	Hexavalent chromium	1,178	B1HR49	1,162	B1HR51	1.4	Yes
199-D5-43	05/03/2006	Hexavalent chromium	1,212	B1J5R7	1,210	B1JR59	0.2	Yes
199-D8-73	03/07/2006	Hexavalent chromium	172	B1HPT4	171	B1HPT3	0.6	Yes
199-D8-88	02/06/2006	Hexavalent chromium	88	B1HF89	86	B1HF90	2.3	Yes
199-D8-88	04/05/2006	Hexavalent chromium	69	B1HXM6	69	B1HXMY	0	Yes
Field/Laboratory Splits (COLOR_TK_CR6_FLD or 7196_CR6)								
199-D3-2	02/01/2006	Hexavalent chromium	16	B1HF98	2(U)	B1HFB0	N/A	Yes
199-D4-15	01/16/2006	Hexavalent chromium	1,590	B1H7R4	1,332	B1H7R2	17.7	Yes
199-D4-15	04/27/2007	Hexavalent chromium	1,520	B1J3H1	1,464	B1J3F9	3.8	Yes

Table 5-1. Hexavalent Chromium and Chromium Quarterly Quality Control Results. (4 sheets)

Well Name	Sample Date	Constituent	Reported Value #1 (µg/L)	Sample Number	Reported Value #2 (µg/L)	Sample Number	RPD (%)	Filtered
199-D4-15	06/06/2006	Hexavalent chromium	1,434	B1JD30	1,410	B1JD32	1.7	Yes
199-D4-23	02/07/2006	Hexavalent chromium	16	B1HFC3	12	B1HF16	28.6	Yes
199-D4-23	08/10/2006	Hexavalent chromium	23	B1K4P0	6	B1K4P2	117.6	Yes
199-D4-38	02/06/2006	Hexavalent chromium	214	B1HJ91	205	B1HF14	4.3	Yes
199-D4-39	02/07/2006	Hexavalent chromium	664	B1HJ94	629	B1HF11	5.4	Yes
199-D4-4	02/06/2006	Hexavalent chromium	5(U)	B1HJ97	2	B1HF09	N/A	Yes
199-D4-5	02/06/2006	Hexavalent chromium	9	B1HF07	7	B1HJB3	25.0	Yes
199-D4-6	02/06/2006	Hexavalent chromium	5(U)	B1HJB6	2	B1HF05	N/A	Yes
199-D4-7	02/07/2006	Hexavalent chromium	58	B1HJC4	50	B1HF03	14.8	Yes
199-D4-78	10/25/2005	Hexavalent chromium	25	B1DH75	24.1	B1DH76	3.7	Yes
199-D4-84	02/06/2006	Hexavalent chromium	32	B1HDY3	31	B1HJD3	3.2	Yes
199-D4-84	04/27/2006	Hexavalent chromium	57	B1H5P1	38	B1H5P3	40.0	Yes
199-D4-85	02/06/2006	Hexavalent chromium	11	B1HJD6	5	B1HDY1	75.0	Yes
199-D4-86	02/06/2006	Hexavalent chromium	14	B1HJD9	11	B1HDY7	24.0	Yes
199-D4-86	04/27/2006	Hexavalent chromium	10	B1J5P9	6	B1J2Y5	50.0	Yes
199-D5-15	05/02/2006	Hexavalent chromium	1,370	B1J3J8	1,370	B1JDJ7	0	Yes
199-D5-36	02/08/2006	Hexavalent chromium	5(U)	B1HFF2	0.1(U)	B1HF20	N/A	Yes
199-D5-37	10/10/2005	Hexavalent chromium	39	B1F3D7	38	B1F3D8	2.6	Yes
199-D5-38	10/10/2005	Hexavalent chromium	600	B1F3H9	586	B1F3H7	2.4	Yes
199-D5-38	02/08/2006	Hexavalent chromium	257	B1HFF8	247	B1HF18	4.0	Yes
199-D5-38	04/04/2006	Hexavalent chromium	223	B1HXN9	220	B1HXP1	1.4	Yes
199-D5-38	05/02/2006	Hexavalent chromium	176	B1J3L5	171	B1J3L7	2.9	Yes
199-D5-39	02/08/2006	Hexavalent chromium	918	B1HFH1	817	B1HDX5	11.6	Yes
199-D5-39	03/08/2006	Hexavalent chromium	968	B1HPV9	914	B1HPV7	5.7	Yes
199-D5-39	07/10/2006	Hexavalent chromium	998	B1JKL3	960	B1JKL1	3.9	Yes
199-D5-41	02/08/2006	Hexavalent chromium	1,792	B1HFH9	1,650	B1HDX7	8.3	Yes
199-D5-43	11/07/2005	Hexavalent chromium	1,030	B1F9P3	1,000	B1F922	3.0	Yes
199-D5-43	12/05/2005	Hexavalent chromium	1,170	B1FVW1	1,100	B1FVV9	6.2	Yes
199-D5-43	02/09/2006	Hexavalent chromium	1,216	B1HFJ2	1,200	B1HDX9	1.3	Yes

Table 5-1. Hexavalent Chromium and Chromium Quarterly Quality Control Results. (4 sheets)

Well Name	Sample Date	Constituent	Reported Value #1 (µg/L)	Sample Number	Reported Value #2 (µg/L)	Sample Number	RPD (%)	Filtered
199-D5-43	08/08/2006	Hexavalent chromium	478	B1K4T5	460	B1K4T3	3.8	Yes
199-D8-73	01/09/2006	Hexavalent chromium	174	B1H7P8	173	B1H7P9	0.6	Yes
199-D8-73	07/11/2006	Hexavalent chromium	141	B1JKC5	128	B1JKC6	9.7	Yes
199-D8-73	08/08/2006	Hexavalent chromium	159	B1K4K2	148	B1KFK3	7.2	Yes
199-D8-88	10/10/2005	Hexavalent chromium	51	BIF3F6	50	BIF3F7	2.0	Yes
199-D8-88	12/27/2005	Hexavalent chromium	81.3	BIF958	81	B1F957	0.4	Yes
Laboratory Replicates (6010_METALS_ICP)5.2								
199-D4-13	11/09/2005	Chromium	2.6	B1F8V0	1.9	B1FCW1	31	No/Yes
199-D4-14	11/09/2005	Chromium	48.8	B1F8V3	40.7	B1F9M0	18.1	No/Yes
199-D4-15	11/07/2005	Chromium	35.5	B15CV9	33.7	B1FCW2	5.2	Yes
199-D4-19	11/21/2005	Chromium	1.9	B1F9M3	1.9	B1F8V9	0	Yes/No
199-D4-20	11/10/2005	Chromium	200	B1F8W2	195	B1F9M4	2.5	No/Yes
199-D4-23	11/07/2005	Chromium	12.9	B1F9M6	12.6	B1F9M5	2.4	Yes
199-D5-13	11/20/2005	Chromium	474	B1F8X0	471	B1F9M7	0.6	No/Yes
199-D5-14	11/10/2005	Chromium	382	B1F8X3	376	B1F9M8	1.6	No/Yes
199-D5-15	11/09/2005	Chromium	472	B1F8X6	467	B1F9M9	1.1	Yes/No
199-D5-17	11/10/2005	Chromium	23.3	B1F8Y2	15.1	B1F9N1	42.7	No/Yes
199-D5-20	11/14/2005	Chromium	560	B1F8Y5	557	B1F9N2	0.5	Yes/No
199-D5-36	11/07/2005	Chromium	2.4	B1F902	2.1	B1F9N3	13.3	Yes/No
199-D5-38	11/07/2005	Chromium	605	BIF9N7	596	B1F9N6	1.5	Yes
199-D5-39	11/09/2005	Chromium	937	B1F9N9	928	B1F913	9.7	No/Yes
199-D5-40	11/09/2005	Chromium	392	B1F9P0	380	B1F916	3.1	No/Yes
199-D5-41	11/10/2005	Chromium	1,890	B1F919	1,860	B1F9P1	1.6	No/Yes
199-D5-44	11/10/2005	Chromium	1.9	B1F928	1.9	B1F9P6	0	No/Yes
199-D4-15	11/07/2005	Chromium	1,400	B1FB24	1,390	B1FB21	0.7	No
199-D4-23	11/07/2005	Chromium	31.4	B1F8W6	29.2	B1F8W5	7.3	No
199-D5-38	11/07/2005	Chromium	603	B1F907	600	B1F908	0.5	No

Table 5-1. Hexavalent Chromium and Chromium Quarterly Quality Control Results. (4 sheets)

Well Name	Sample Date	Constituent	Reported Value #1 (µg/L)	Sample Number	Reported Value #2 (µg/L)	Sample Number	RPD (%)	Filtered
Laboratory Splits (6010_METALS_ICP [chromium] or CR6_HACH_M [hexavalent chromium])5.2								
199-D2-6	11/09/2005	Chromium	35.5	B1FCV9	33.7	BIFCS2	5.2	Yes
199-D3-2	11/09/2005	Chromium	21.2	B1F8T7	18.6	B1FCW0	13.1	No/Yes
199-D4-22	11/10/2005	Chromium	1,400	B1F9X0	1,390	B1FB20	0.7	Yes
199-D5-43	11/07/2005	Chromium	1,040	B1F9P5	954	B1F9P4	8.6	Yes
199-D2-6	11/09/2005	Chromium	50.4	B1F8T3	48.7	B1F8T1	3.4	No
199-D2-22	11/10/2005	Chromium	1,100	B1F9X1	1,040	B1F9X4	5.6	No
199-D5-43	11/07/2005	Chromium	1,050	B1F923	972	B1F925	7.7	No

ICP = inductively coupled plasma
N/A = RPD percentage not calculated because analytical results are below the detection limit
RPD = relative percent difference
U = constituent not detected; value shown is the analysis detection limit

Table 5-2. Sulfate Quarterly Quality Control Results. (2 sheets)

Well Name	Sample Date	Constituent	Reported Value #1 (mg/L)	Sample Number	Reported Value #2 (mg/L)	Sample Number	RPD (%)	Filtered
Field Replicates (COLOR_TK_FLD)								
199-D2-6	02/01/2006	Sulfate	82	B1HJ60	74	B1HJ62	10.3	No
199-D3-2	08/09/2006	Sulfate	53	B1K6D7	46	B1K6D5	14.1	No
199-D4-15	10/10/2005	Sulfate	148	B1F3H3	140	B1F3H5	5.6	No
199-D4-15	11/07/2005	Sulfate	184	B1F9M2	144	B1F9M1	24.4	No
199-D4-15	04/04/2006	Sulfate	152	B1HY03	152	B1H705	0	No
199-D4-20	04/26/2006	Sulfate	124	B1J5V5	122	B1J5V7	1.6	No
199-D4-23	08/10/2006	Sulfate	176	B1K6F9	172	B1K6H1	2.3	No
199-D4-4	08/15/2006	Sulfate	430	BIK6K4	420	B1K6K2	2.4	No
199-D4-62	02/06/2006	Sulfate	260	B1HJC2	240	BIHJC0	8.8	No
199-D5-36	05/03/2006	Sulfate	21	B1J3L0	20	B1J3K8	4.9	No
199-D5-38	11/07/2005	Sulfate	92	B1F9N4	90	B1F9N5	2.2	No
199-D5-38	01/09/2006	Sulfate	144	B1H7T4	142	B1H7T2	1.4	No
199-D5-38	06/06/2006	Sulfate	42	B1JD39	40	B1JD37	4.9	No
199-D5-39	11/09/2005	Sulfate	114	B1F9N8	110	B1FB96	3.6	No
199-D5-39	12/05/2005	Sulfate	100	B1FY12	100	B1FY10	0	No
199-D5-39	02/08/2006	Sulfate	78	B1HFH2	76	B1HFH4	2.6	No
199-D5-43	03/07/2006	Sulfate	124	BHR52	124	B1HR50	0	No
199-D5-43	05/03/2006	Sulfate	118	B1J5R8	116	B1J5T0	1.7	No
Field/Laboratory Splits (COLOR_TK_FLD/300.0_ANIONS_IC)								
199-D3-2	01/01/2006	Sulfate	82	B1HFB2	74	BIHF99	10.3	No
19-D4-15	01/16/2006	Sulfate	152	B1H7R3	140	B1H7R7	8.2	No
199-D4-15	04/27/2006	Sulfate	164	B1J3H0	123	B1J3H3	28.6	No
199-D4-15	06/06/2006	Sulfate	124	B1J5V5	122	B1J5V7	1.6	No
199-D4-23	02/07/2006	Sulfate	305	B1HFC4	303	B1HFC7	0.6	No
199-D4-23	08/10/2006	Sulfate	210	B1K4P1	208	B1K4P4	1.0	No
199-D5-36	02/08/2006	Sulfate	19	B1HFF3	16	B1HFF6	17.1	No
199-D5-38	10/10/2005	Sulfate	86	B1F3H8	68	B1F3J2	23.4	No

Table 5-2. Sulfate Quarterly Quality Control Results. (2 sheets)

Well Name	Sample Date	Constituent	Reported Value #1 (mg/L)	Sample Number	Reported Value #2 (mg/L)	Sample Number	RPD (%)	Filtered
199-D5-38	04/04/2006	Sulfate	92	B1HXP3	88	B1HXP0	4.4	No
199-D5-38	05/02/2006	Sulfate	96	B1J3L6	94	B1J3L9	2.1	No
199-D5-39	03/08/2006	Sulfate	74	B1HPV8	67	B1HPW1	9.9	No
199-D5-39	07/10/2006	Sulfate	68	B1JKL2	61	B1JKL2	10.9	No
199-D5-43	11/07/2005	Sulfate	138	B1FBR7	115	B1F923	18.3	No
199-D5-43	11/072005	Sulfate	136	B1F9P2	101	B1F925	29.5	No
199-D5-43	12/05/2005	Sulfate	148	B1FVW0	120	B1FVW3	20.9	No
199-D5-43	08/08/2006	Sulfate	104	B1K4T4	98	B1K4T7	5.9	No
Laboratory Replicates (300.0_ANIONS_IC)								
199-D4-15	11/07/2005	Sulfate	130	B1FB21	128	B1FB24	1.6	No
199-D4-23	08/10/2006	Sulfate	351	B1FDP3	349	B1FDP4	1.1	No
Laboratory Splits (300.0_ANIONS_IC)								
199-D2-6	11/09/2005	Sulfate	126	BIF8T1	118	B1FD64	6.6	No

IC = ion chromatography
RPD = relative percent difference

6.0 IN SITU REDOX MANIPULATION COST DATA

All projected costs are burdened and are based on costs through September 30, 2006. These costs are inclusive of design, construction, operation, and performance monitoring of the ISRM, as discussed in *Explanation of Significant Difference for the Record of Decision, U.S. Department of Energy Hanford 100-HR-3 Operable Unit Interim Remedial Action, Involving In Situ Redox Manipulation (ISRM)* (Price 2003). Actual costs for the 100-D Area ISRM interim remedial action were recorded in the FH code of accounts databases. Cost accruals are recorded, sorted by activity, and summed bi-monthly in the database. The data can then be used to determine the actual capital and labor costs associated with a specific activity over a given time period. These data have been used to estimate actual project costs (burdened) and projected future costs (based on actual costs to date). Specific activities are briefly described below:

- **Remedial design:** This includes all initial design activities to support ISRM construction, permitting, peer reviews, quality assurance, and all other design documentation.
- **Capital construction:** This includes all fees paid to the construction subcontractor for capital equipment, initial construction (i.e., construction of new wells and an evaporation pond), and modifications to the system. This includes all FH labor required for oversight and support and all fees paid to the construction subcontractor for capital equipment, installation of new wells, pond construction, and operation and maintenance. This cost represents labor and material costs associated with establishment of the treatment zone. Also included are costs associated with performance monitoring and waste management.
- **Performance monitoring:** This includes the costs associated with monitoring water levels and the associated systems used to support these activities. It also supports groundwater sampling, analysis, and the technical evaluation and reporting of results. Certain technical studies (including geochemical studies, geophysical studies, groundwater flow meter studies, and laboratory groundwater chemistry studies) are also included.
- **Waste management:** This includes the costs incurred from the processing of wastes associated with the placement of the barrier, monitoring of water levels, and groundwater sampling.

The cost breakdown for the ISRM project is presented in Figure 6-1 and Table 6-1. Total costs by percent of the total in the pie chart show that the majority of cost for FY06, in decreasing order of magnitude, is charged to performance monitoring (82%), remedial design (17%), and waste management (1%). No capital construction was carried out in FY06.

Figure 6-1. Cost Breakdown for 100-D Area In Situ Redox Manipulation Operations, Fiscal Year 2006.

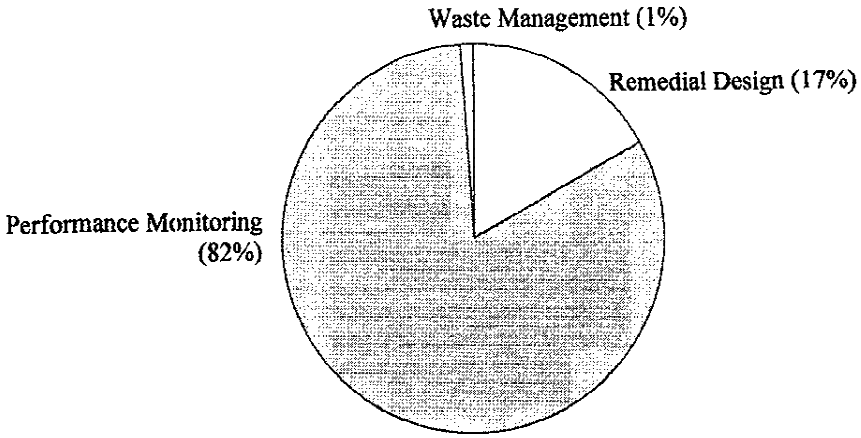


Table 6-1. In Situ Redox Manipulation Operating Cost Breakdown.

Description	Costs for 100-D Area ISRM				
	Actual Cost x 1,000				
	2002	2003	2004	2005	2006
Remedial design	--	--	--	--	$47.31
Capital construction	$2,793.80	$330.67	--	$692.70	--
Performance monitoring	$430.00	$536.10	$430.30	$778.30[a]	$229.72
Waste management	$106.10	$19.60	$7.40	$4.60	$2.94
Totals	**$3,329.90**	**$886.37**	**$437.70**	**$1,475.60**	**$279.97**

[a] FY05 performance monitoring costs include technical studies (i.e., electromagnetic borehole flow meter study, sediment/geophysical studies, and laboratory nitrate investigation).

FY = fiscal year

ISRM = In Situ Redox Manipulation

7.0 CONCLUSIONS

Monitoring results collected in FY06 allow for a preliminary performance evaluation of the ISRM barrier performance in relation to the RAOs (EPA et al. 1996). Specific progress for FY06 toward meeting each RAO is discussed below:

- *Protect aquatic receptors in the river substrate from contamination in groundwater entering the Columbia River.*

  Result: Operational monitoring of treatment zone wells indicates that reducing conditions persist throughout most of the ISRM barrier, particularly in the southwestern portion. However, operational monitoring data from the northeastern portion of the barrier showed hexavalent chromium concentrations much greater than 30 µg/L in two areas, indicating decreasing or failing reductive capacity in these areas.

- *Protect human health by preventing exposure to contaminants in the groundwater.*

  Result: Institutional controls were maintained to prevent public access to groundwater.

- *Provide information that will lead to the final remedy.*

  Result: The project continues to collect operational and monitoring data to support development and implementation of a final remedy. Although no capital construction work was carried out during FY06, planning was carried out for field programs scheduled for FY07 (see Section 4.0). This work will include injection of micron-size, zero-valent iron into two treatment barrier wells, an upgradient biostimulation test, and a drilling program aimed at identifying the upgradient source of the hexavalent chromium found in the groundwater plume.

The ROD Amendment (EPA et al. 1999) and RDR/RAWP (DOE-RL 2000) identified the overall key design elements of the ISRM remedial action. The following is a summary of the key design elements and current assessment of ISRM performance through FY06:

- The barrier will be approximately parallel the Columbia River but may also contain other orientations, depending on the distribution of the chromium contaminant plume.

  Result: The treatment zone is currently 680 m (2,230.96 ft) in length and roughly parallels the Columbia River. The axis of ISRM treatment zone has an orientation of approximately 220 degrees. The optimum flow direction of groundwater for treatment is 307 degrees, which is roughly perpendicular to the axis of the barrier.

  The net groundwater flows directions along most of the barrier are within the optimum range (307 ±30 degrees) to achieve this key design element related to barrier performance in FY06.

- The treatment barrier will be designed in accordance with the RDR/RAWP to attain RAOs.

  Result: ISRM barrier construction and implementation is consistent with the key design elements outlined in the RDR/RAWP (DOE-RL 2000).

- The treatment zone shall treat the chromium plume to 20 μg/L or less at each compliance well to achieve 10 μg/L at the river.

  Result: On a quarterly basis, hexavalent chromium concentrations met the RAO of 20 μg/L in two of the seven compliance wells during the first, third, and fourth quarters of FY06, and in four of the seven compliance wells during the second quarter of FY06. On an annual basis, hexavalent chromium concentrations met the RAO in two of the seven compliance wells. Annual average concentrations show decreasing trends in four compliance wells and stable trends in the remaining three compliance wells.

- Compliance monitoring wells will monitor chromium and DO concentrations between the injection wells and the Columbia River to determine the effectiveness of the treatment zone.

  Result: Compliance monitoring wells are sampled quarterly for chromium, DO, and other constituents. Hexavalent chromium concentrations met the RAO of 20 μg/L in two of the seven compliance wells during the first, third, and fourth quarters of FY06, and in four of the seven compliance wells during the second quarter of FY06. All seven compliance wells had DO concentrations less than 75% of the saturation level.

- Performance monitoring wells will measure other field parameters including sulfate, DO, pH, temperature, and specific conductance.

  Result: Monitoring wells are sampled on a quarterly basis for these field parameters.

- The siting, design, and sampling of the compliance monitoring wells shall be adequate to define the boundaries of the plume and the effectiveness of the treatment zone and shall be capable of assessing if barrier "breakthrough" occurs. This requires wells to be located between the treatment barrier and the Columbia River and also to be located beyond the end of the treatment barrier to ensure compliance with the RAOs.

  Result: There are seven compliance wells for the ISRM treatment zone. The wells are distributed parallel to the treatment zone. Five of the wells are located approximately midway between the treatment zone and the Columbia River, and two wells are located slightly beyond the limits of the treatment zone (one at the southwest and one at the northeast, which are wells 199-D4-86 and 199-D4-83, respectively).

  Hexavalent chromium concentrations in compliance wells have generally been decreasing over the past 3 to 4 years, with the exception of compliance well 199-D4-38, which shows an overall upward trend (Figure 3-9). Hexavalent chromium was seen to be increasing in compliance well 199-D4-85 in the fourth quarter of FY06; the change between the fourth quarter of FY05 (17 μg/L) and the fourth quarter of FY06 (31 μg/L) was 15 μg/L.

- Installation of the treatment barrier shall be initiated within 15 months after signing the ROD Amendment (EPA et al. 1999) and shall be fully implemented by the end of FY02, based on current knowledge of the plume and implementability of the treatment technology.

  Result: Phase I of the large-scale deployment of the ISRM was initiated in FY00; Phases II and III are completed.

- If barrier breakthrough is identified, the Washington State Department of Ecology and EPA will determine alternative action to be taken.

  Result: Treatment zone wells are monitored quarterly and reported. Areas of the barrier that have lost reductive capacity have been identified. These areas are being evaluated to determine the best option(s) for re-establishing reductive capacity.

- Post-treatment extraction purgewater shall be collected and disposed to an evaporation pond constructed at the ISRM site. High-concentration purgewater generated during post-treatment extraction shall be disposed to the evaporation pond, with the option of sending a portion of the concentrated purgewater to the Purgewater Storage and Treatment Facility (*Resource Conservation and Recovery Act of 1976* [RCRA] interim status unit) and/or to the Effluent Treatment Facility (RCRA final status unit), both of which are located in the 200 Areas. Subsequent low-concentration purgewater volumes will continue to be disposed to the evaporation pond or to the ground surface through a localized drip field constructed at the ISRM site. The withdrawn water that is to be discharged to the ground will be analyzed to confirm that the sulfate SDWS of 250 mg/L will not be exceeded in the underlying groundwater.

  Result: Extraction of post-treatment water from the treatment zone was completed during FY03. There has been no subsequent disposal of post-treatment extraction purgewater.

- Institutional control for protection of human health required by EPA is unchanged (EPA et al. 1996).

  Result: Institutional controls were maintained to prevent public access to the groundwater.

- Applicable or relevant and appropriate requirements set forth in the 100-HR-3 and 100-KR-4 ROD (EPA et al. 1996) are unchanged, with the exception of *Washington Administrative Code* (WAC) 173-218 and 40 CFR 144, Subpart B, which are not applicable or relevant and appropriate requirements of the ROD Amendment.

  The underground injection control regulations in WAC 173-218 and 40 CFR 144, Subpart B, prohibit the use of an injection well that may result in a violation of any "National Primary Drinking Water Standards" (DWS) (40 CFR 141) or that may otherwise adversely affect beneficial use of groundwater. The solution being injected does not contain any constituents that have a DWS, and beneficial use of groundwater will not be affected. However, the groundwater will exceed the sulfate SDWS for a brief period following injection. WAC 173-218 prohibits certain discharges to groundwater; however, this regulation specifically excludes cleanup actions undertaken pursuant to CERCLA.

  Result: Sulfate concentrations were above the SDWS of 250 mg/L in 10 wells during FY06.

Additional conclusions are supported by assessment of the data collected during the course of the year:

- The 182-D reservoir continued to leak during FY06. Water-level monitoring data in the 182-D reservoir detected the loss of approximately 31 million L (8.2 million gal) of water to the ground between November 2005 through March 2006. There were three distinct

leakage events: November 5, 2005, through December 15, 2005 (approximately 22 million L [5.8 million gal]); January 1, 2006, through February 3, 2006 (approximately 4.9 million L [1.3 million gal]); and from February 23, 2006, through March 13, 2006 (approximately 4.5 million L [1.2 million gal]). Leakage rates for the three events were 386 L/min, 100 L/min, and 163 L/min (102 gpm, 26.4 gpm, and 43.1 gpm), respectively. The water table below the reservoir rose temporarily in response to the first and third events. The water-level monitoring systems did not show an obvious response to the second leakage event. The cause(s) of the changes in the 182-D reservoir leakage rates is not known.

Leakage from the reservoir that would adversely affect the ISRM barrier would be indicated by an increase in DO concentration of the groundwater and a decrease in nitrate concentrations at the barrier itself or in wells upgradient of the barrier. An increase in DO is detrimental to the barrier, because it decreases the barriers reducing capabilities for hexavalent chromium. A decrease in nitrate concentrations would be beneficial to the barrier, because the presence of nitrate also decreases the barriers reducing capacity. Observed DO data from wells upgradient of the barrier but downgradient of the reservoir do not show any obvious increases in FY06. Nitrate concentrations do not show any obvious decreases. These data indicate that the current operating conditions of the reservoir are not having an adverse effect on the ISRM barrier. However, there are wells in the northeast part of the barrier where DO concentrations have increased, this may have been caused by river influences, or other factors described in '*Mending the ISRM Barrier*' (FH 2006e) such as high hydraulic conductivity, heterogeneity, and low iron content.

Leakage from the reservoir has modified groundwater flow directions and produced a hydraulic divide. The hydraulic divide is beneficial in that southwestern ISRM plume and the northern 100-D plume are prevented from moving to the Columbia River in the area between the northern end of the ISRM barrier and the DR-5 extraction wells. Without the hydraulic divide the southwestern ISRM plume may shift to a more northerly flow, potentially bypassing the northern end of the ISRM barrier. Changing the hydraulic characteristics in this area might necessitate additional remedial measures to intercept the plume.

The mitigation effort of keeping the water level within the 182-D reservoir at low levels decreases the effects on the barrier. The water level in the reservoir is maintained at 0.6 to 1.8 m during pumping operations and 0.3 to 1 m during 'standby conditions' and water is only pumped from the 182-D reservoir during emergency conditions. This mitigation effort has reduced leakage from the 182-D reservoir. Maintaining the water level in the 182-D reservoir at 0.3 to 1 m (1 to 3 ft) and continuation of the automated water level monitoring in the reservoir and nearby wells is warranted.

- Arsenic was analyzed in first quarter FY06 samples due to concern that the treatment of the aquifer to create the ISRM barrier might mobilize naturally occurring arsenic. Twenty-eight wells were sampled and analyzed for arsenic, including 13 monitoring wells, 7 compliance wells, and 8 aquifer treatment (treatment zone injection) wells. Arsenic was detected in six aquifer treatment wells, two monitoring wells, and three proximal monitoring wells. Analytical values ranged from 0.58 to 6.1 μg/L, with all results below the MCL of 10 μg/L for arsenic. Arsenic was not detected in other wells that were sampled during the first quarter.

- Aquifer and porewater sampling tubes along the Columbia River shoreline were sampled during second quarter of FY06. Samples were collected from 12 aquifer tube sites and 4 porewater sites during the period. Groundwater containing hexavalent chromium exceeding 20 µg/L was found at eight aquifer tube sites and four porewater tube sites, with concentrations ranging from 25 to 394 µg/L. Many of the aquifer tube sites and porewater tube sites in an area immediately downgradient of the northeastern portion of the treatment barrier (i.e., from aquifer tube site DD-43 to porewater tube site 166-D-1) over a distance of approximately 380 m (1,247 ft) had hexavalent chromium concentrations from at least one depth in excess of 100 µg/L.

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8.0 RECOMMENDATIONS

Based on observations made during FY06, the following recommendations are made:

- Continue quarterly operational monitoring of all treatment zone wells in the barrier for hexavalent chromium, in addition to continuation of monthly operational monitoring of treatment zone wells that exceed 30 μg/L.
- Continue monitoring water levels in the 182-D reservoir and the wells in the 100-D area as part of the automated groundwater monitoring network to track reservoir influences on the groundwater flow system and the ISRM barrier.
- Develop an integrated plan for 100-D that addresses groundwater remediation (e.g., ISRM, pump-and-treat operations, biostimulation, and other technologies) and infrastructure needs for the usage of the 182-D reservoir.
- If water levels permit, sample aquifer tube and porewater tube sites more frequently than annually in order to better monitor increasing hexavalent chromium levels downgradient of the ISRM treatment barrier.

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9.0 REFERENCES

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40 CFR 142, "National Primary Drinking Water Standards Implementation," *Code of Federal Regulations*, as amended.

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APPENDIX A

FISCAL YEAR 2006 GROUNDWATER FLOW DIRECTION AND GRADIENT SOLUTIONS

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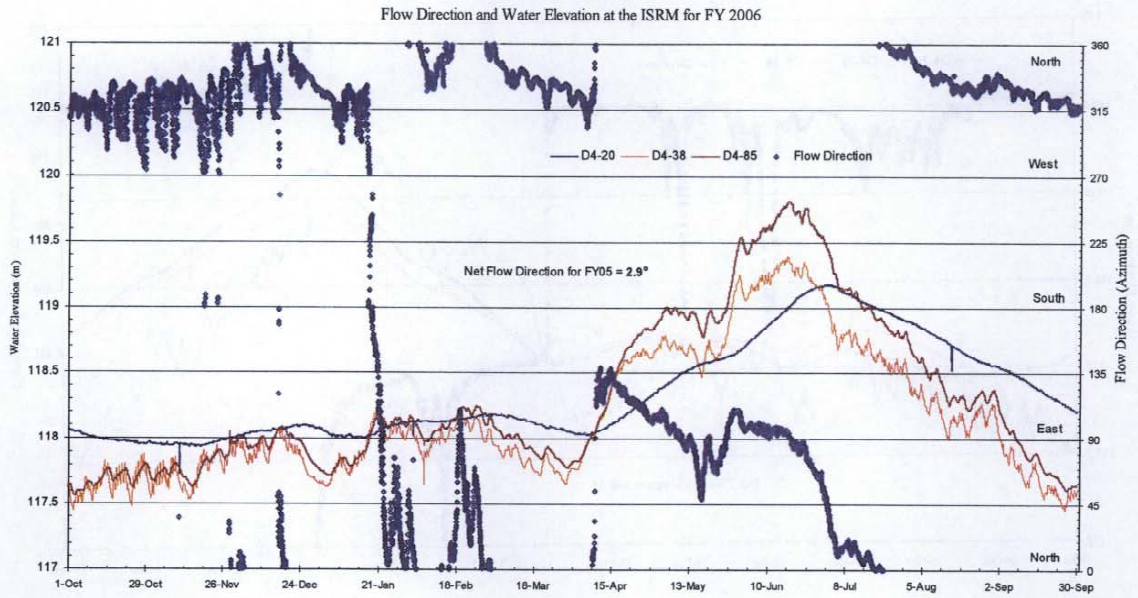
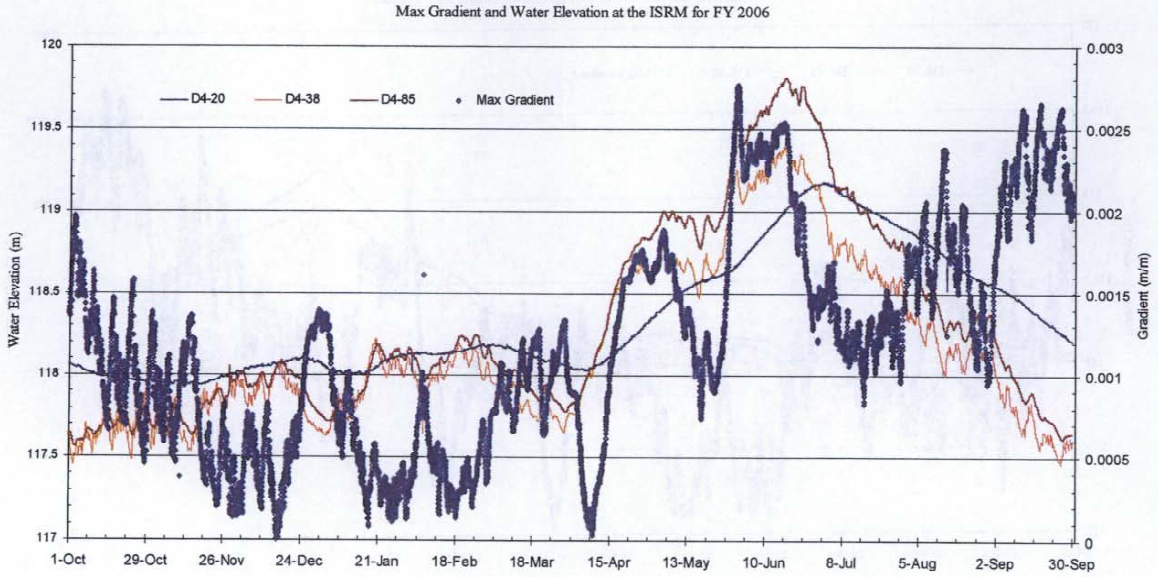
Flow Direction and Gradient Triangle 1, Wells 199-D4-20, 199-D4-38, and 199-D4-85, Fiscal Year 2006.

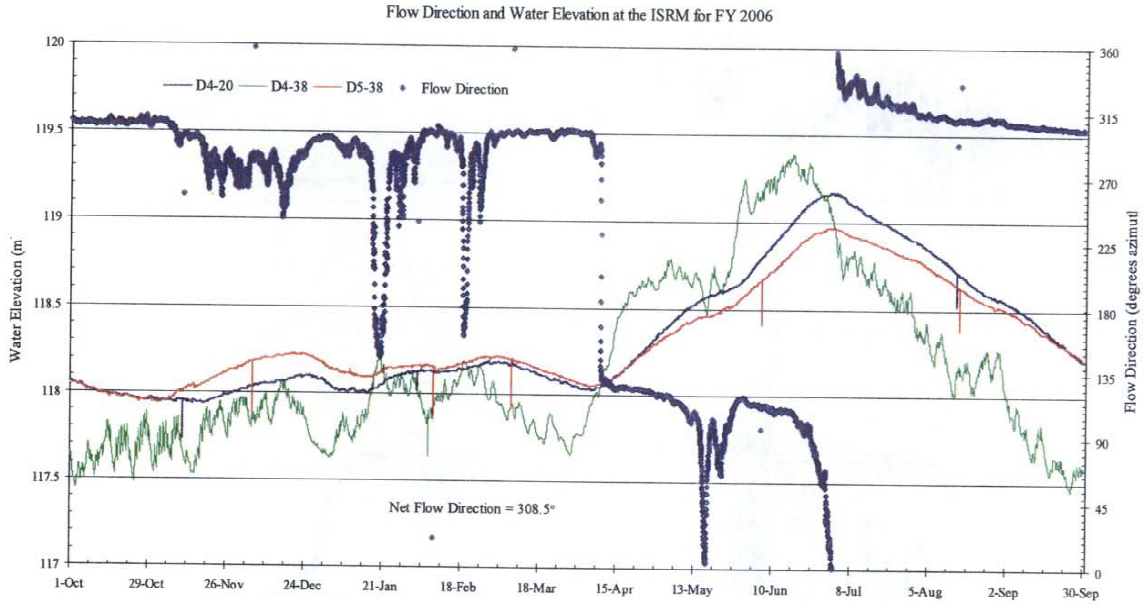
Total distance 11.98 m, net flow direction 2.9°, average gradient 0.0012, 61% optimal flow direction.

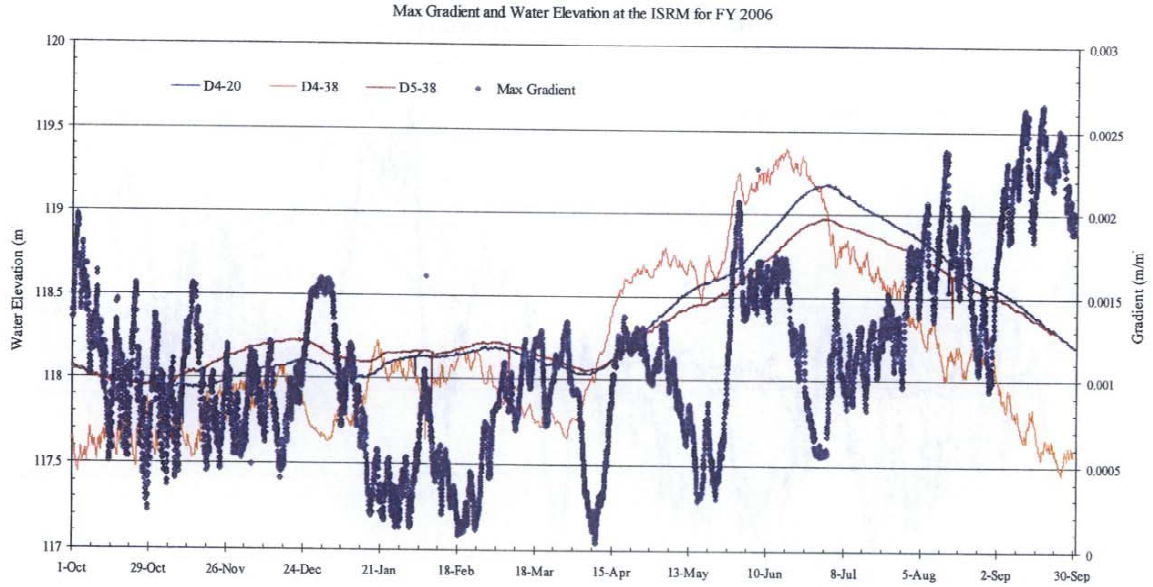




Flow Direction and Gradient Triangle 2, Wells 199-D4-20, 199-D4-38, and 199-D5-38, Fiscal Year 2006.

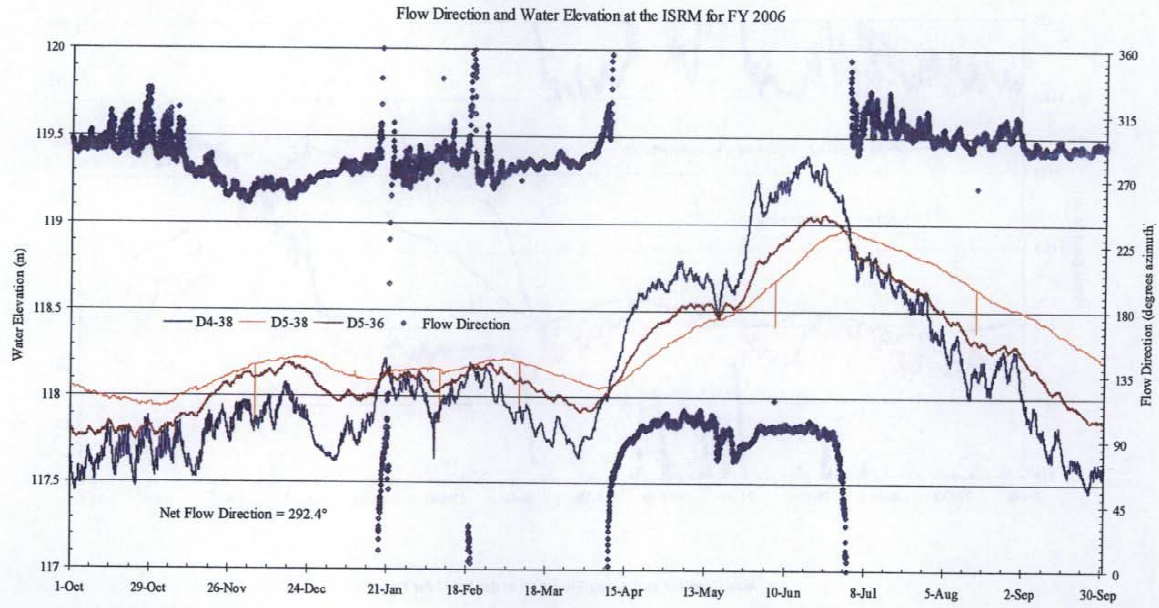
Total distance 11.18 m, net flow direction 308.5°, average gradient 0.0011, 68% optimal flow direction.

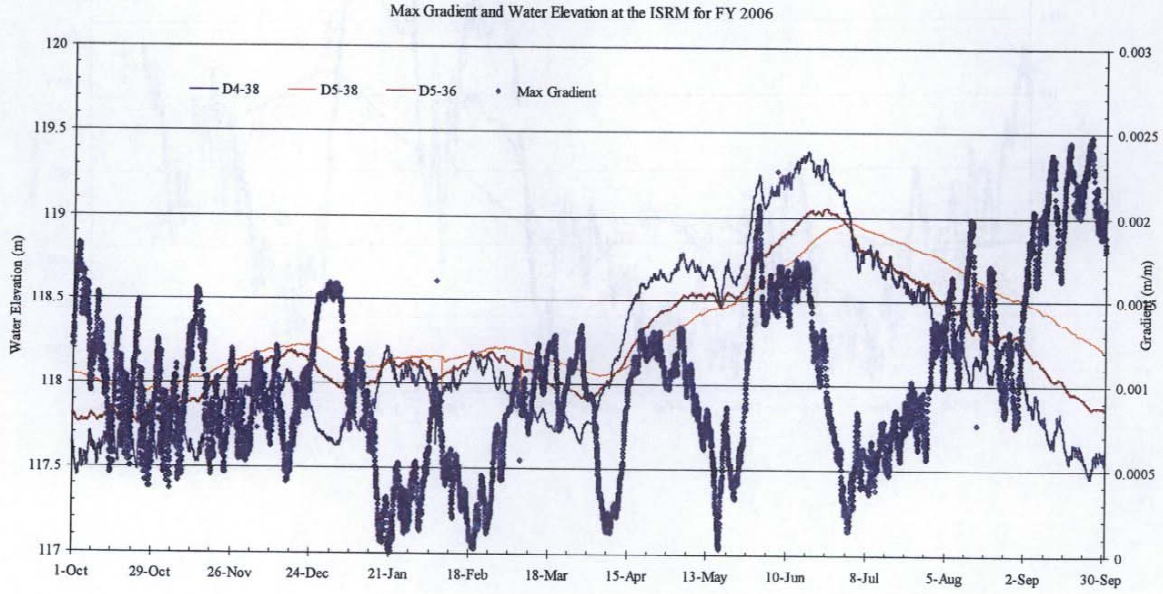




Flow Direction and Gradient Triangle 3, Wells 199-D4-38, 199-D5-38, and 199-D5-36, Fiscal Year 2006.

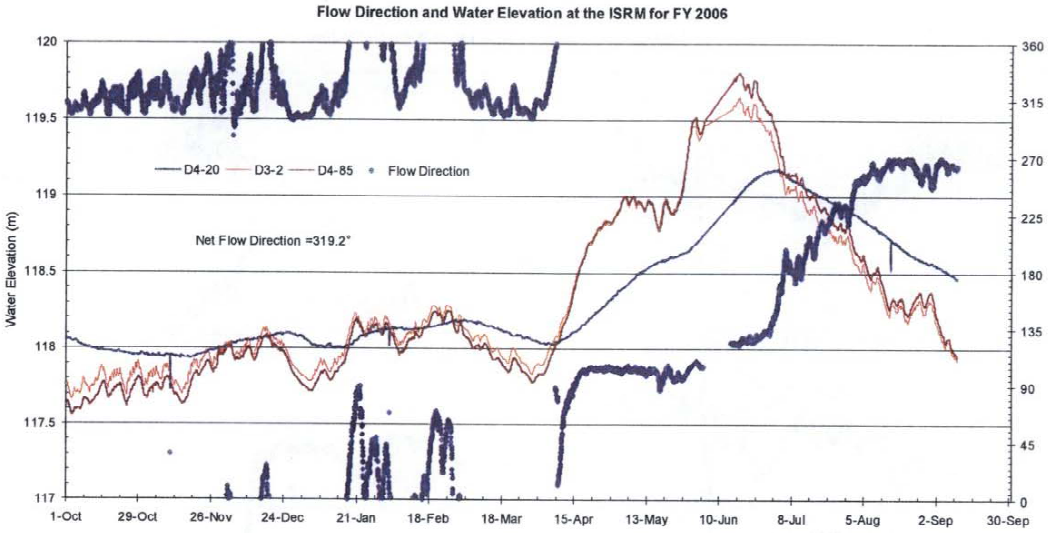
Total distance 9.53 m, net flow direction 292.4°, average gradient 0.0010, 57% optimal flow direction.

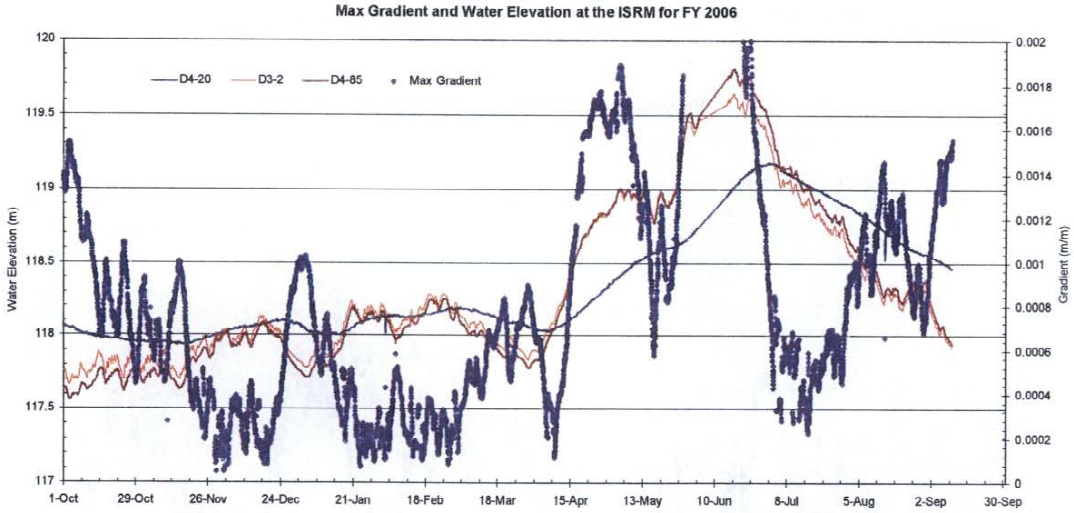




Flow Direction and Gradient Triangle 4, Wells 199-D4-20, 199-D3-2, and 199-D4-85, Fiscal Year 2006.

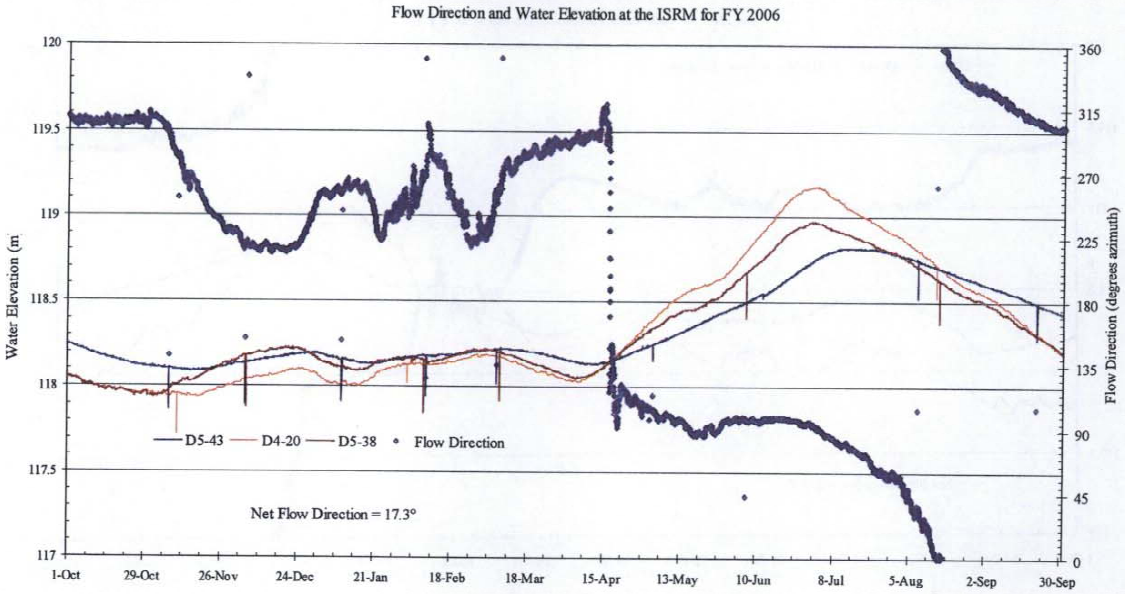
Total distance 1.13 m, net flow direction 319.2°, average gradient 0.0008, 47% optimal flow direction.

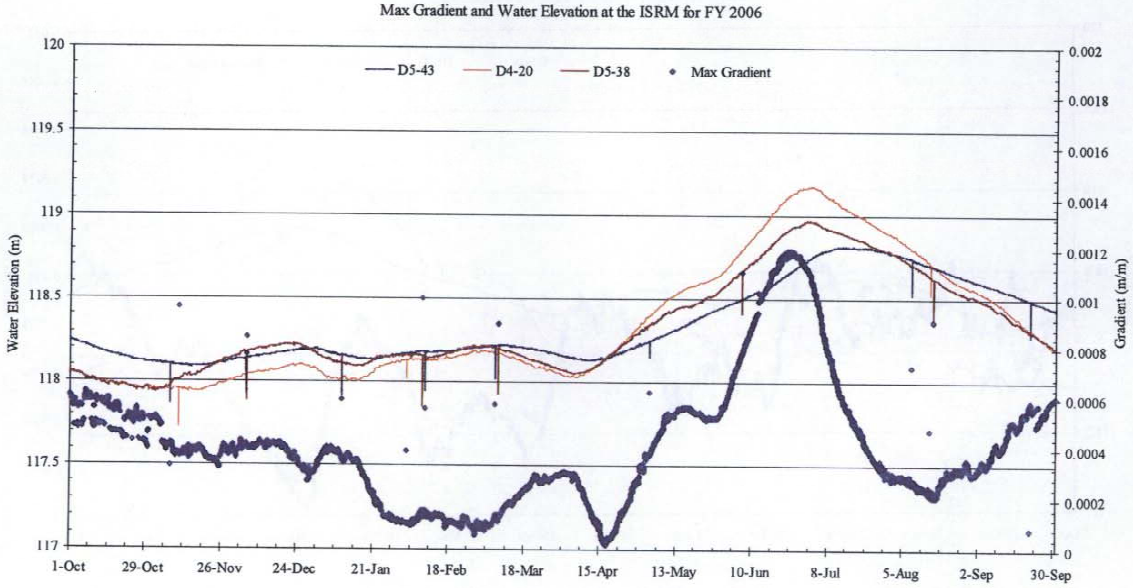




Flow Direction and Gradient Triangle 5, Wells 199-D5-43, 199-D4-20, and 199-D5-38, Fiscal Year 2006.

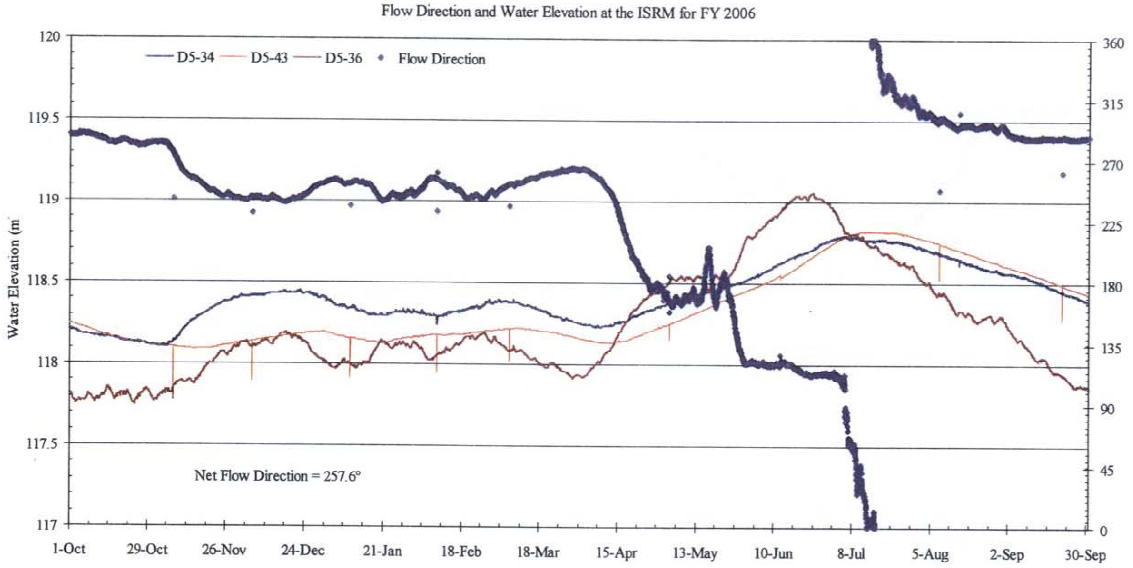
Total distance 0.73 m, net flow direction 17.3°, average gradient 0.0004, 35% optimal flow direction.

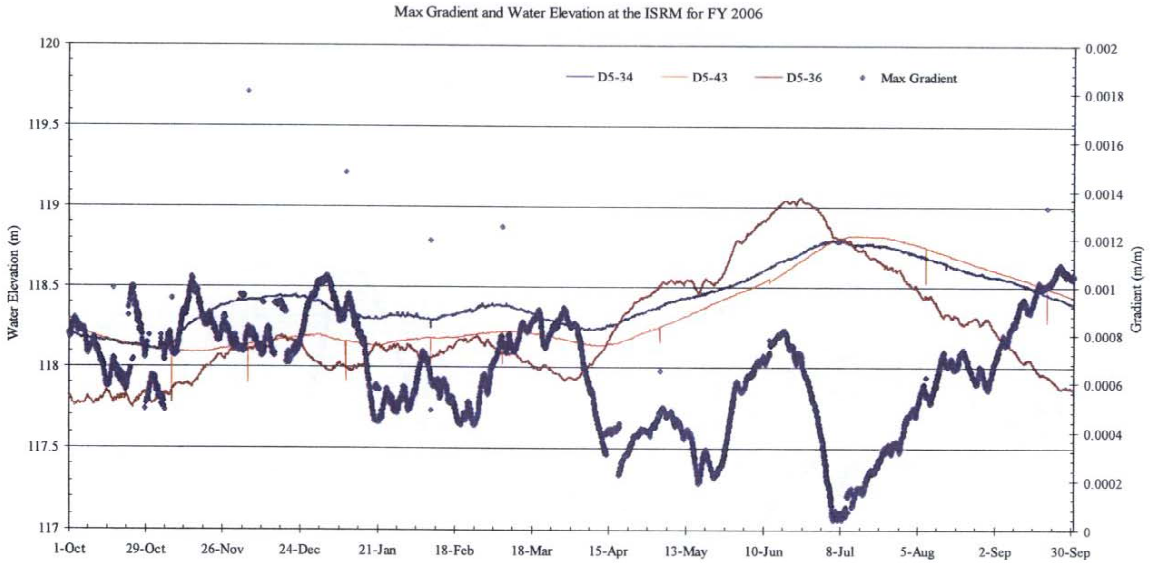




Flow Direction and Gradient Triangle 6, Wells 199-D5-34, 199-D5-43, and 199-D5-36, Fiscal Year 2006.

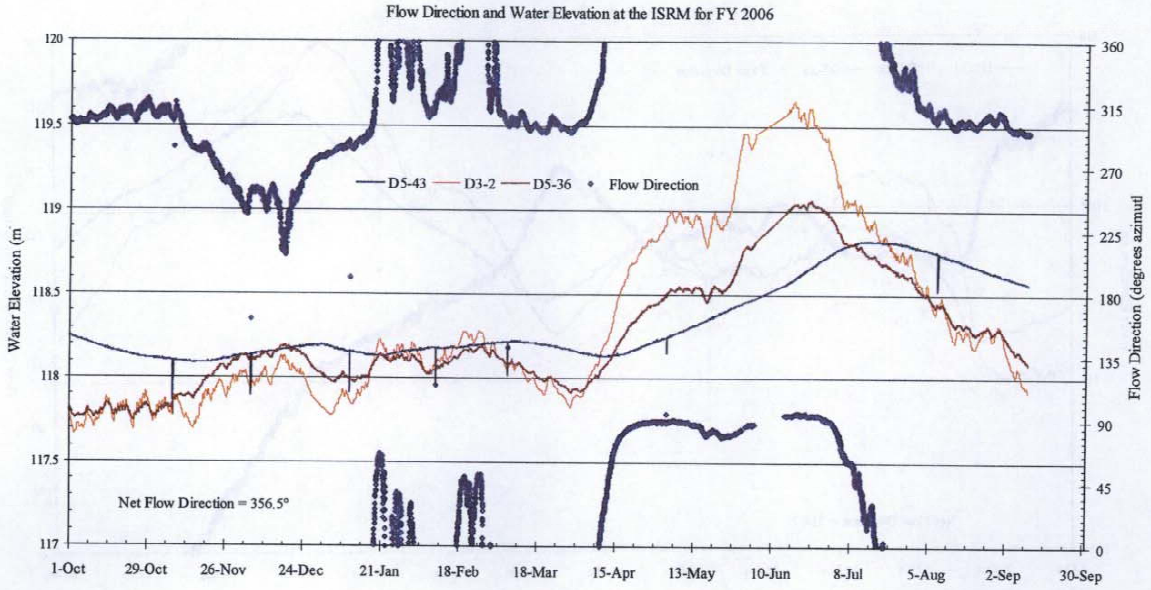
Total distance 8.35 m, net flow direction 257.6°, average gradient 0.0006, 31% optimal flow direction.

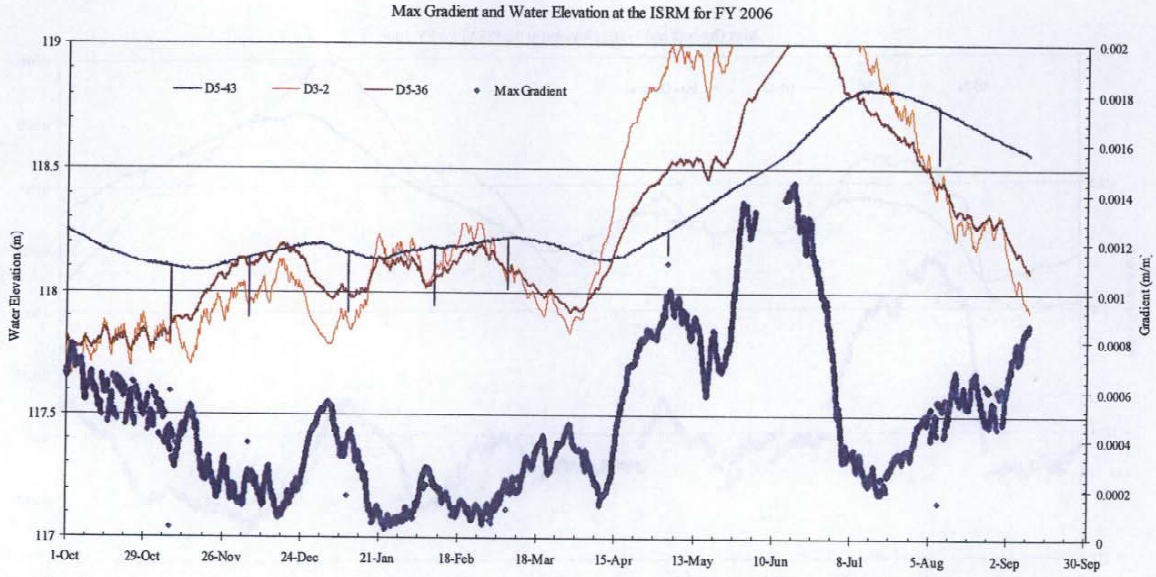




Flow Direction and Gradient Triangle 7, Wells 199-D5-43, 199-D3-2, and 199-D5-36, Fiscal Year 2006.

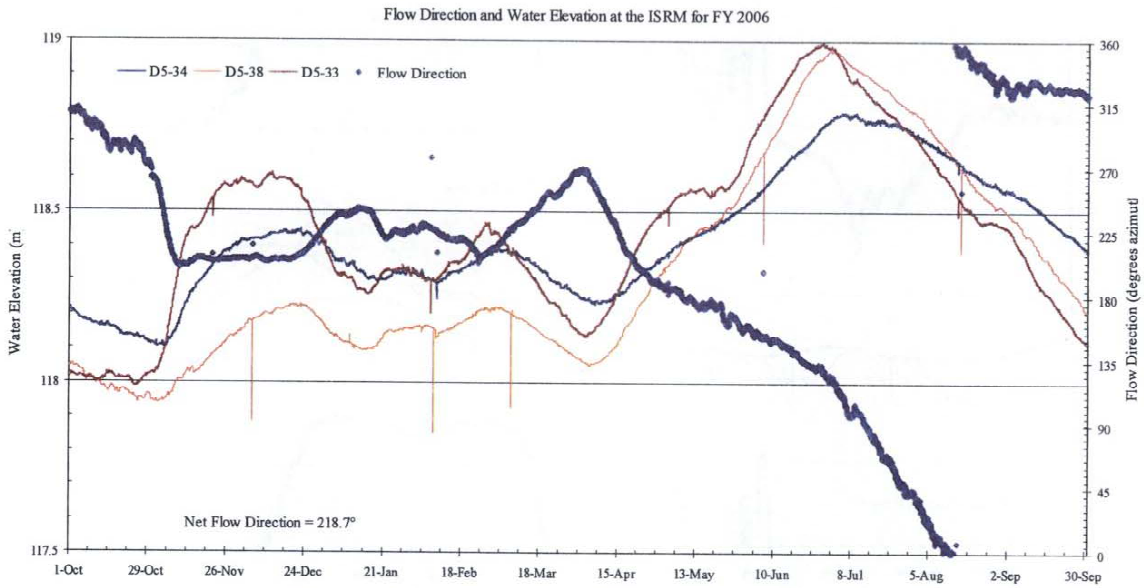
Total distance 2.39 m, net flow direction 356.5°, average gradient 0.0005, 52% optimal flow direction.

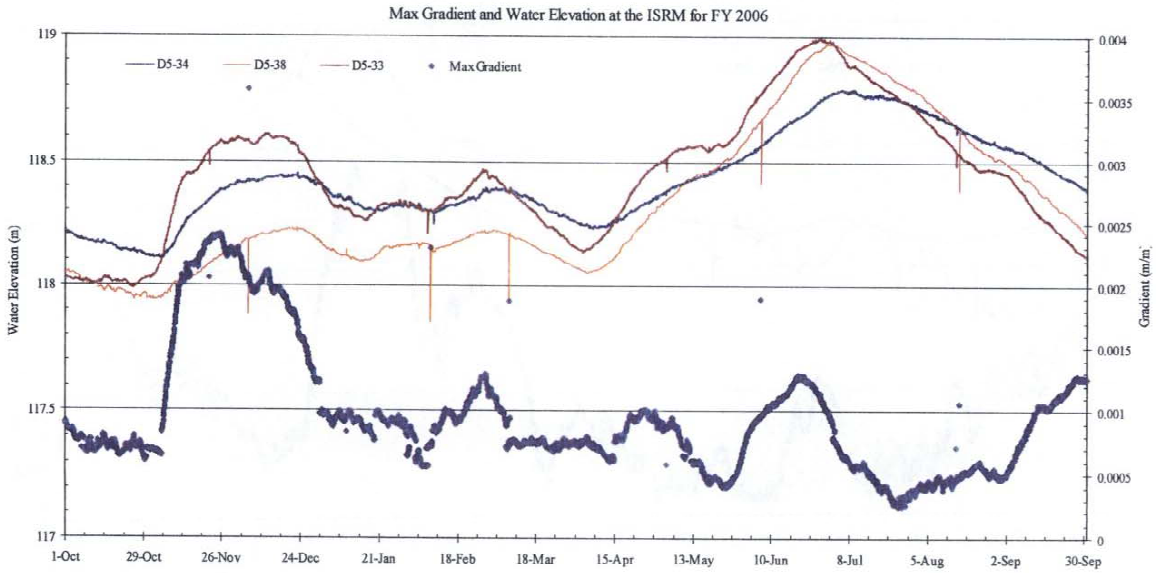




Flow Direction and Gradient Triangle 8, Wells 199-D5-34, 199-D5-38, and 199-D5-33, Fiscal Year 2006.

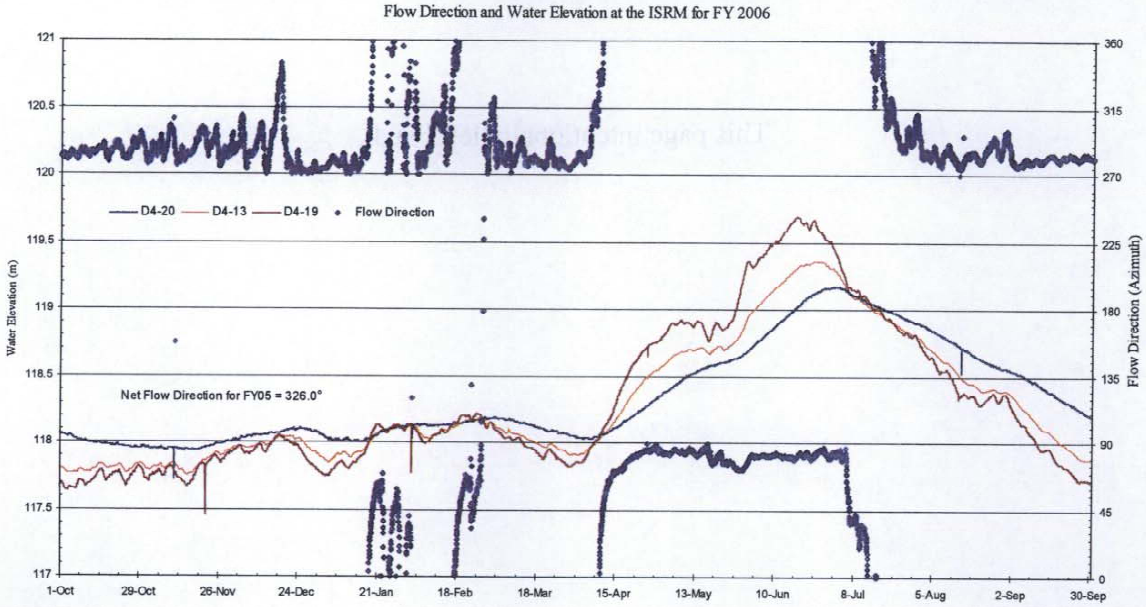
Total distance 10.48 m, net flow direction 218.7°, average gradient 0.0010, 17% optimal flow direction.

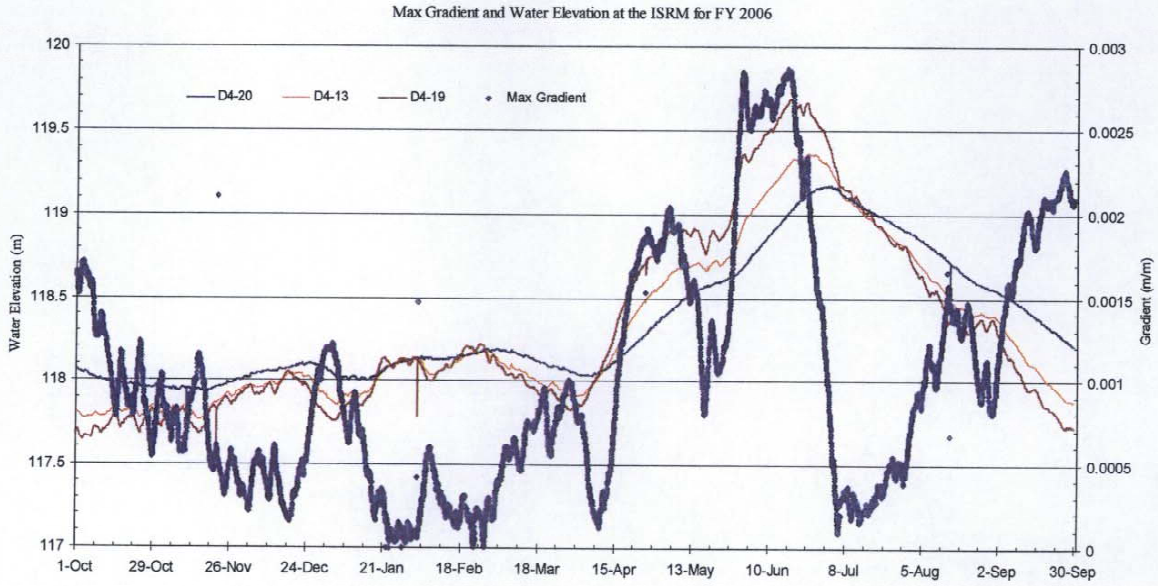




Flow Direction and Gradient Triangle 9, Wells 199-D4-13, 199-D4-19, and 199-D4-20, Fiscal Year 2006.

Total distance 15.37 m, net flow direction 326.0°, average gradient 0.0010, 61% optimal flow direction.





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APPENDIX B

FISCAL YEAR 2006 HEXAVALENT CHROMIUM AND CHROMIUM TREND PLOTS

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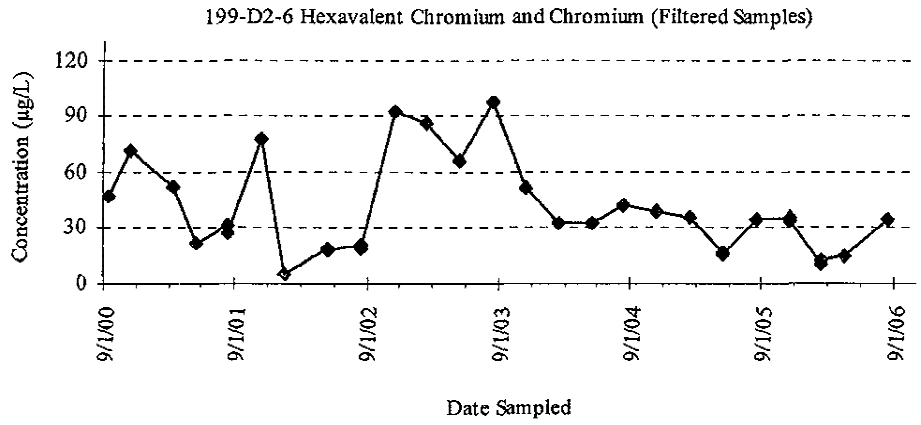

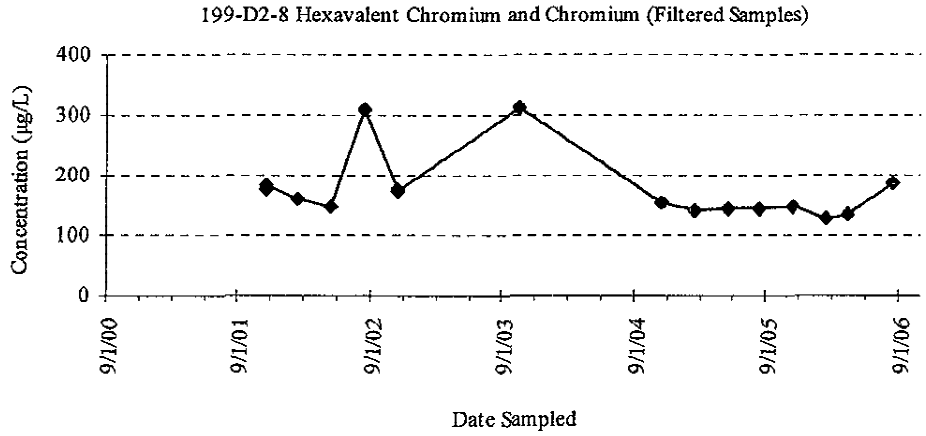

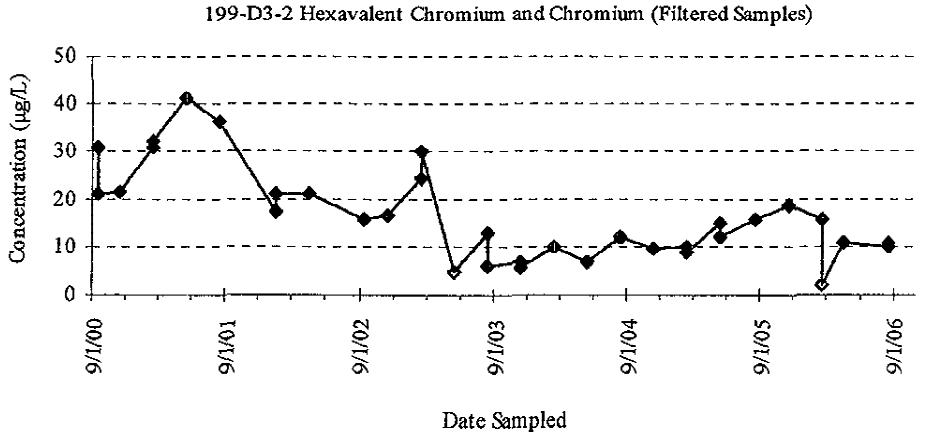

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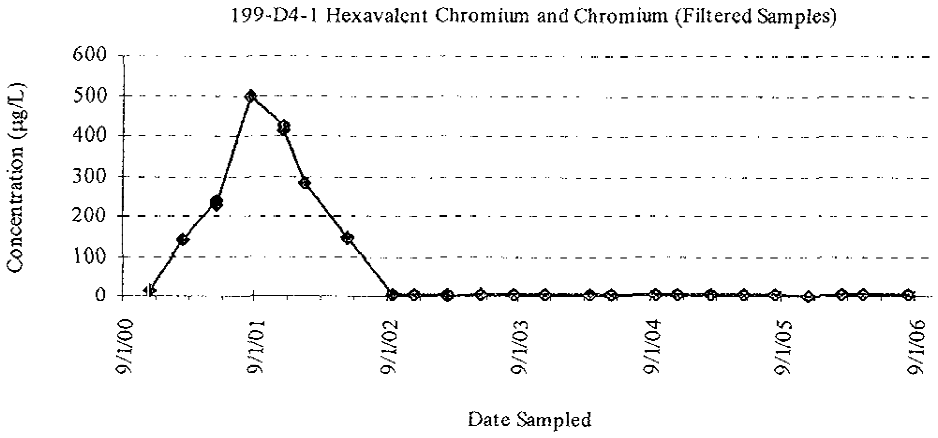

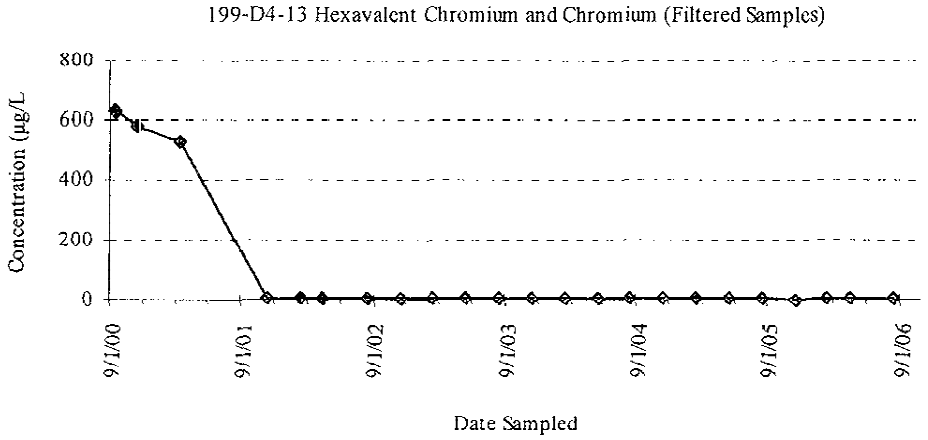

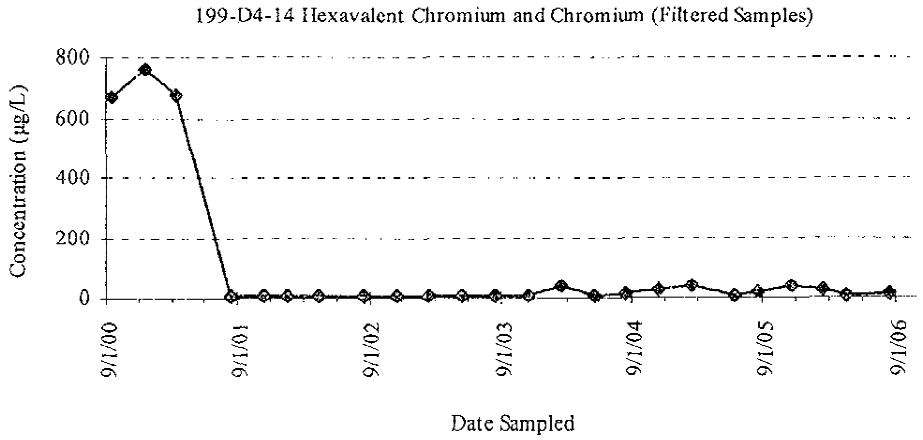

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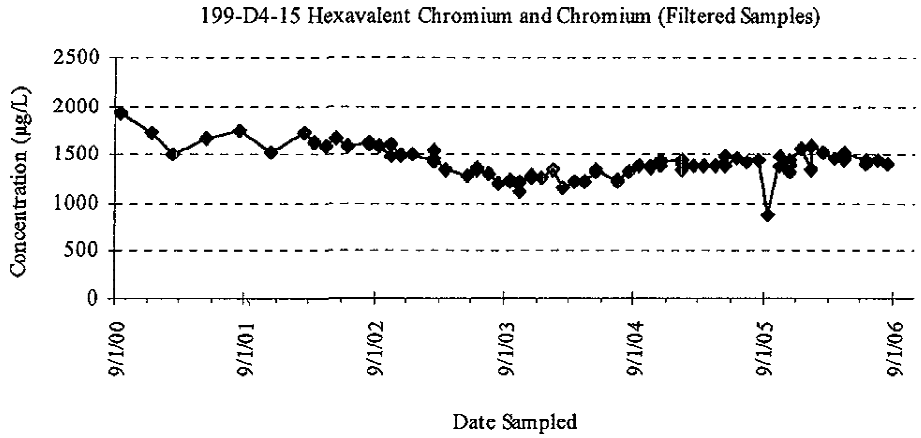

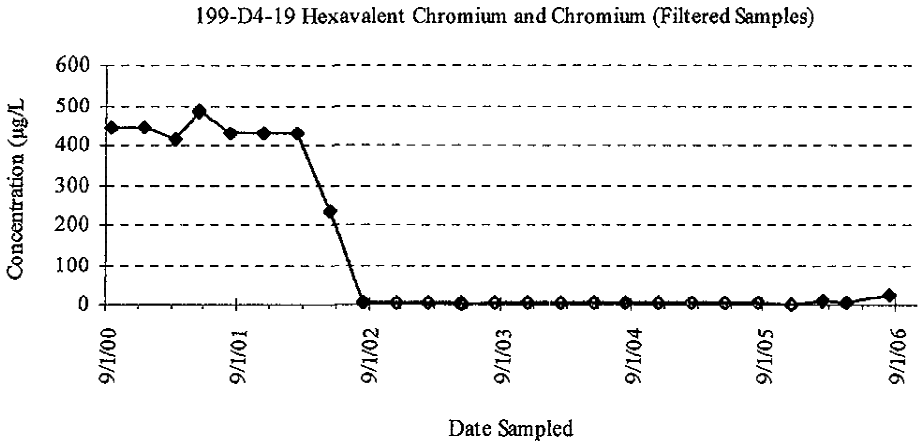

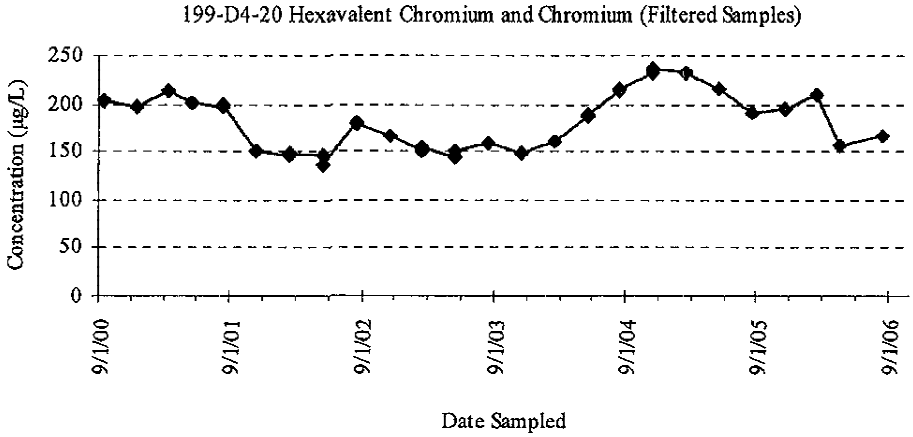

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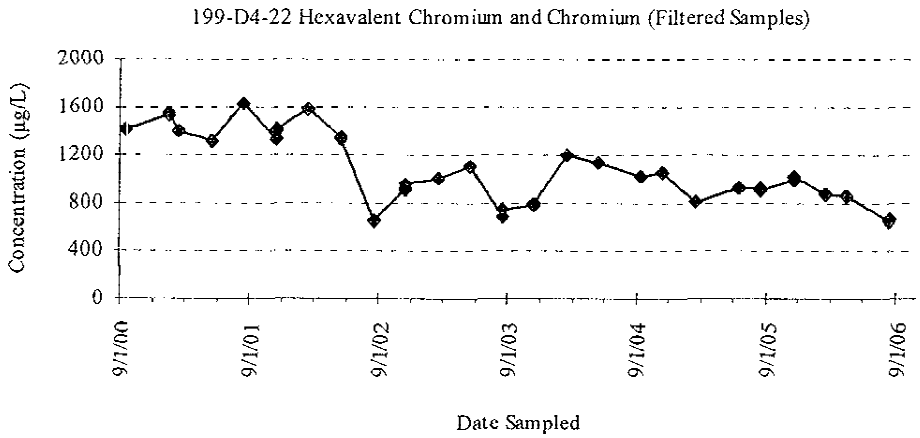

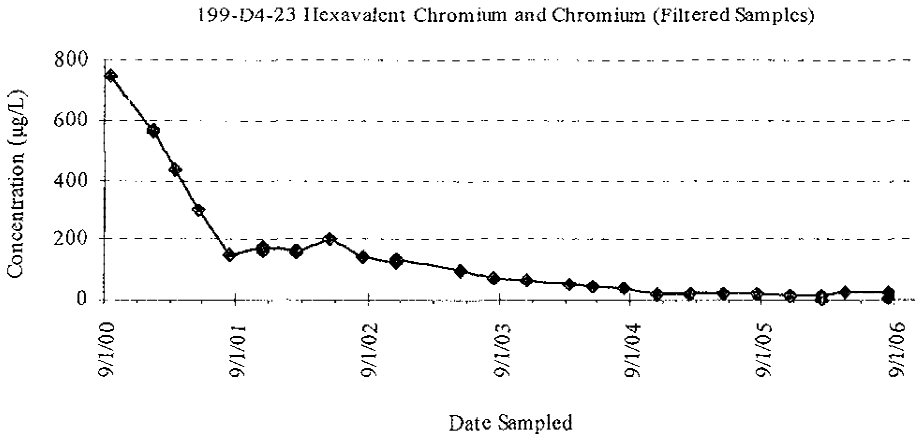

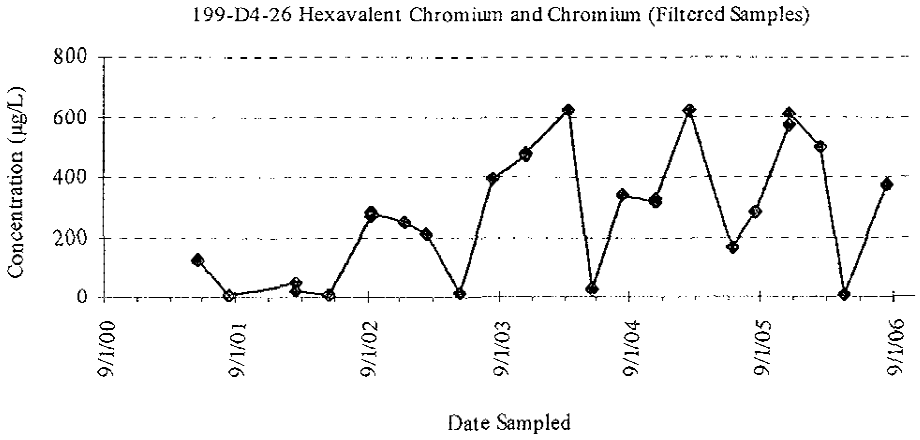

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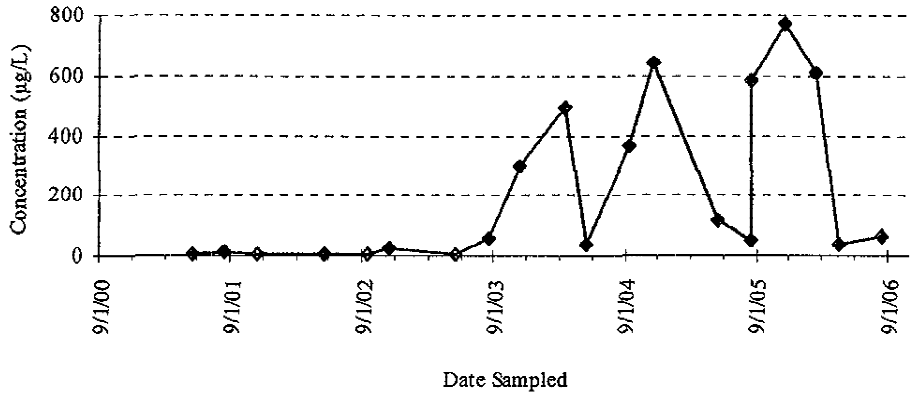
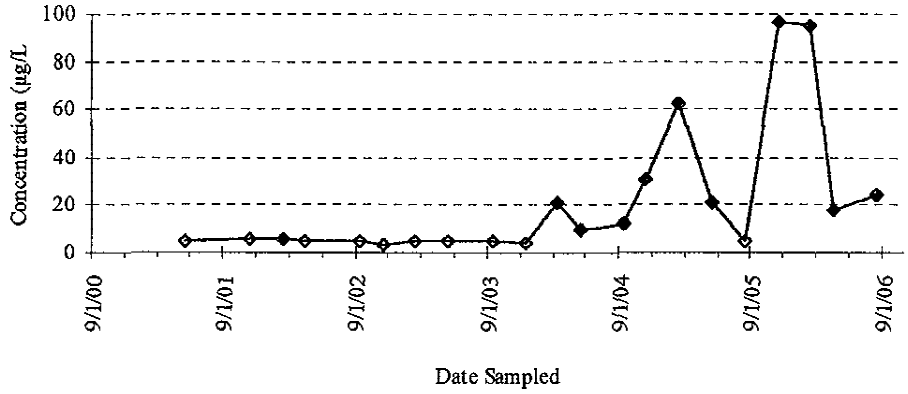
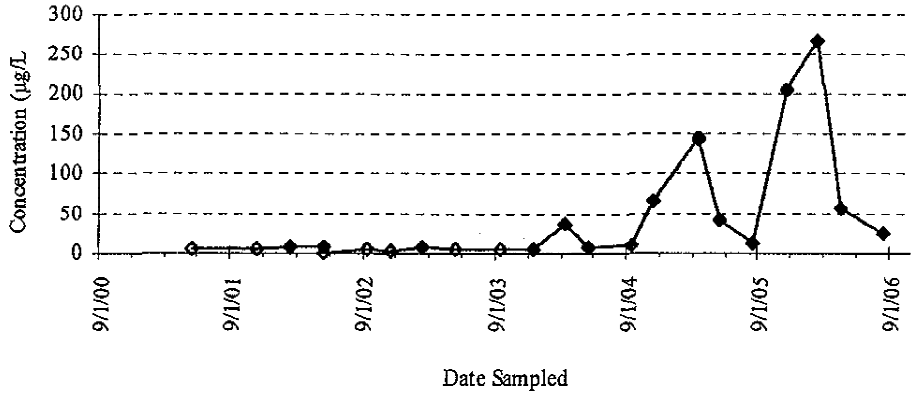
199-D4-31 Hexavalent Chromium and Chromium (Filtered Samples)



199-D4-32 Hexavalent Chromium and Chromium (Filtered Samples)



199-D4-36 Hexavalent Chromium and Chromium (Filtered Samples)



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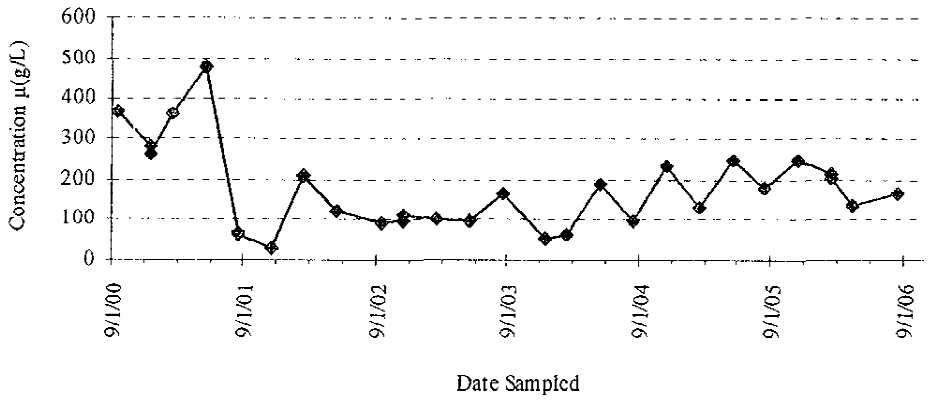
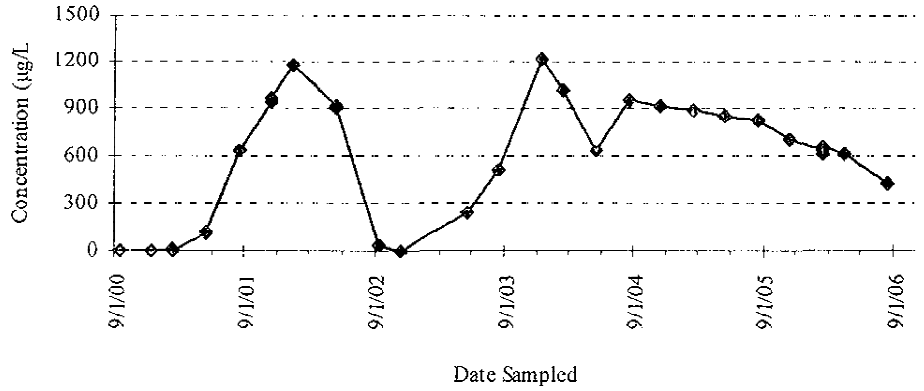
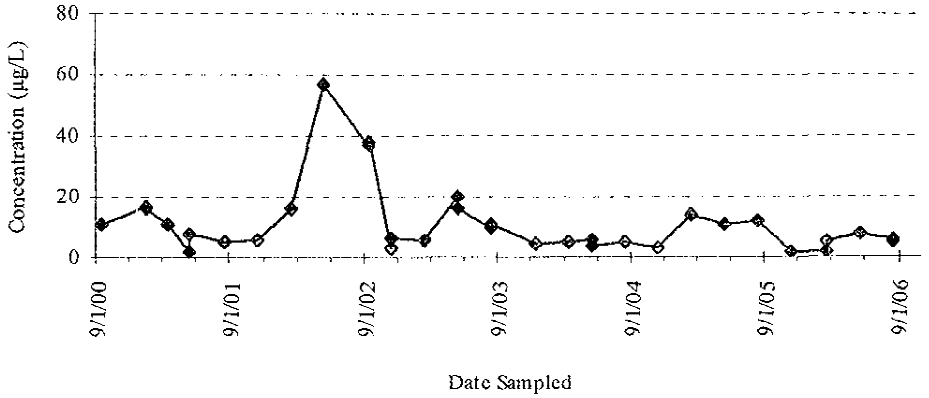
199-D4-38 Hexavalent Chromium and Chromium (Filtered Samples)



199-D4-39 Hexavalent Chromium and Chromium (Filtered Samples)



199-D4-4 Hexavalent Chromium and Chromium (Filtered Samples)



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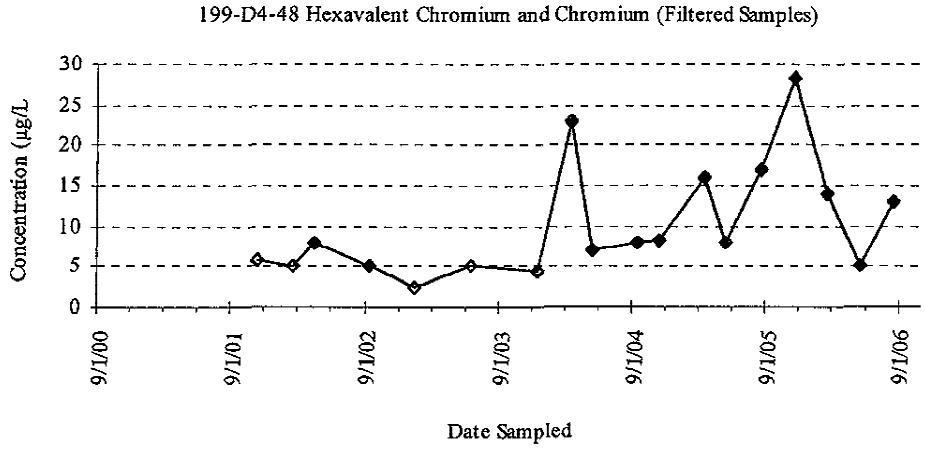

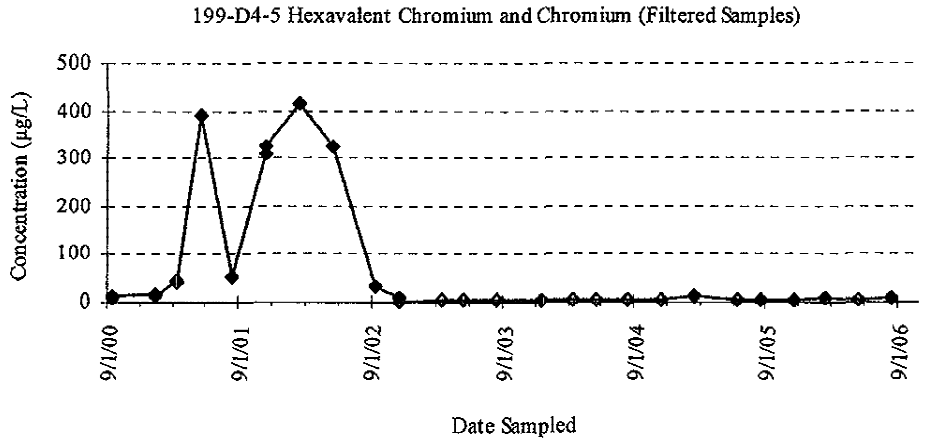

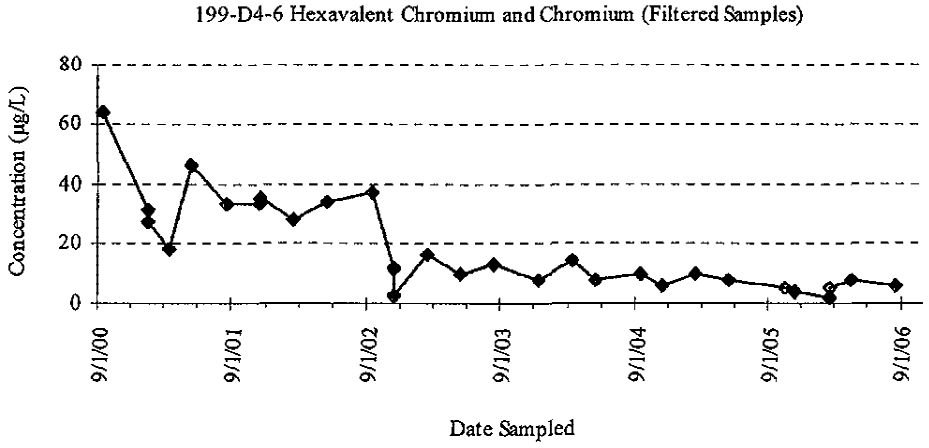

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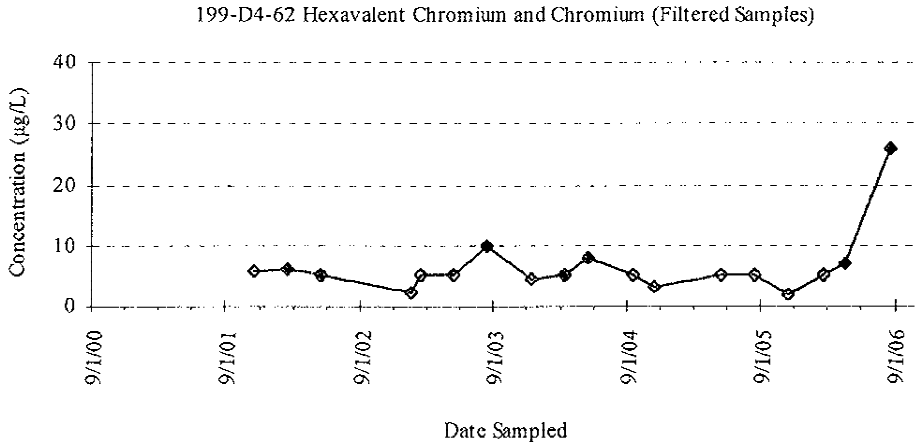

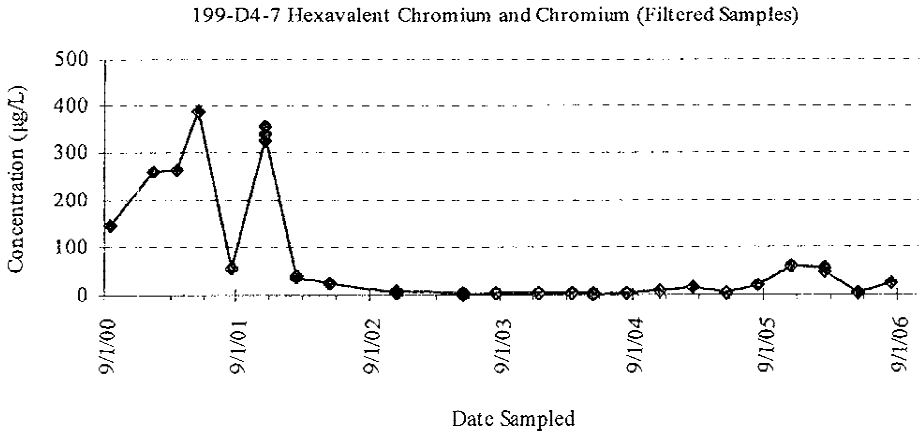

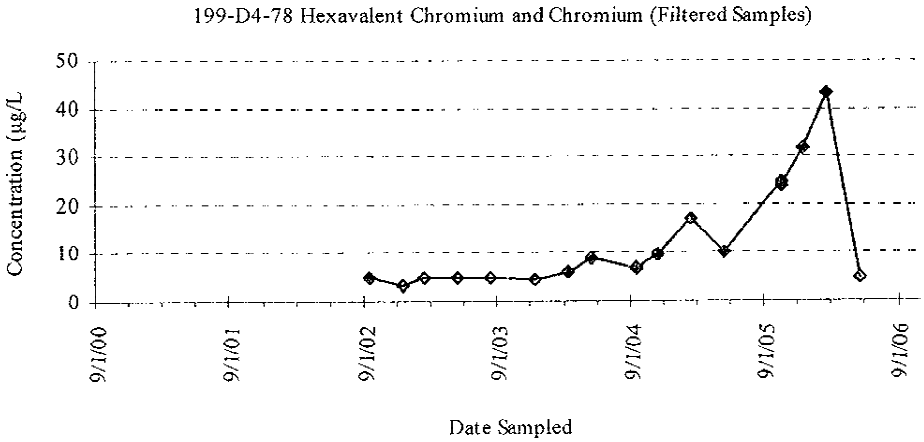

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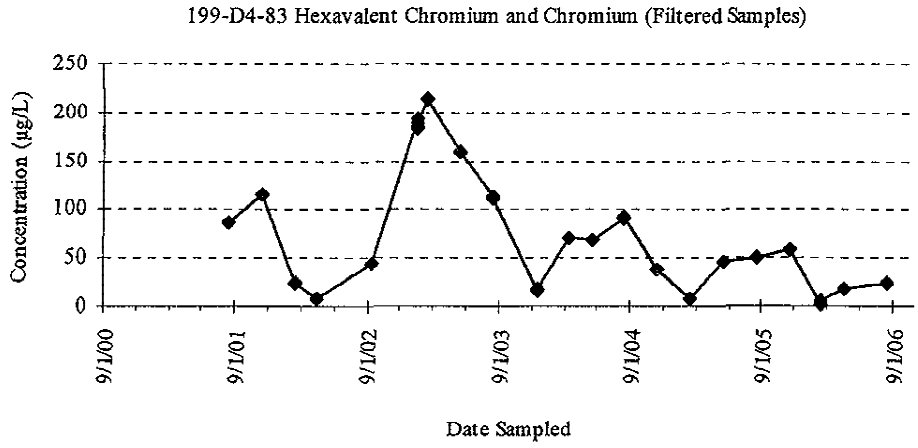

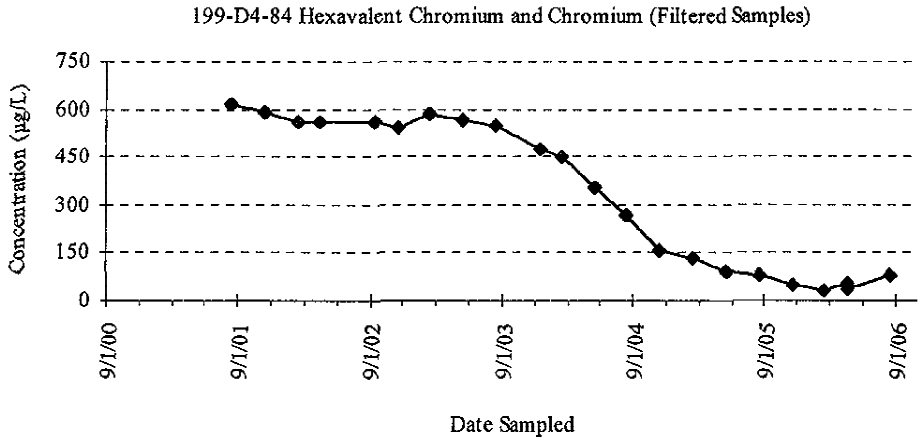

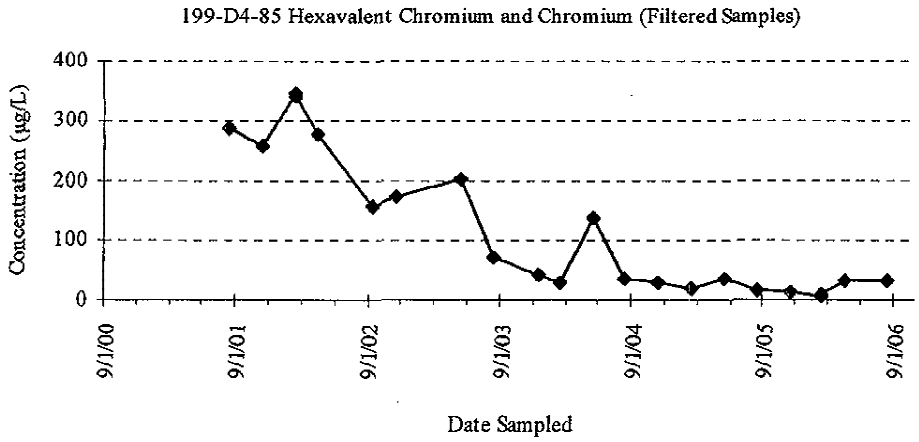

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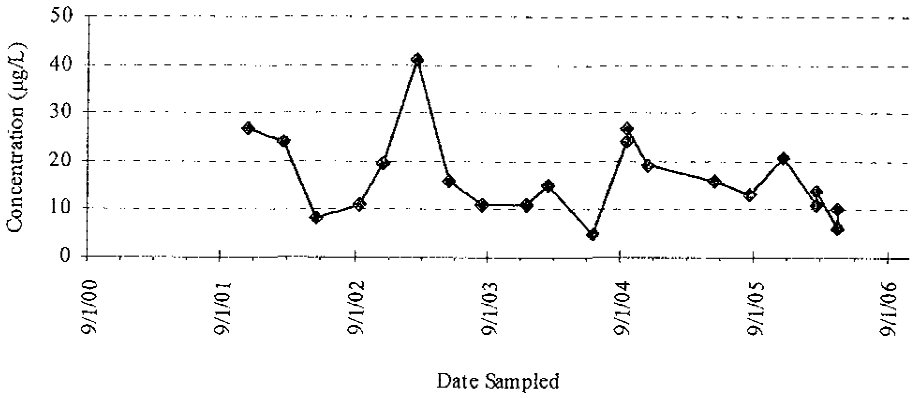
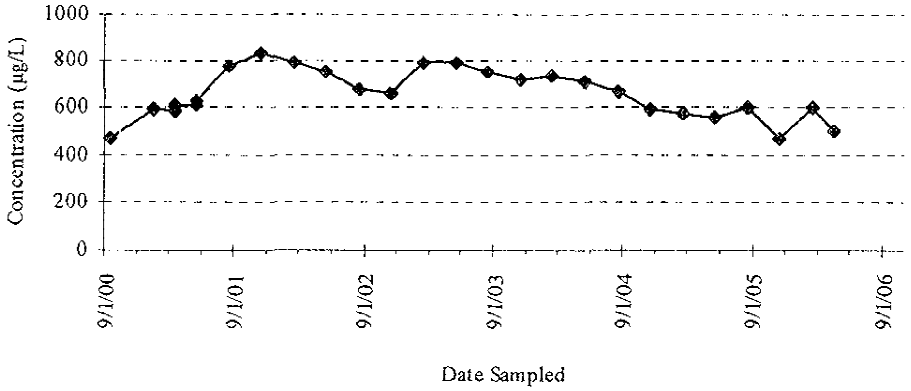
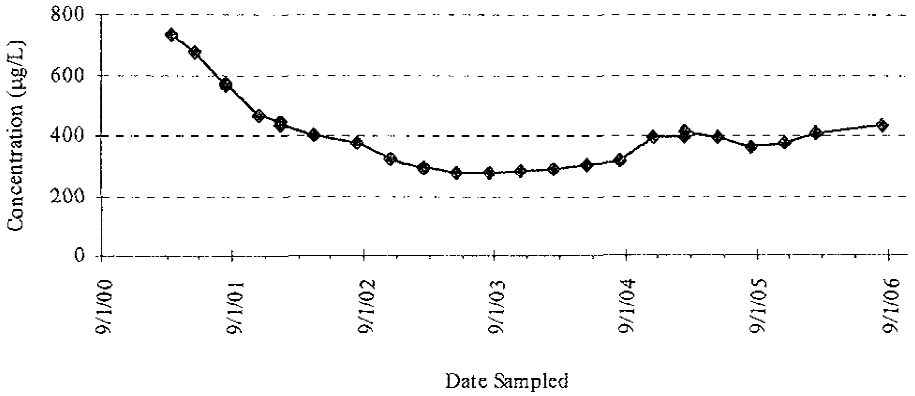
199-D4-86 Hexavalent Chromium and Chromium (Filtered Samples)



199-D5-13 Hexavalent Chromium and Chromium (Filtered Samples)



199-D5-14 Hexavalent Chromium and Chromium (Filtered Samples)



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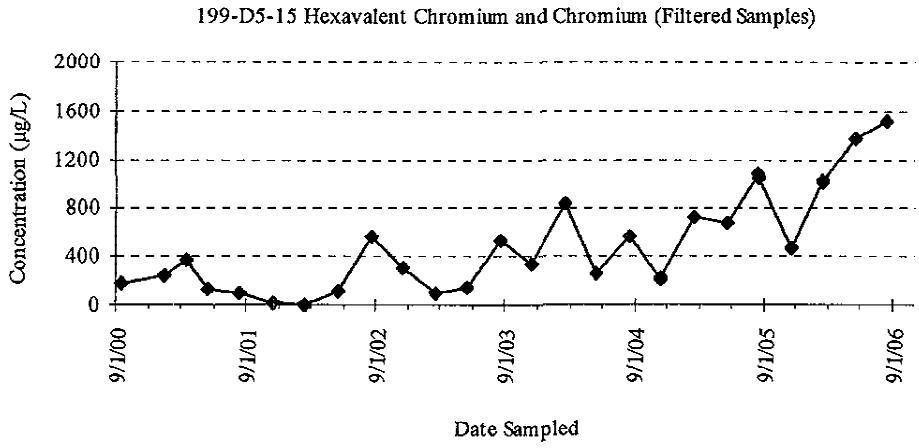

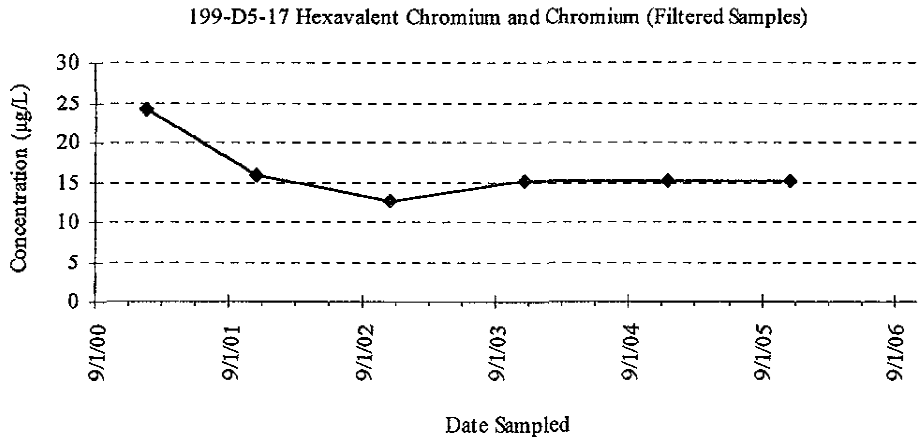

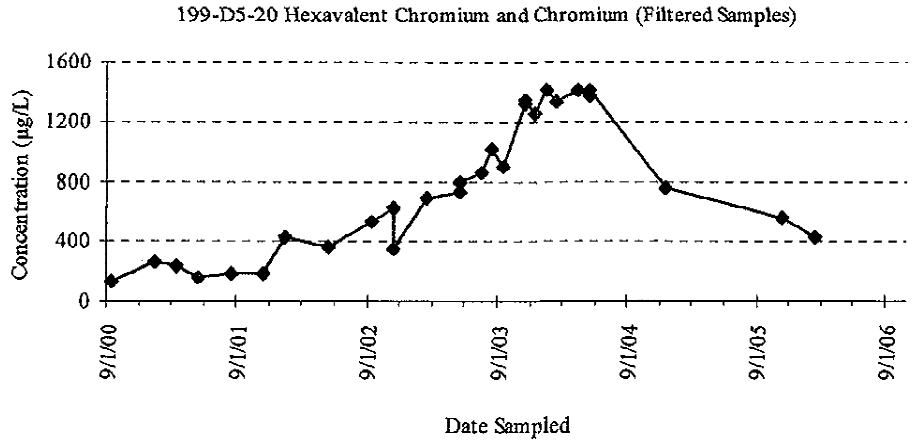

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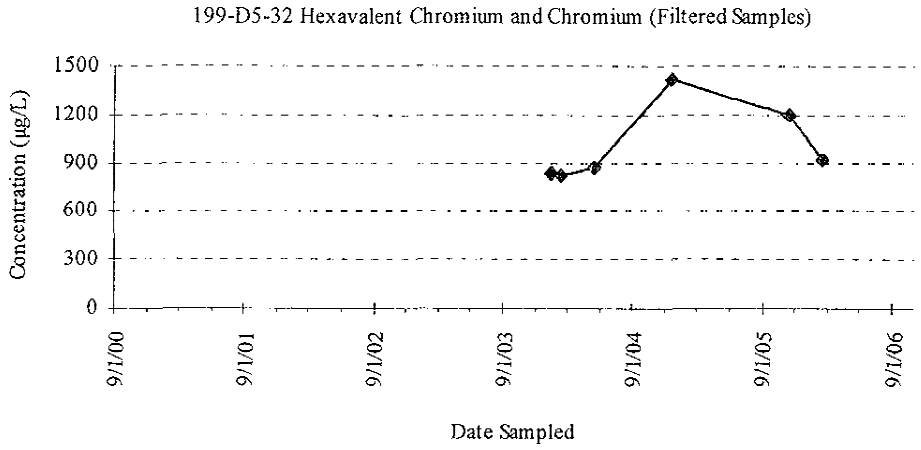

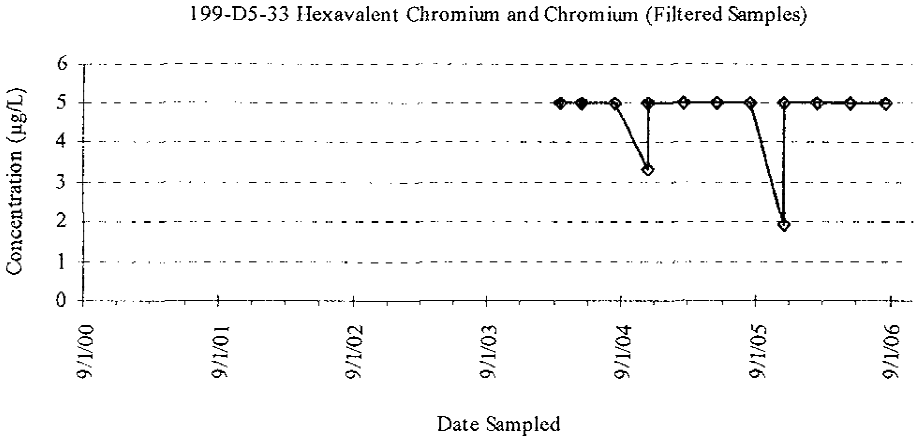

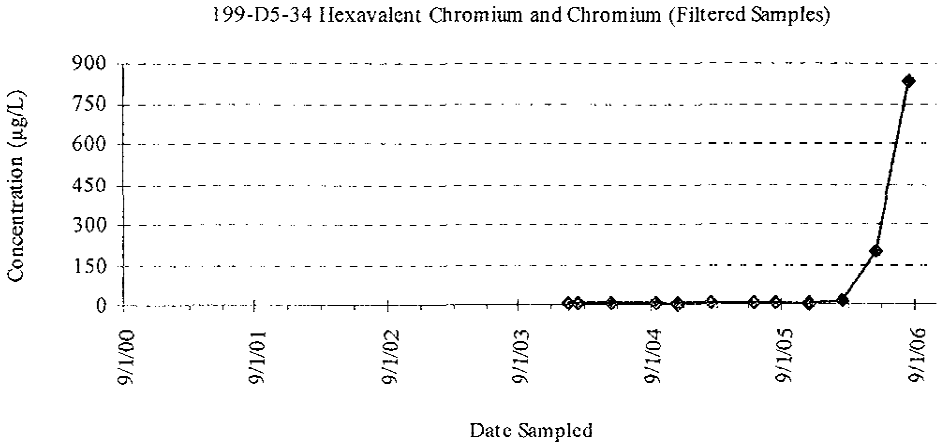

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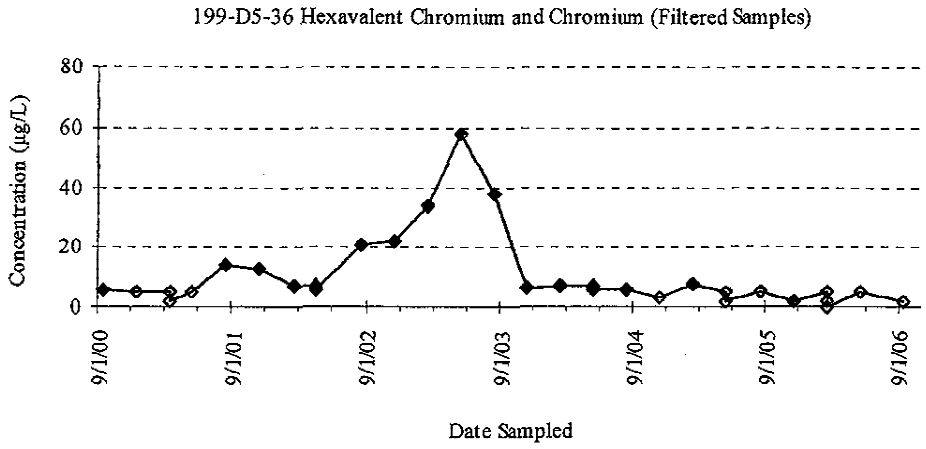

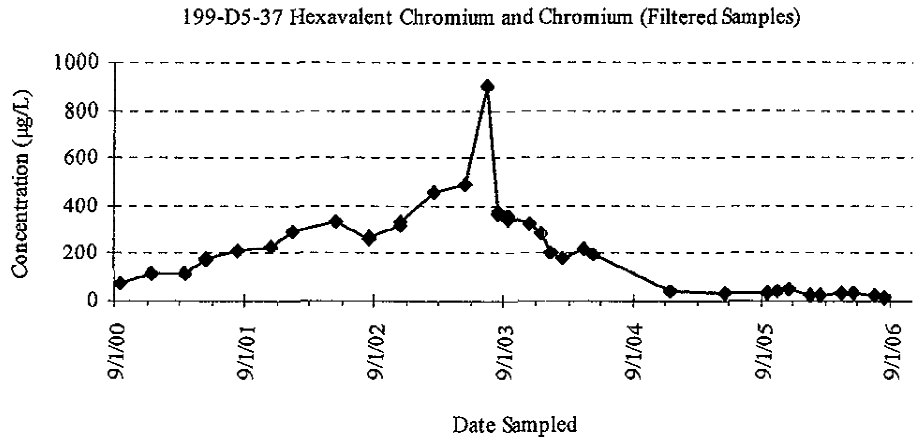

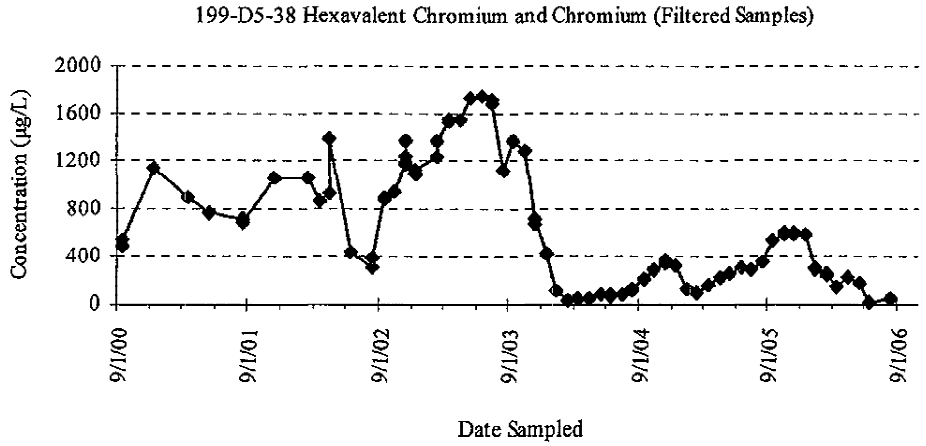

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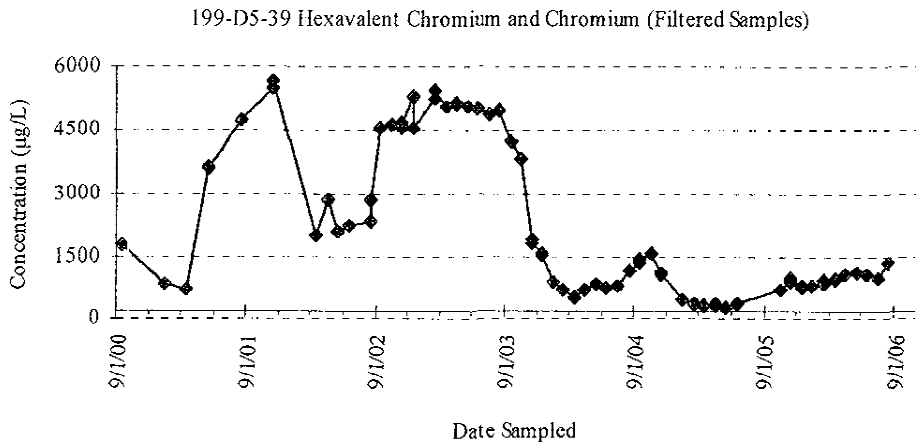

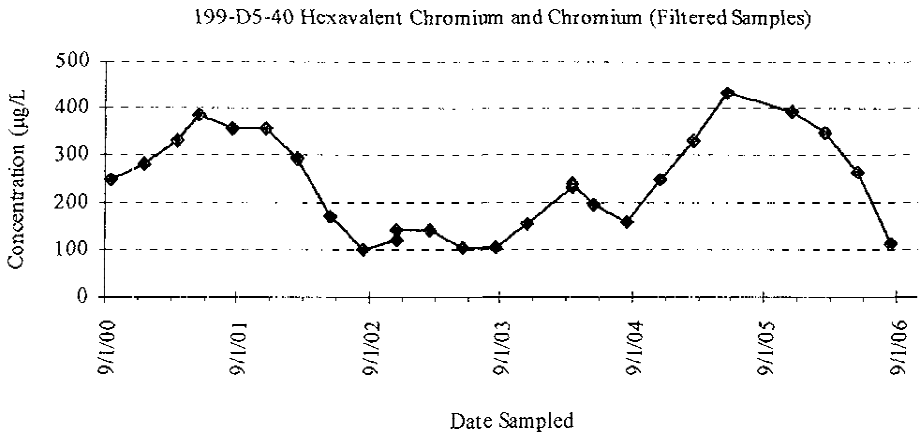

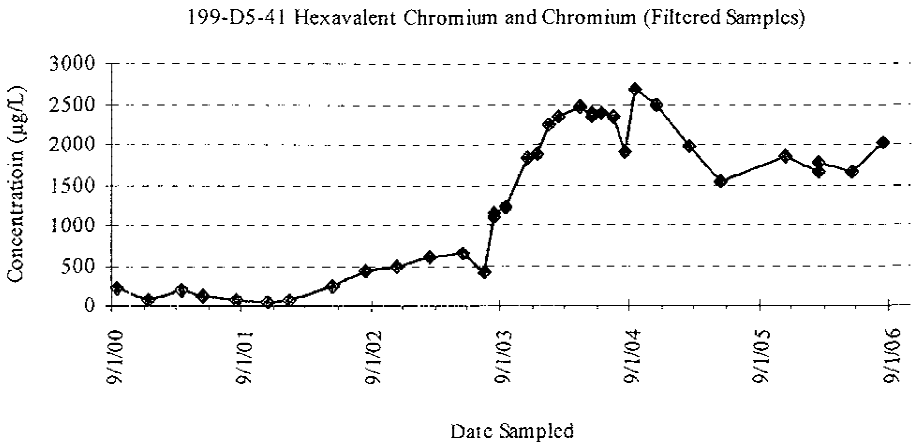

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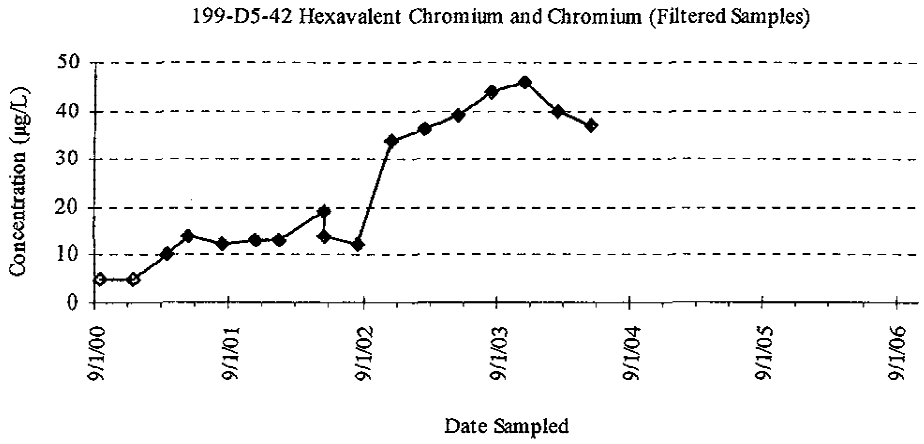

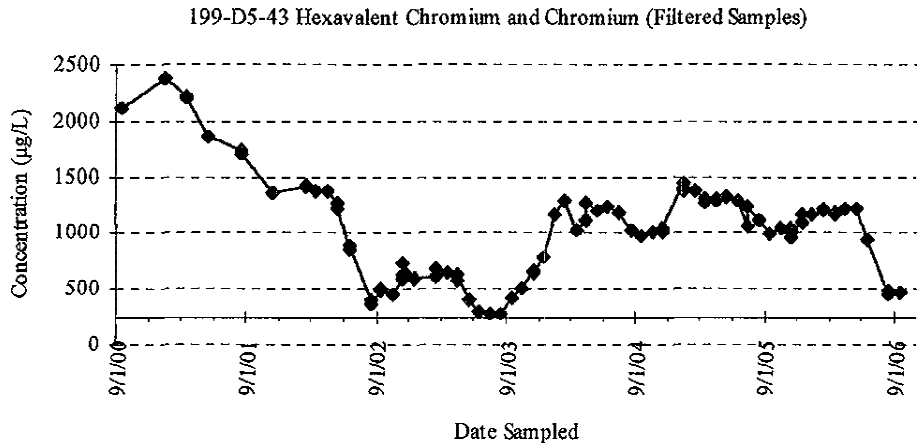

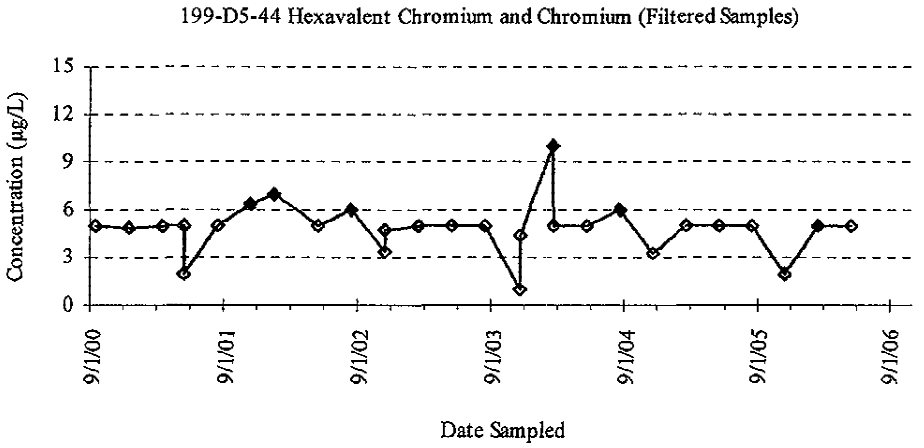

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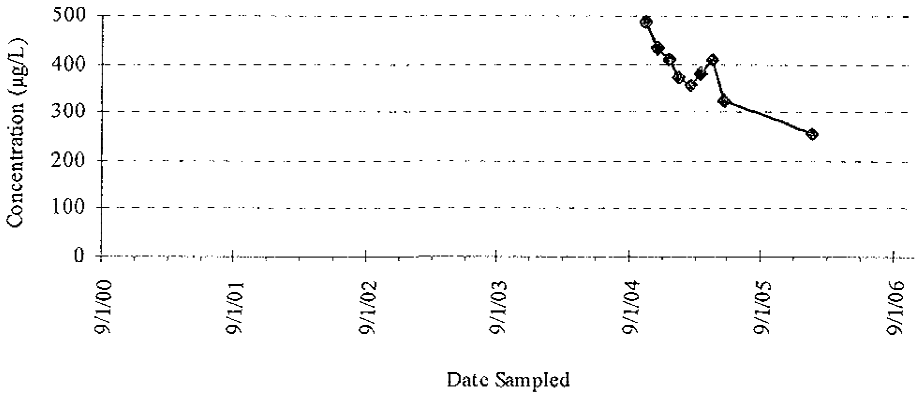
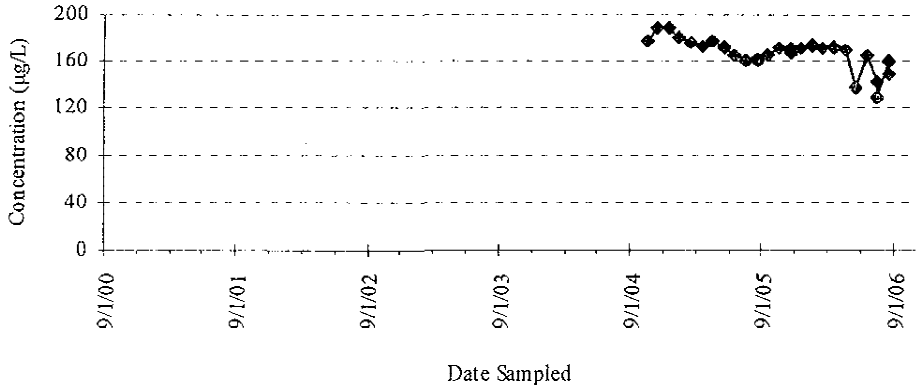
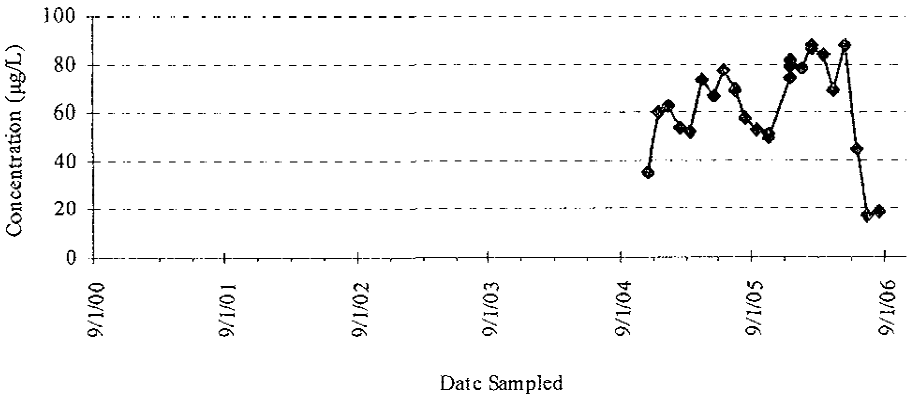
199-D5-92 Hexavalent Chromium and Chromium (Filtered Samples)



199-D8-73 Hexavalent Chromium and Chromium (Filtered Samples)



199-D8-88 Hexavalent Chromium and Chromium (Filtered Samples)



◊ = Analyte not detected, plotted value is laboratory reporting limit for the analysis.

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