This document was too large to scan as a single document. It has been divided into smaller sections.

Section 1 of 2

Document Information			
Document #	DOE/RL-2003-05	Revision	0
Title	FY2002 ANNUAL SUMMARY REPORT FOR THE IN SITU REDOX MANIPULATION OPERATIONS		
Date	4/3/03		
Originator	MAHOOD RO	Originator Co.	DOE-RL
Recipient		Recipient Co.	
References			
Keywords			
Projects			
Other Information			

Date Received for Clearance Process (MM/YY/DD)
04/03/30

INFORMATION CLEARANCE FORM

A. Information Category

- ☐ Abstract
- ☐ Summary
- ☐ Visual Aid
- ☐ Full Paper
- ☐ Journal Article
- ☐ Internet
- ☐ Software
- ☒ Report
- ☐ Other _____

B. Document Number DOE-RL-2003-05, Rev. 0

C. Title
Fiscal Year 2002 Annual Summary Report for the In Situ Redox Manipulation Operations

D. Internet Address

E. Required Information

1. Is document potentially Classified? ☒ No ☐ Yes (MANDATORY)

(See below.)
Manager's Signature Required

If Yes _____ ☐ No ☐ Yes Classified
ADC Signature Required

2. References in the Information are Applied Technology ☒ No ☐ Yes

Export Controlled Information ☒ No ☐ Yes

3. Does Information Contain the Following: (MANDATORY)
   a. New or Novel (Patentable) Subject Matter? ☒ No ☐ Yes
      If "Yes", Disclosure No.: _____
   b. Information Received in Confidence, Such as Proprietary and/or Invention
      ☒ No ☐ Yes If "Yes", Affix Appropriate Legends/Notices.
   c. Copyrights? ☒ No ☐ Yes If "Yes", Attach Permission.
   d. Trademarks? ☐ No ☒ Yes If "Yes", Identify in Document.
4. Is Information requiring submission to OSTI? ☐ No ☐ Yes
5. Release Level? ☒ Public ☐ Limited

F. Complete for a Journal Article

1. Title of Journal

G. Complete for a Presentation

1. Title for Conference or Meeting _____
2. Group Sponsoring _____
3. Date of Conference _____
4. City/State _____
5. Will Information be Published in Proceedings? ☐ No ☐ Yes
6. Will Material be Handed Out? ☐ No ☐ Yes

H. Author/Requestor
Richard O. Mahood Richard O. Mahood
(Print and Sign)

Responsible Manager
L. Craig Swanson L. Craig Swanson
(Print and Sign)

I. Reviewers

	Yes	Print	Signature	Public Y/N (If N, complete
General Counsel	☒	R. Southworth	[illegible]	(Y) / N
Office of External Affairs	☐			Y / N
DOE-RL	☒	A-C. Tortoso	John Morefar	(Y) / N
Other	☐			Y / N
Other	☐			Y / N

J. If Information Includes Sensitive Information and is not to be released to the Public indicate category below.

- ☐ Applied Technology
- ☐ Personal/Private
- ☐ Proprietary
- ☐ Business-Sensitive
- ☐ Predecisional
- ☐ UCNI
- ☐ Protected CRADA
- ☐ Export Controlled
- ☐ Procurement-Sensitive
- ☐ Patentable
- ☐ Other (Specify) _____

Information Clearance Approva

APPROVED FOR RELEASE
OFFICIAL DOCUMENT
Date 5-1-2003

K. If Additional Comments, Please Attach Separate Sheet

A-6001-401 (12/00)

0059658

DOE/RL-2003-05
Revision 0

Fiscal Year 2002 Annual Summary Report for the In Situ Redox Manipulation Operations

RECEIVED
JUN 10 2003
EDMC

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

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

Approved for public release; further dissemination unlimited

DOE/RL-2003-05
Revision 0

Fiscal Year 2002 Annual Summary Report for the In Situ Redox Manipulation Operations

Date Published
May 2003

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

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

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

Release Approval Date 5-1-2003

Approved for public release; further dissemination unlimited

LEGAL DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or any third party's use or the results of such use of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

This report has been reproduced from the best available copy.

Printed in the United States of America

EXECUTIVE SUMMARY

This report presents a construction activity 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. The ISRM is a permeable groundwater treatment zone technology established to remedy the hexavalent chromium-contaminated groundwater plume. This report is for the period of October 1, 2001, through September 30, 2002.

The remedial action objectives of the ISRM treatment zone are the same as those stated in the original record of decision for the 100-HR-3 Operable Unit (*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 remedial action objectives are as follows.

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

An ISRM treatability test was conducted in the 100-D Area in 1997 and 1998. Five treated wells created a reducing zone in the unconfined aquifer that was approximately 46 m in length by 15 m in width. A sixth well was added and treated in 1999. The treatment zone emplacement activities at the six wells provided data supporting the decision to implement large-scale treatment zone construction.

The 1999 amended record of decision for the 100-HR-3 Operable Unit (*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 the newly defined groundwater plume located west of the D/DR Reactors. The amended record of decision authorized large-scale deployment of the ISRM technology to remediate the plume and deferred the details of the

design to *Remedial Design Report and Remedial Action Work Plan for the 100-HR-3 Groundwater Operable Unit In Situ Redox Manipulation* (DOE/RL-99-51). A 3-year/three-phase emplacement schedule was developed. The three phases (Phases I, II, and III) coincide with fiscal years (FY) 2000, 2001, and 2002. The treatment zone will be established outward from the treatability test area located at the center of the most contaminated portion of the groundwater plume. The anticipated total length of the treatment zone is approximately 680 m. At the end of FY 2002, the treatment zone length is approximately 630 m.

The ISRM barrier was extended to about 92 percent of the full design length in FY 2002. Five barrier wells still need to be treated. Overall, the barrier appears to be effectively mitigating hexavalent chromium contamination even though some breakdown (i.e., significant and sustained increases in hexavalent chromium concentrations in a barrier well) was observed at 8 of the 61 treated barrier wells. Six of these wells were treated again to reestablish reducing conditions.

While hexavalent chromium concentrations were near zero in most barrier wells, the compliance wells near the central portion of the barrier still have relatively high concentrations (i.e., ranging from 93 to 560 μg/L). Concentrations did not significantly decrease from FY 2001 values. Compliance wells near the northern and southern portions of the barrier did show decreasing hexavalent chromium concentrations in response to barrier installation. Now that the barrier is nearly completed (only five untreated wells remain), chromium concentrations should begin to decline at the compliance wells, thereby meeting the primary remedial action objective to protect receptors in the river.

Monitoring of water levels near the barrier and the far field show that the flow direction of the contaminant plume for part of the year may not be perpendicular to the barrier axis, because of changing river elevations. The influence of the river on chromium plume movement will continue to be monitored to ensure that the plume is contained.

The FY 2002 Phase III ISRM activities included the following.

- In FY 2002, 20 new wells were installed (three small-diameter monitoring wells and 17 treatment zone wells).

- The ISRM barrier was extended to a total length of 630 m by the treatment of 17 wells; treatment of the remaining 5 Phase III treatment zone wells is scheduled for FY 2003.

- Chemical treatment was performed in 23 wells. Seventeen of these wells were treated for the first time and 6 of the 23 wells were treated for a second time as part of the "ISRM Mitigation Plan" (CCN 091481, Attachment 1).

- Re-treatment of six wells was necessary based on sample results from the aquifer in the treatability test area. Analytical data indicated hexavalent chromium breakthrough. Five of the six wells were treated initially in 1997 or 1998. The sixth well, 199-D4-35, was treated initially in August 2000. The reasons for the premature breakdown are not fully understood but several potential mechanisms have been identified. Investigation and analysis of the barrier performance are ongoing.

- Operational monitoring of the 61 barrier wells indicates that treatment has effectively reduced hexavalent chromium to near zero with a few exceptions. The re-treatment of the six wells appears to have been successful. Re-treatment also may be necessary in wells 199-D4-26 and 199-D4-37, where hexavalent chromium concentrations recently have increased to 200 and 220 μg/L, respectively.

- The hexavalent chromium plume inland of the ISRM treatment zone appears to have a seasonal component of flow to the northeast. This movement, as indicated by increasing hexavalent chromium concentrations in wells, is consistent with observations of variations in groundwater flow direction and gradient in wells undergoing long-term water-level monitoring associated with the ISRM activities.

Establishment of the ISRM treatment zone specified in the *Remedial Design Report and Remedial Action Work Plan for the 100-HR-3 Groundwater Operable Unit In Situ Redox Manipulation* (DOE/RL-99-51) is on schedule based on current knowledge of the plume and implementability of the treatment technology. Treatment of the remaining five Phase III treatment zone wells is scheduled for completion by June 30, 2003.

This page intentionally left blank.

CONTENTS

1.0 INTRODUCTION 1-1

1.1 PURPOSE 1-1

1.2 HISTORY OF OPERATIONS 1-2

1.3 REPORT ORGANIZATION 1-3

2.0 IN SITU REDOX MANIPULATION TECHNOLOGY OVERVIEW 2-1

3.0 TREATMENT ZONE ESTABLISHMENT 3-1

3.1 INSTALLATION OF WELLS 3-1

3.2 INTERPRETATION OF THE GEOLOGIC CONDITIONS OBSERVED DURING WELL DRILLING 3-1

3.3 DESIGN UPGRADES 3-3

3.4 SUMMARY OF FISCAL YEAR 2002 TREATMENT ZONE EMPLACEMENT ACTIVITIES 3-4

3.4.1 Treatment Zone (Barrier) Sampling and Analytical Activities 3-6

3.4.2 Treatment Zone Performance Results 3-7

3.4.3 Evaporation Pond Data Review 3-10

3.5 EXTRACTION WATER DISPOSITION 3-10

4.0 AQUIFER RESPONSE 4-1

4.1 MONITORING DURING ESTABLISHMENT OF THE TREATMENT ZONE 4-1

4.2 HYDRAULIC MONITORING 4-2

4.2.1 Groundwater Contours 4-2

4.2.2 Groundwater Flow Direction 4-3

4.3 CONTAMINANT MONITORING 4-5

4.3.1 Downgradient Compliance Monitoring Wells 4-6

4.3.2 Established Treatment Zone Monitoring 4-6

4.3.3 Sulfate and Other Reaction Byproducts 4-8

4.4 AQUIFER TUBES 4-9

5.0 QUALITY ASSURANCE/QUALITY CONTROL 5-1

5.1 CHROMIUM 5-1

5.2 SULFATE 5-2

6.0 100-D AND 100-DR AREAS IN SITU REDOX MANIPULATION COST DATA 6-1

7.0 MITIGATION PLAN IMPLEMENTATION 7-1

7.1 MITIGATION PLAN 7-1

7.2 2002 MITIGATION PLAN ACTIONS 7-2

7.2.1 Analysis of Treatment Zone Samples 7-2

7.2.2 Chemical Treatment 7-3

7.2.3 Barrier Monitoring Activities 7-3

8.0 CONCLUSIONS 8-1

9.0 RECOMMENDATIONS 9-1

10.0 REFERENCES 10-1

APPENDICES

A INJECTION DATA FOR WELL 199-D4-58 ..... A-i

B INJECTION DATA FOR WELL 199-D4-59 ..... B-i

C INJECTION DATA FOR WELL 199-D4-60 ..... C-i

D INJECTION DATA FOR WELL 199-D4-61 ..... D-i

E INJECTION DATA FOR WELL 199-D4-62 ..... E-i

F INJECTION DATA FOR WELL 199-D4-07 ..... F-i

G INJECTION DATA FOR WELL 199-D4-09 ..... G-i

H INJECTION DATA FOR WELL 199-D4-10 ..... H-i

I INJECTION DATA FOR WELL 199-D4-11 ..... I-i

J INJECTION DATA FOR WELL 199-D4-12 ..... J-i

K INJECTION DATA FOR WELL 199-D4-35 ..... K-i

L INJECTION DATA FOR WELL 199-D4-63 ..... L-i

M INJECTION DATA FOR WELL 199-D4-64 ..... M-i

N INJECTION DATA FOR WELL 199-D4-65 ..... N-i

0 INJECTION DATA FOR WELL 199-D4-66 ..... O-i

P INJECTION DATA FOR WELL 199-D4-67 ..... P-i

Q INJECTION DATA FOR WELL 199-D4-68 ..... Q-i

R INJECTION DATA FOR WELL 199-D4-69 ..... R-i

S INJECTION DATA FOR WELL 199-D4-70 ..... S-i

T INJECTION DATA FOR WELL 199-D4-71 ..... T-i

U INJECTION DATA FOR WELL 199-D4-72 ..... U-i

V INJECTION DATA FOR WELL 199-D4-73 ..... V-i

W INJECTION DATA FOR WELL 199-D4-74 ..... W-i

X INJECTION DATA FOR WELL 199-D4-75 ..... X-i

Y INJECTION DATA FOR WELL 199-D4-76 ..... Y-i

Z INJECTION DATA FOR WELL 199-D4-77 ..... Z-i

AA INJECTION DATA FOR WELL 199-D4-78 ..... AA-i

BB INJECTION DATA FOR WELL 199-D4-79 ..... BB-i

CC SPECIFIC METALS AND ANIONS ANALYZED IN 100-D AREA IN SITU REDOX MANIPULATION TREATMENT WELLS ..... CC-i

DD WATER LEVEL IN IN SITU REDOX MANIPULATION WELLS DURING INJECTION AND EXTRACTION ..... DD-i

EE HYDROGRAPHS OF MONITORING WELLS ..... EE-i

FF HEXAVALENT CHROMIUM TREND PLOTS OF MONITORING WELLS .....FF-i

GG GEOCHEMICAL AND PHYSICAL PROPERTY ANALYSIS OF SEDIMENT CORE SAMPLES COLLECTED FROM THE IN SITU REDOX MANIPULATION TREATABILITY TEST SITE ..... GG-i

FIGURES

Figure 1-1. In Situ Redox Manipulation Site Location Map. 1-4

Figure 2-1. Chromium Speciation Diagram..... 2-2

Figure 3-1. Current In Situ Redox Manipulation Treatment Zone Well Locations..... 3-11

Figure 3-2. Contour Map of Ringold Upper Mud Surface Elevation, 100-D Area. 3-13

Figure 3-3. Location of Geologic Cross Section in the Area of the In Situ Redox Manipulation Treatment Zone. 3-15

Figure 3-4. In Situ Redox Manipulation Treatment Zone Geologic Cross Section A-A. 3-17

Figure 3-5. Relative Screened Interval Elevations for the In Situ Redox Manipulation Wells. 3-19

Figure 3-6. Schematic of the 100-D Area In Situ Redox Manipulation Liquid Injection/Extraction System. 3-21

Figure 4-1. Comparison of Seasonal Water-Level Fluctuations in Five Wells at the In Situ Redox Manipulation Site. 4-10

Figure 4-2. 100-D Area Water Table Map, Spring 2002. 4-12

Figure 4-3. 100-D Area Water Table Map, Fall 2002. 4-13

Figure 4-4. Layout of Three-Point Solution. 4-15

Figure 4-5. Flow Direction Variations, In Situ Redox Manipulation and 100-D Area, Fiscal Year 2002. 4-17

Figure 4-6. In Situ Redox Manipulation Hexavalent Chromium Plume Map, Fall 2001..... 4-19

Figure 4-7. In Situ Redox Manipulation Hexavalent Chromium Plume Map, Fall 2002..... 4-21

Figure 4-8. In Situ Redox Manipulation Sulfate Plume, Fall 2001. 4-23

Figure 4-9. In Situ Redox Manipulation Sulfate Plume, Fall 2002. 4-25

Figure 6-1. Cost Breakdown for 100-D Area In Situ Redox Manipulation Operations, Fiscal Year 2002. 6-2

Figure 7-1. Hexavalent Chromium in Wells 199-D4-5, 199-D4-7, and 199-D4-23. 7-4

TABLES

Table 3-1. In Situ Redox Manipulation Phase III Treatment Zone Well Construction Summary, Fiscal Year 2002. 3-23

Table 3-2. In Situ Redox Manipulation Phase III Well Completion Summary for Fiscal Year 2002 Wells. 3-24

Table 3-3. Stratigraphic Summary of Wells Drilled in Fiscal Year 2002. 3-26

Table 3-4. In Situ Redox Manipulation Wells Treated and Sampled in Fiscal Year 2002 3-27

Table 3-5. Summary of Fiscal Year 2002 Trace Metals, Anion, Uranium, and Sulfate Concentrations. 3-28

Table 3-6. Summary of Fiscal Year 2002 Evaporation Pond Results. 3-29

Table 4-1. Summary of Observations of Water-Level Effects During In Situ Redox Manipulation Injection. 4-27

Table 4-2. Summary of Observations of Chemical Effects During In Situ Redox Manipulation Injection and Extraction. 4-29

Table 4-3. Comparison of 2001 and 2002 Semiannual Water-Level Measurements at 100-D Area. 4-31

Table 4-4. Hexavalent Chromium Concentrations in In Situ Redox Manipulation Monitoring and Compliance Wells. 4-33

Table 4-5. Fiscal Year 2002 In Situ Redox Manipulation Treatment Zone Operational Sampling Hexavalent Chromium Results. 4-35

Table 4-6. Sulfate Concentrations in In Situ Redox Manipulation Monitoring and Compliance Monitoring Wells. 4-37

Table 4-7. Summary of Hexavalent Chromium and Sulfate in Aquifer Tubes Downgradient of the In Situ Redox Manipulation Treatment Zone. 4-39

Table 5-1. Fiscal Year 2001 Quality Control Sample Analyses for Hexavalent Chromium in 100-D Area Wells 5-3

Table 5-2. Fiscal Year 2002 Quality Control Sample Analyses for Sulfate 100-D Area Wells..... 5-5

Table 6-1. 100-D Area In Situ Redox Manipulation Operating Cost Breakdown..... 6-2

TERMS

BCC	bentonite chip
bgs	below ground surface
BP	bentonite pellet
DO	dissolved oxygen
DWS	40 CFR 141, "National Primary Drinking Water Standards"
Eh	reduction/oxidation potential
FY	fiscal year
HEIS	*Hanford Environmental Information System*
ID	identification
ISRM	in situ redox manipulation
N/A	not applicable
n/a	not available
NAVD88	*North American Vertical Datum of 1988*
OU	operable unit
RAO	remedial action objective
RCRA	*Resource Conservation and Recovery Act of 1976*
RDR/RAWP	remedial design report/remedial action work plan (DOE/RL-99-51)
redox	reduction-oxidation
ROD	record of decision (see EPA et al. 1996)
ROD Amendment	see EPA et al. 1999
RPD	relative percent difference
RUM	Ringold Upper Mud (unit)
SDWS	40 CFR 143, "National Secondary Drinking Water Standards"
TZ	treatment zone
UNK	unknown
WE	welded end

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	0.0836	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	millibecquerel	0.027	picocuries

1.0 INTRODUCTION

This annual progress and performance report discusses the In Situ Redox (reduction-oxidation) Manipulation (ISRM) interim remedial action at the 100-HR-3 Operable Unit (OU) from October 1, 2001, through September 30, 2002. The OU is located in the 100-D and 100-H Areas of the Hanford Site. This report specifically addresses actions performed at the hexavalent chromium plume in the southwest portion of the 100-D Area (Figure 1-1). Interim pump-and-treat remedial actions performed at the northeast portion of the 100-D and 100-H Areas will be discussed in a separate annual summary report. This is the third annual summary report that specifically addresses the ISRM remediation technology presently being installed in this portion of the 100-D Area, as specified in *Remedial Design Report and Remedial Action Work Plan for the 100-HR-3 Groundwater Operable Unit In Situ Redox Manipulation* (RDR/RAWP, DOE/RL-99-51).

The ISRM technology involves creating a permeable subsurface treatment zone by injecting sodium dithionite into the aquifer, which creates a chemically reduced environment. Unreacted sodium dithionite and reduction reaction byproducts then are extracted from the aquifer. 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) (ROD Amendment). Following are the remedial action objectives (RAO) 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 is designed to achieve key design elements described in the RDR/RAWP (DOE/RL-99-51).

1.1 PURPOSE

The purpose of this annual report is to support the following information needs:

- Document the treatment zone construction progress
- Document the progress toward achieving key design elements specified in the RDR/RAWP (DOE/RL-99-51)

- Document the groundwater remediation system performance and status
- Document the 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 north-central part of the Hanford Site along the Columbia River. This OU includes groundwater underlying source OUs associated with the D/DR and H Reactor areas and the property between the two areas. During operation of the D/DR Reactors from 1944 to 1967, large volumes of water were pumped from the Columbia River to cool the reactors. Sodium dichromate, which was added to the cooling water to inhibit corrosion of the reactor piping, leaked into the soil and contaminated the groundwater.

An ISRM treatability test was conducted in the 100-D Area, and the first ISRM treatment took place in well 199-D4-7 in September 1997. Four additional wells were treated from May through July 1998. The five treated wells created a reducing zone in the unconfined aquifer that was approximately 46 m long by 15 m wide.

In the fall of 1999, the treatment zone in the treatability test area was extended by the treatment of a sixth well (199-D4-21), which resulted in hexavalent chromium concentrations being reduced from 1,050 µg/L to below detection in that well. The treatment zone emplacement activities at the sixth well provided additional data that allowed for proceeding from treatability testing to large-scale treatment zone construction.

ISRM was identified in the ROD Amendment as the selected alternative for hexavalent chromium treatment in the newly defined groundwater plume southwest of the 100-D/DR Reactor area. This alternative is different than the selected remedial action of pump-treat-reinjection activities specified in EPA et al. (1996) for the 100-HR-3 OU. The ROD Amendment deferred the details of the full-scale design of the treatment zone to the RDR/RAWP (DOE/RL-99-51). 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 fiscal years (FY) 2000, 2001, and 2002. The ISRM treatment zone is being constructed outward from the center of the most contaminated portion of the groundwater plume near the Columbia River shoreline. The treatment zone will be expanded until the edge of the 20 µg/L hexavalent chromium groundwater plume has been reached, as identified in the RDR/RAWP.

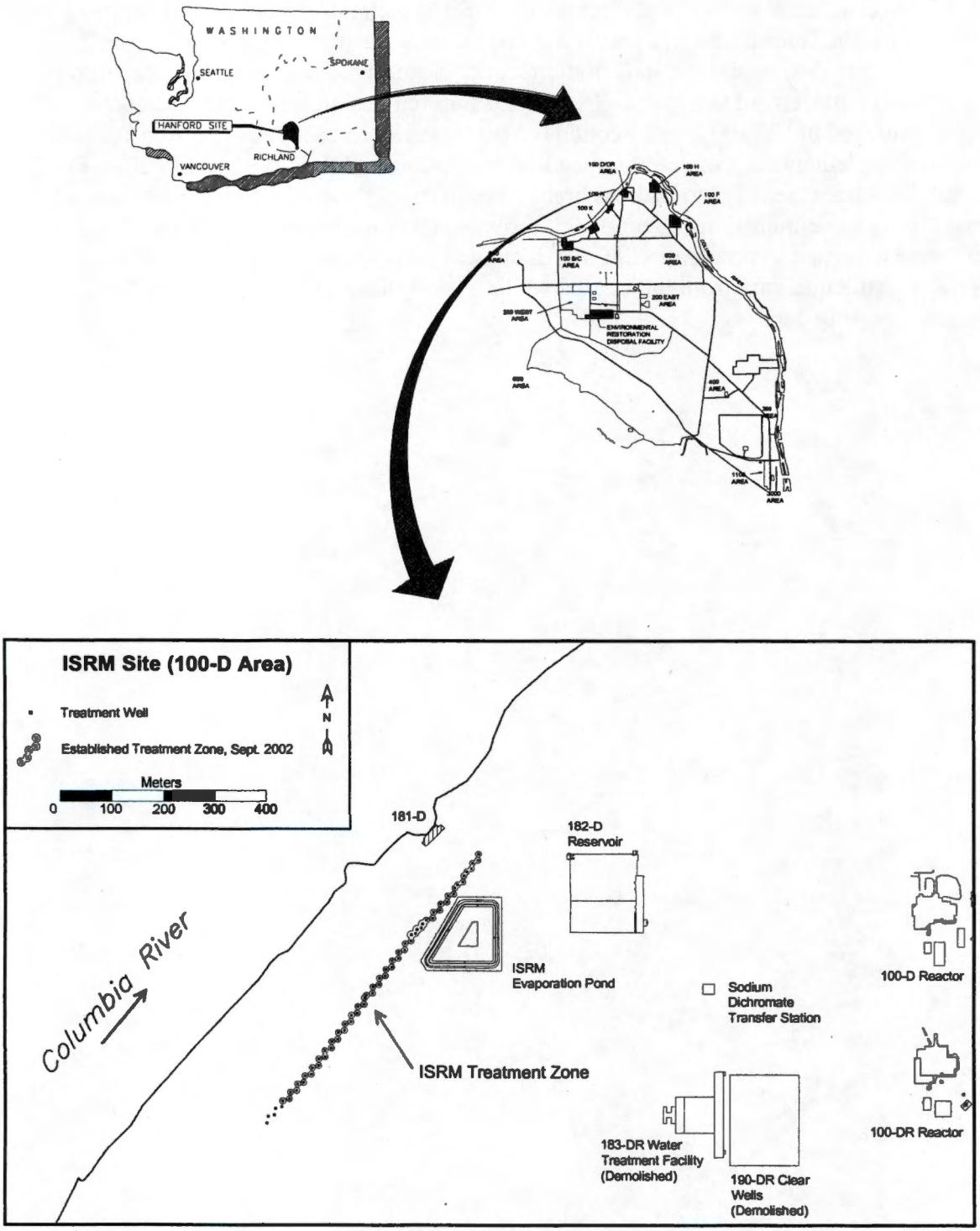
In FY 2000, Phase I of the large-scale deployment of the ISRM technology was initiated. Sixteen wells were installed (2 compliance wells and 14 treatment zone wells), and chemical treatment was performed in 10 wells. Treatment of the 10 wells extended the existing ISRM treatment zone 60 m to the northeast and 60 m to the southwest.

In FY 2001, Phase II well construction and treatment zone emplacement activities began. Thirty-two wells were installed (4 compliance wells and 28 treatment zone wells). Chemical treatment was performed in 28 wells. The 28 treatment wells extend the ISRM treatment zone to 195 m.

1.3 REPORT ORGANIZATION

Specific results from FY 2002 ISRM treatment zone construction and monitoring activities are summarized in this document, which consists of nine sections. Section 1.0 is the introduction. Section 2.0 provides an overview and discussion of ISRM technology and its development and demonstration at the Hanford Site. Section 3.0 summarizes treatment zone emplacement activities, including design and implementation work. Section 4.0 discusses aquifer response to treatment zone emplacement activities. Section 5.0 summarizes quality assurance/quality control of samples analyzed in FY 2002, and Section 6.0 presents ISRM cost data. Section 7.0 is a discussion of implementation of actions specified by Option 3 of the "ISRM Mitigation Plan" (CCN 091481, Attachment 1) , to address breakthrough in sections of the ISRM barrier. Section 8.0 provides conclusions. Section 9.0 provides recommendations. Section 10.0 provides a list of references used in preparation of this document. Appendices A through BB contain injection and extraction data from the treated wells. Appendices CC through GG contain additional supporting data.

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



2.0 IN SITU REDOX MANIPULATION TECHNOLOGY OVERVIEW

A plume of dissolved hexavalent chromium in the groundwater was discovered in 1995 along the Columbia River shoreline to the west of the D/DR Reactors in the 100-D Area during groundwater characterization activities. The source of the observed hexavalent chromium contamination is believed to be sodium dichromate.

($Na_2Cr_2O_7 \cdot 2H_2O$) that was previously used for corrosion control in reactor cooling water. Either chemical stock material or concentrated sodium dichromate solutions may have been released near the historical 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 has not been identified.

The ISRM technology creates a chemically reduced permeable treatment zone that removes hexavalent chromium from the groundwater. Hexavalent chromium is reduced to less mobile and less toxic trivalent chromium within the treatment zone.

The treatment zone within the aquifer is created by injecting a solution of sodium dithionite ($Na_2S_2O_4$) into the aquifer through a series of groundwater wells. 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 are effected in a groundwater system during the ISRM treatment process. In addition, numerous oxidation reactions occur on a continuous basis following the establishment of the treatment zone. The principal reaction understood to provide the residual reduction capacity to treat chromate ions flowing through the treatment zone is reduction of ferric iron (Fe^{+3}) to ferrous iron (Fe^{+2}). After the reduction treatment, ferrous iron is present in two forms, dissolved ferrous iron in solution in the groundwater and structural ferrous iron associated with the geologic material forming the aquifer matrix. Dissolved ferrous iron will migrate downgradient with the groundwater flow, while structural ferrous iron will provide a residual reduction capacity that can react with the hexavalent chromium in the incoming groundwater.

Chromium is removed from groundwater as it flows into and through the treatment zone at the natural groundwater velocity. As the dissolved hexavalent chromium (in the form of the water-soluble chromate ion, CrO_4^{-2}) in the aquifer enters the reducing environment, it will react with the ferrous iron in the treatment zone and will be 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, which both have very low solubility in water and are less toxic than hexavalent chromium at typical groundwater pH and reduction/oxidation potential (Eh) conditions. A diagram showing the chemical speciation of chromium at varying Eh/pH conditions is shown in Figure 2-1. As the treatment zone ultimately becomes reoxidized 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 reoxidation of trivalent chromium may be facilitated by the presence

of manganese oxide in the water; however, it is anticipated that the hexavalent chromium concentrations will remain below levels of concern following complete treatment of the plume.

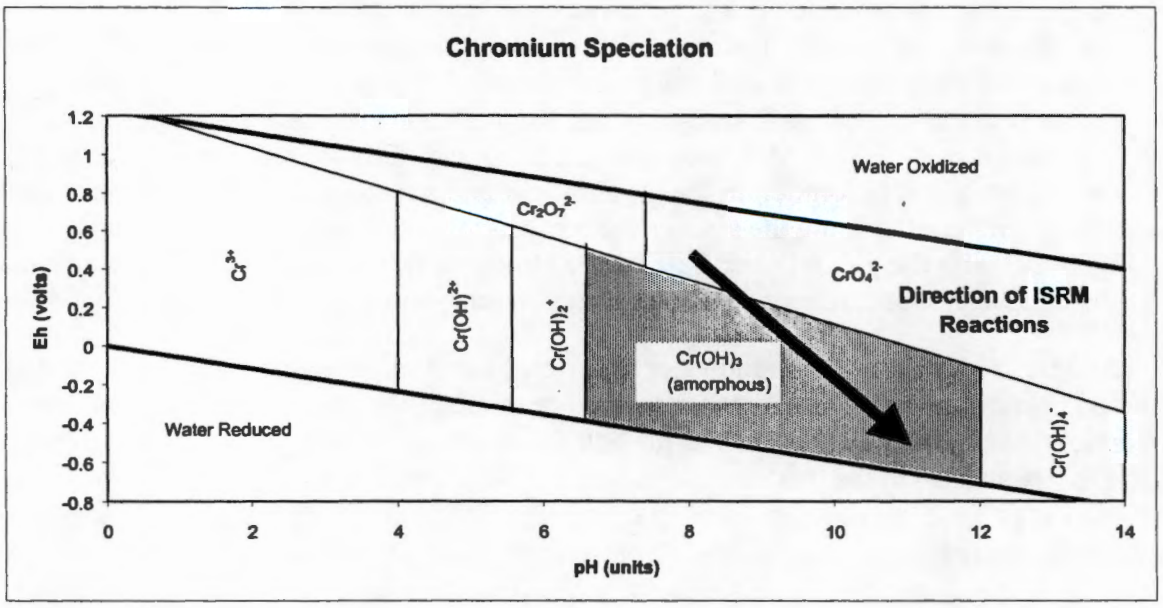
The results of the ISRM technology evaluation were updated in *100-D Area In Situ Redox Treatability Test for Chromate-Contaminated Groundwater, September 2000* (PNNL-13349). The year-end report provided additional information regarding the feasibility and apparent effectiveness of the ISRM technology.

The longevity of the treatment zone's capacity to reduce hexavalent chromium within the aquifer (estimated at 23 years +/- 15) is a function of the combined effects of chemical and physical characteristics of the aquifer, including the following aspects:

- The quantity and distribution of residual structural ferrous iron within the aquifer matrix following the treatment process
- The flow rate of untreated groundwater into, and through, the treatment zone
- The concentration of oxidizing constituents in the incoming groundwater (e.g., dissolved oxygen, nitrate, and hexavalent chromium).

Figure 2-1. Chromium Speciation Diagram.

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



3.0 TREATMENT ZONE ESTABLISHMENT

The ISRM treatment zone was extended to the west during FY 2002. The process to establish the treatment zone included drilling and constructing wells screened across the target aquifer and subsequent injection, reaction, and extraction of the sodium dithionite reductant solution. The activities related to the treatment zone establishment in FY 2002 are discussed in the following sections.

3.1 INSTALLATION OF WELLS

During FY 2002, 17 ISRM treatment wells and 3 characterization boreholes/small diameter monitoring wells were drilled. Figure 3-1 shows the location of wells and other features of the ISRM site. A complete description of drilling methods, well design, and well development can be found in the *ISRM Barrier Well Completion Report for the 100-HR-3 Groundwater Operable Unit, Fiscal Year 2002* (BHI-01638).

The well drilling and construction activities were completed during the first and second quarters of FY 2002. Table 3-1 summarizes the wells drilled during FY 2002. Table 3-2 summarizes the well completion data for the Phase III wells.

The 17 treatment wells were drilled using cable tool methods. The three characterization/small diameter monitoring wells were drilled using resonant sonic methods to minimize potential reoxidation of the treatment zone. Cores were collected using anoxic methods. Samples of the core were collected for analysis by Pacific Northwest National Laboratory to assess the geochemical and physical properties of the aquifer in the ISRM treatability test area. The sampling and analyses were part of the "ISRM Mitigation Plan" (CCN 091481, Attachment 1) activities for FY 2002.

3.2 INTERPRETATION OF THE GEOLOGIC CONDITIONS OBSERVED DURING WELL DRILLING

Information from well logs compiled during the FY 2002 Phase III drilling includes stratigraphic data, particle size, color, cementation characteristics, depth to groundwater, and other subsurface conditions along the axis of the ISRM treatment zone. A complete presentation of the geology encountered in the Phase III drilling is presented in the *ISRM Barrier Well Completion Report for the 100-HR-3 Groundwater Operable Unit, Fiscal Year 2002* (BHI-01638).

Backfill material from construction work in the area (i.e., gravel and sandy gravel) was encountered at most of the well sites and ranged from 0.5 to 3 ft (0.2 to 0.9 m) in thickness. Stratigraphic units in the ISRM area are the Hanford formation (informal), the Ringold Unit E, and the Ringold Upper Mud (RUM) unit. These units were encountered in all of the Phase III wells except one. At well 199-D4-88, drilling was stopped at the request of the subcontractor technical representative before the RUM was encountered, because it was thought to be missing or at greater than anticipated depth. The RUM is the drilling target horizon for the ISRM project because it effectively forms the lower boundary of the contaminated aquifer being treated.

Table 3-3 includes stratigraphic data, depth to water, and calculated aquifer thickness from the Phase III wells.

The Hanford formation ranges in thickness from 57 to 66.6 ft (17.4 to 20.3 m) in the Phase III wells. It consists of clast-supported unconsolidated gravel, silty-sandy gravel, gravelly sands, and sands deposited by the Pleistocene and Missoula floods. Occasional sand lenses and silt stringers are intercalated with the gravel. Caliche was occasionally observed on the gravel. The Hanford formation is moderately to very poorly sorted. Basalt constitutes 50 to 90 percent of the coarser sediments (e.g., pebbles, gravel, cobbles); the remaining coarse sediments are granitics, felsics, and various metamorphics. Hanford formation sand fractions are high in basalt content, and feldspar, quartz, and traces of mica also are present. Caliche sometimes is found in the gravels and is believed to be associated with the probable historic high groundwater level.

Directly and unconformably underlying the Hanford formation in this area is the Ringold Unit E. The Ringold Unit E ranges in thickness from 32 to 54 ft (9.8 to 16.5 m) in the Phase III wells. In the eastern part of the treatment barrier (i.e., the treatability test area) it is 32 to 32.2 ft (9.8 to 9.9 m) thick in the two wells where the RUM was encountered. In the 17 Phase III wells at the western end of the treatment barrier, the Ringold Unit E ranges in thickness from 45.4 to 54 ft (13.8 to 16.5 m) and generally increases in thickness toward the west. This unit consists of fluvial deposits (i.e., sediments deposited by the action of a stream or river, chiefly gravel with minor silt and sand). Basalt typically constitutes 20 to 45 percent of the gravel fraction, with the remaining 55 to 80 percent of the fraction being granitics, felsics, and various metamorphics. Micaceous sand lenses occasionally are encountered. The calcium carbonate content of the unit varies substantially. A significant zone of calcium carbonate-enriched sediment (caliche) occurs in the silty sandy gravel of the Ringold Unit E in all 17 of the Phase III wells at the western end of the treatment barrier. The calcium carbonate-enriched zone occurs above and occasionally into the water table, generally at elevations between 119.5 and 123.5 m *North American Vertical Datum of 1988* (NAVD88). No significant caliche zones occur in the three Phase III wells drilled in the treatability test area.

In the 17 Phase III wells at the western end of the treatment barrier, the contact between the Ringold Unit E and the RUM gently slopes to the west. The RUM is a silt- and clay-rich unit that was formed by paleosol and overbank depositional processes. A nonplastic to moderately plastic, usually noncalcareous, massive silt or clay characterizes the RUM in the Phase III wells. The upper part of the layer generally contains gravel in a silt/clay matrix that may represent a transition zone to the massive silt or clay. During drilling, the RUM was penetrated a minimum of 0.2 ft (0.06 m). Because the drilling was terminated after the RUM was entered, the total unit thickness of the RUM is unknown.

Observations made during drilling of the FY 2002 ISRM wells show that the surface of the RUM is encountered substantially deeper in the western portion of the ISRM treatment zone (i.e., west of well 199-D4-61). The average thickness of the unconfined aquifer in the western part of the treatment zone is 29.8 ft (9.1 m), almost twice the 15.8 ft (4.8 m) average thickness in the eastern part of the treatment zone. The thickness of the unconfined aquifer is defined by the distance between an average water table elevation of 118.25 m and the surface of the RUM. The close spacing of the ISRM wells along a single axis provides a high-resolution picture of the undulant surface of the RUM within the treatment zone. Figure 3-2 is a contour map of the RUM surface

elevation for the 100-D Area, based on elevations calculated from geologic contacts recorded in well logs. The contours were generated with Surfer8[1] software that used the nearest neighbor contouring technique. The contours suggest the presence of a paleochannel oriented southeast from the Columbia River that intersects the western end of the treatment zone at 199-D4-62. Inland, the axis of the channel turns more to the north as suggested by wells 199-2-6, 199-D5-43, 199-D5-42, and 199-D5-13.

The historical Columbia River drainage was dramatically impacted by catastrophic events that include the Bonneville and Missoula floods at the end of the last period of continental glaciation. The floods reworked preexisting Columbia River channel systems, which in turn deposited the sediments found at the Hanford Site that are known as the Hanford formation. A plan view map depicting a geologic cross-section surface trace is presented in Figure 3-3. A cross section of the ISRM treatment zone and nearby wells, indicating the water-level elevation and RUM surface elevation, is shown in Figure 3-4. Figure 3-5 shows the screen intervals, top of RUM elevations, and the FY 2002 average and minimum water level elevations for the ISRM treatment zone wells.

In the 100 Areas of the Hanford Site, past locations of Columbia River channels are indicated by cut-and-fill structures exhumed in sand and gravel pits and by large-scale ripple marks on the surface. Channels have been identified over the past few years that cut through or pass in the immediate vicinity of the ISRM site. The subsurface geologic units and the nature and topography of their contacts and interfaces directly reflect changes in those river courses.

3.3 DESIGN UPGRADES

A number of upgrades were implemented in FY 2002 to improve performance and reliability of the ISRM treatment injection, extraction, and monitoring system. A schematic of the ISRM treatment system is shown in Figure 3-6. The following design upgrades were completed in FY 2002:

- Modified the sampling manifold to relocate the DO and pH/Eh probes, installed an air release valve, and replaced the rotameters with turbine-type digital flowmeter/totalizers
- Changed the maximum range of the fresh water flowmeter from 265 L/min (70 gal/min) to 379 L/min (100 gal/min) to allow higher fresh water flow rates
- Increased the diameter of the injection and fresh water flex hoses from 2 to 3 in. to allow higher flow rates
- Increased the length of all four injection piping well sets to 30 m (100 ft) below the top of the casing
- Completed major electrical system modifications that are described in *Exhibit D, Scope of Work 100-D In-Situ Redox Electrical Power Upgrades* (BHI 2002).

---

[1]Surfer8 is a trademark of Golden Software, Inc., Golden Colorado.

Overall, each of these design upgrades was successful in improving system reliability and performance.

To facilitate timely completion of the treatment zone establishment, permission was granted by the Washington State Department of Ecology to reduce the number of pore volumes extracted under certain conditions. For any individual well with a sustainable extraction rate of less than 50 percent of the nominal design rate of 57 L/min (15 gal/min), only four volumes will be removed from the well instead of the design five volumes. For those wells with extraction rates less than 25 percent of nominal design rate, only three pore volumes will be removed from the well. During FY 2001, seven wells were subject to reduced extraction volumes. In FY 2002, five wells were subject to reduced extraction volumes.

The ROD Amendment states that 75 percent of the sulfate is removed in the first pore volume extracted. The results of the extraction water sampling performed during a number of extractions support this assumption. The extraction water sampling results also indicate that limited sulfate is present in the fourth and fifth pore volume removed during the extraction process. In FY 2001, sulfate data were available for evaluation from seven extraction events. The sulfate data indicated that approximately 94 percent of the average total sulfate is removed in the first three pore volumes extracted per well. The FY 2001 data also indicated that approximately 6 percent of the total average sulfate is removed in the last two pore volumes extracted. The presence of sulfate in groundwater downgradient of treated wells indicates that the extraction phase does not succeed in removing 100 percent of the sulfate.

3.4 SUMMARY OF FISCAL YEAR 2002 TREATMENT ZONE EMPLACEMENT ACTIVITIES

In FY 2002 Phase III activities, 20 wells were installed in the treatment zone, 17 injection/ extraction wells and 3 small-diameter monitoring wells. The FY 2002 wells will extended the ISRM barrier to a total length of 680 m (2,231 ft) when all the wells are treated. Twenty-three wells were chemically treated to extend or reestablish the treatment zone. Seventeen wells were treated to extend the existing treatment zone to the west, while six ISRM wells were chemically treated a second time to reestablish the ISRM treatment zone. In addition, the extraction process for nine wells treated in FY 2001 was completed in FY 2002. Five of the wells installed in FY 2002 will be chemically treated to complete the western extent of the treatment zone during FY 2003 Phase III activities.

The following is a description of the Phase II and III ISRM treatment zone emplacement activities that occurred from October 1, 2001, through September 30, 2002. Table 3-4 summarizes start and completion dates for the injections and extractions performed in FY 2002.

The changing aquifer conditions required modification of the treatment process as the treatment zone was extended to the west; specifically, an increased aquifer thickness in the wells on the western end of the treatment zone required an additional volume of treatment chemicals to establish the zone. The expected volume for wells in the western end of the treatment zone was estimated to be nearly double that required in wells in the eastern part of the treatment zone.

Well-specific injection volumes were adjusted based on field conditions and were reduced significantly in one case, at well 199-D4-63. Injection for well 199-D4-64 occurred in March 2002 and significant groundwater mounding occurred during the injection, although the predicted volume was injected. Discussions occurred after this injection between Pacific Northwest National Laboratory; the U.S. Department of Energy, Richland Operations Office; and the Environmental Restoration Contractor regarding significant mounding in the well and lower-than-expected injection flow rates. It was agreed that during future injections where similar conditions were observed and that would not meet the design specifications, an evaluation would be performed to determine the best approach on how to modify operations. During the June 2002 injection at well 199-D4-63, it became apparent that this well also would have significant mounding and reduced injection flow rates. The Pacific Northwest National Laboratory and the U.S. Department of Energy, Richland Operations Office, were consulted and the injection volume was reduced to a single tanker. The injection of chemicals from the usual second tanker for this well was cancelled.

As noted above, the increased aquifer thickness in the western part of the treatment zone was not accompanied by an increase in specific capacity at all well locations. Stratigraphic analysis of the well logs reveals a sharp drop (2 m) in the elevation of the surface of the RUM unit between wells 199-D4-61 and 199-D4-62 (see Figures 3-4 and 3-5). Wells located in the thinner portion of the aquifer immediately to the east of the apparent paleochannel exhibited very low sustained pumping rates. Well 199-D4-62, while exhibiting a substantially thicker aquifer section, had a sustained pumping rate of less than 37.9 L/min (10 gal/min). The aquifer in wells 199-D4-63 and 199-D4-64 also permitted low flow rates during injection, 72.3 and 66.6 L/min (19.1 and 17.6 gal/min), respectively, and consequently the reaction phase of treatment was not attempted at well 199-D4-63. As expected, the Phase III wells located to the west of well 199-D4-64 exhibited increased specific capacity and correspondingly higher sustained pumping rates.

Each treatment zone well was established using a four-phase approach, which is briefly described as follows.

- Injection phase: Concentrated sodium dithionite solution from a chemical tanker and dilution water is mixed and injected into a process well. Approximately 19,000 to 41,000 L of a concentrated sodium dithionite solution (0.6 M), and 87,000 to 265,000 L of water were mixed and injected into each barrier well. The concentration of the injected sodium dithionite solution is 0.09 M. The injection phase typically lasts 15 hours at an average injection rate of about 170 to 340 L/min.

- Postinjection push phase: After the injection phase, approximately 1,360 to 1,800 L of a low-concentration sodium dithionite solution is mixed with 5,400 to 10,800 L of dilution water to produce a 0.001 m solution injected into each barrier well. The postinjection phase is intended to flush dithionite solution from the injection mound and to "push" the sodium dithionite solution further into the aquifer. The postinjection push phase lasts approximately 2 hours.

- Reaction phase: During this phase, the sodium dithionite is given additional time to react with the groundwater and aquifer sediments. The reaction develops an environment

capable of reducing hexavalent chromium to trivalent chromium through a reaction with the aquifer sediments. The reaction phase lasts approximately 36 to 48 hours.

- Extraction phase: The extraction phase is required to remove the majority of the remaining sodium dithionite solution and reaction byproducts from the aquifer. The duration of the extraction phase is dependent on the yield of the well.

Throughout the entire process, the water level in the injection well is monitored and groundwater samples are analyzed in a mobile process trailer. In general, groundwater samples also are analyzed from the two wells adjacent to the process well (Table 3-4). Argon gas is used during all phases of the treatment zone emplacement process to maintain an oxygen-free atmosphere within the well, to prevent degradation of the sodium dithionite solution. Argon gas also is added to the chemical tanker for the same reason.

3.4.1 Treatment Zone (Barrier) Sampling and Analytical Activities

This section summarizes treatment zone (barrier) sampling and analytical activities that occurred from October 1, 2001, through September 30, 2002. Table 3-4 references the start and completion dates for the 23 injections and 32 extractions performed in FY 2002 and the sampling performed on each well. Of the 23 injections completed, 17 wells were treated for the first time, while 6 were re-treated. Of the 32 extractions completed in FY 2002, 9 were started in FY 2001 and finished in the first quarter of FY 2002, 20 were started and completed in FY 2002, and 3 were started in FY 2002 and completed in the first quarter of FY 2003.

For the barrier wells treated (injected) and sampled in FY 2002, results indicate that all hexavalent chromium concentrations are less than 20 μg/L. The potential exceptions to these are the 199-D4-35 posttreatment laboratory result and the 199-D4-7 posttreatment field parameter result, which will be discussed later in this section. To date, 61 barrier wells have been treated and 6 have been re-treated. The six wells were re-treated because they consistently exceeded 20 μg/L for hexavalent chromium, as shown through performance monitoring. It should be noted that the RAO is 20 μg/L at the compliance monitoring wells, not at the treatment zone wells.

During each injection, samples were collected from the well being treated and its two adjacent wells. Adjacent wells (summarized in Table 3-4) typically are located approximately 11 m on either side of the treated well. The exception to this is the central barrier wells (199-D4-7, 199-D4-9, 199-D4-10, 199-D4-11, and 199-D4-12), in which the adjacent wells are typically 8.7 m from the treated well. Sampling was done before the start of an injection (baseline), during an injection, and after an extraction was completed (posttreatment). Monitoring was not performed during either the reaction stage (because it is not critical in determining barrier emplacement performance) or the extraction stage (because previous results have defined consistent patterns).

Samples were collected from the main well in an effort to evaluate the effectiveness of the injection, while samples from the adjacent wells were collected to help determine the extent of reduced aquifer zone emplacement for each barrier well. In addition, samples were collected

from the evaporation pond to confirm that pond design and operational requirements were being achieved.

3.4.2 Treatment Zone Performance Results

As summarized in Tables 3-4 and 3-5, field parameter and laboratory samples were analyzed for all stages except the reaction stage. Specific field parameters measured were pH, Eh, DO, specific conductance (conductivity), hexavalent chromium concentration, and dithionite concentration. Laboratory samples were analyzed off-site for trace metals, anions, uranium, sulfur, and sulfate. Results of these sampling efforts are discussed in the following subsections. In addition, laboratory results from the evaporation pond are summarized in Table 3-6. All field parameter and laboratory results were compared to 40 CFR 141, "National Primary Drinking Water Standards," (DWS) and 40 CFR 143, "National Secondary Drinking Water Standards" (SDWS).

3.4.2.1 Field Parameter Results

Field parameter samples were analyzed for each well treated (Table 3-4). Field parameter analyses provided real-time information to determine if the treatment zone at the injected well was being effectively established, identify any potential technical issues, and allow personnel the ability to adjust flow rates and injection duration as needed. To mitigate the potential for future water quality concerns, all field parameter results were later compared to the DWS. Results for the treated and adjacent wells are summarized in Appendices A through BB and discussed below.

pH. The pH values during injections ranged from 10.88 to 11.42 for the 23 wells treated in FY 2002, which is expected with a buffered sodium dithionite solution. The solution is buffered with potassium carbonate to decrease the degradation rate of the sodium dithionite. The posttreatment values ranged from 8.55 to 10.06, which was an increase from baseline values of 7.49 to 9.70. High baseline values were experienced during the reinjections in some wells, because of to previous injections in nearby wells. Although many of the samples analyzed exceeded the SDWS pH of 8.5, it is anticipated that these values will return to normal baseline conditions of 7.80 to 8.00 after the buffering capacity is reduced.

Oxidation-Reduction Potential. Oxidation-reduction potential indicating transmitters are part of the ISRM liquid injection/extraction system instrumentation. Measured oxidation-reduction potential values (mV) are converted to Eh and are used to assess the aquifer environment. The more negative the Eh value, the more strongly reducing the environment. The values collected during the injections were negative, ranging from approximately –256 mV to –813 mV for the 23 wells treated. Posttreatment Eh measurements ranged from –504 mV to +801 mV.

Specific Conductance. Values collected during the injections ranged from 47 to 71 mS/cm for the treated wells. This value is expected from a typical sodium dithionite solution, because sulfates and potassium carbonate increase the conductivity. During the last few injections, the conductivity typically increases, because the probe becomes coated with potassium carbonate. As the carbonate buildup increases, the probe becomes harder to clean, which results in higher

and inaccurate conductivity values. This pattern is consistent with past results and typically is resolved by installing a new probe.

The posttreatment conductivity values ranged from 0.73 to 32.0 mS/cm, with the majority around 1.0-5.0. Baseline conditions ranged from 0.22 to 20.30 mS/cm with the majority around 1.0. The highest values occurred in treated well 199-D4-7 and adjacent wells 199-D4-8 and 199-D4-9; the conductivities were 25.9, 32, and 12.39 mS/cm, respectively.

Dissolved Oxygen. Samples analyzed during the injections were all non-detect, which indicates that a reducing environment is being established for a treatment zone. Posttreatment DO values from the barrier wells ranged from non-detect to 0.25 mg/L, with the majority being non-detect. Air entrained in the process line is the probable cause for the posttreatment values exceeding detection limits. This was confirmed by the observation that all field parameter values correlating to these DO values were normal.

Dithionite. Values collected during the injections ranged from 0.0796 to 0.1005 moles/L for the wells treated, with the majority around 0.09 moles/L. These values are as expected and meet documented design criteria.

Hexavalent Chromium. When a reducing condition is established after chemical treatment, hexavalent chromium is reduced to trivalent chromium, and concentrations of hexavalent chromium are expected to drop below detection. Posttreatment values, sampled from the barrier, ranged from non-detect to 0.03 mg/L with the majority being non-detect. The only exception was the well 199-D4-7 posttreatment value of 0.03 mg/L. Because the well 199-D4-7 posttreatment laboratory results were 0.0088 mg/L for total chromium, and subsequent sampling indicated less than 0.01 mg/L of hexavalent chromium, the 0.03 mg/L is being attributed to calibration and/or sampling errors.

3.4.2.2 Laboratory Analyses

Laboratory Data Review. Laboratory samples were analyzed for eight wells listed in Table 3-4. Specific analyses were for trace metals, anions, uranium, sulfur, and sulfate. Laboratory results help define the extent to which groundwater was affected during treatment activities. By comparing the results to DWS and SDWS, potential water quality issues can be identified. The results of laboratory samples are summarized in Table 3-5, with the raw data available in Appendix CC.

Trace Metals. Overall, with only a few exceptions, the range of concentrations for each trace metal was well below the regulatory DWS. The exceptions are reviewed below and focus only on posttreatment values. Although a few baseline concentrations exceeded DWS, it is primarily the barrier zone posttreatment concentrations that alert personnel to potential water quality concerns.

For total chromium, only the well 199-D4-35 value of 172 μg/L exceeded the primary DWS of 100 μg/L and the RAO of 20 μg/L. Results from the other seven wells were below the DWS and RAO. A total chromium analysis includes all chromium species in a sample (i.e., trivalent and hexavalent chromium). Because the ISRM process converts hexavalent chromium to trivalent, it

is believed that the 172 μg/L represents trivalent chromium attributed to particulate matter in the sample. The sample was not filtered. The filtered hexavalent chromium value from the field parameter analysis was non-detect at 0.0 μg/L. This also is consistent with the baseline value for well 199-D4-35, which had 70 μg/L total chromium versus non-detect for field parameter hexavalent chromium. This is confirmed by posttreatment and quarterly sampling, which each resulted in hexavalent chromium concentrations of 0 mg/L.

For arsenic, only the well 199-D4-7 value of 80.1 μg/L exceeded the DWS of 50 μg/L. The arsenic results for the other seven wells were well below 50 μg/L. For manganese, with the exception of well 199-D4-57, all concentrations exceeded the SDWS of 50 μg/L. For iron, with the exception of wells 199-D4-35 and 199-D4-74, all concentrations exceeded the SDWS of 300 μg/L.

Although it is expected that some trace metal concentrations in the treatment zone will increase as a result of the injection, because they become mobilized in a reduced environment, it is also expected that the posttreatment concentrations should be below the DWS after five pore volumes are extracted. However, as previously noted, arsenic, manganese, and iron concentrations exceeded the relevant DWS or SDWS after five pore volumes were extracted. Because arsenic and other trace metal results from downgradient wells are unavailable, efforts should be initiated to collect samples and include trace metals in future analyses.

Anions. With a few exceptions, the range of concentrations for each anion analyzed was well below the regulatory DWS. The exceptions are reviewed below and focus only on posttreatment values.

For fluoride, all results were reported as non-detect. However, the non-detect limit for wells 199-D4-35, 199-D4-57, and 199-D4-62 was reported as 2.5 mg/L, while the non-detect limit for 199-D4-7 was reported as 12.5 mg/L. Because the DWS and SDWS limits are 4.0 and 2.0 mg/L, respectively, it is uncertain if the DWS concentrations were exceeded in these situations, because of the high detection limits reported by the laboratory.

For nitrite, wells 199-D4-7, 199-D4-62, 199-D4-66, and 199-D4-70 exceeded the DWS of 3.14 mg/L. The concentrations for these four wells ranged from 4.36 to 6.93 mg/L. For well 199-D4-7, it is uncertain if the DWS was exceeded, because it was reported as a non-detect value under 5.0 mg/L. Although it is expected that nitrite concentrations in the treatment zone will increase as a result of the injection because nitrates are reduced to nitrites in a reduced environment, the concentrations are expected to drop below DWS before entering the river downgradient. Therefore, as noted in the trace metal section, it is recommended that laboratory results data be reviewed from downgradient compliance and monitoring wells.

Uranium. The uranium samples analyzed in FY 2002 were well below the DWS of 30 μg/L. Posttreatment concentrations for the eight wells sampled ranged from 0.076 to 0.680 μg/L. The decrease in uranium concentration after treatment is caused by the reduction of uranium VI (soluble) to uranium IV (insoluble), similar to the reduction of hexavalent chromium to trivalent chromium.

3.4.2.3 Sulfate Analyses

Sulfate Analyses. The sulfate concentrations for all posttreatment samples collected from the barrier wells exceeded the SDWS of 250 mg/L. Posttreatment concentrations for the eight wells ranged from 318 to 4,380 mg/L.

Although it is expected that sulfate concentrations in the treatment zone will increase as a result of the injection (because sulfur in sodium dithionite eventually oxidizes to sulfates), the concentrations are expected to drop below the SDWS before entering the river downgradient.

3.4.3 Evaporation Pond Data Review

As defined by the *Sampling and Analysis Instruction to Support Operation of the 100-D Area In Situ Redox Manipulation Process*, e.g. the SAI, (BHI-01516), a grab sample must be collected near the location of the discharge into the evaporation pond. According to BHI-01516, the sample should be collected once during the fiscal year when the evaporation rate is high, and analyzed for total strontium, tritium, total uranium, alkalinity, and sulfate. The main reason for collecting these samples is to recalculate personnel exposure from radiological and hazardous constituents in the pond. The results also confirm the basis for the evaporation pond design.

In addition to the sampling and analyses required by the SAI (BHI-01516), samples also were collected twice during the fiscal year from the other end of the pond and analyzed for trace metals and anions. The purpose of the additional sampling and analyses was to confirm consistency in results and determine potential personnel risks during higher activity periods.

Based on the FY 2002 results received, preliminary calculations confirmed that threshold quantities for personnel exposure to radiological and hazardous constituents were not exceeded.

Consistency in analytical results from different sampling points in the pond was confirmed. As shown in Table 3-6, third and fourth quarter results from the north and south end of the pond were very similar. For example, during the third quarter analysis, total uranium from the north and south ends was 3.61 and 3.93 μg/L, respectively. In addition, slightly higher concentrations for most constituents were seen in the fourth quarter, compared to the third quarter. This indicates that one grab sample from the pond, collected during peak evaporation, provides an accurate inventory as defined by the SAI (BHI-01516).

3.5 EXTRACTION WATER DISPOSITION

Posttreatment extraction water containing high sulfate levels is collected and disposed of in an evaporation pond located at the ISRM site. Optionally, this water can be trucked to the Purgewater Storage and Treatment Facility for storage. Extraction water with low sulfate levels can be disposed to the evaporation pond or to the ground surface through a dripfield at the ISRM site. During FY 2002, approximately 28,500,000 L (7,500,000 gal) of extraction water was sent to the evaporation pond, while approximately 6,250,000 L (1,650,000 gal) of extraction water was sent to the dripfield.

Figure 3-1. Current In Situ Redox Manipulation Treatment Zone Well Locations.

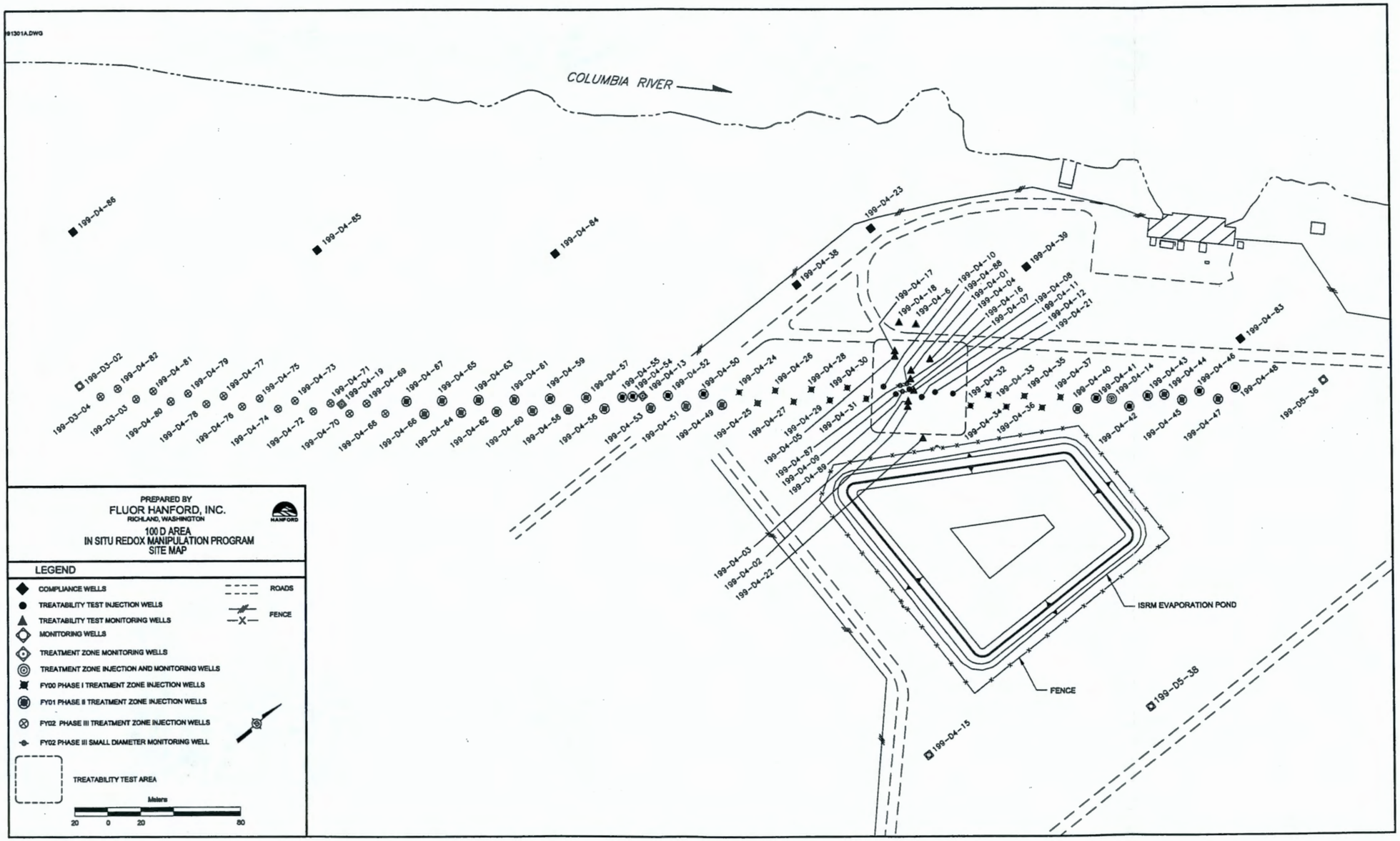


Figure 3-2. Contour Map of Ringold Upper Mud Surface Elevation, 100-D Area.

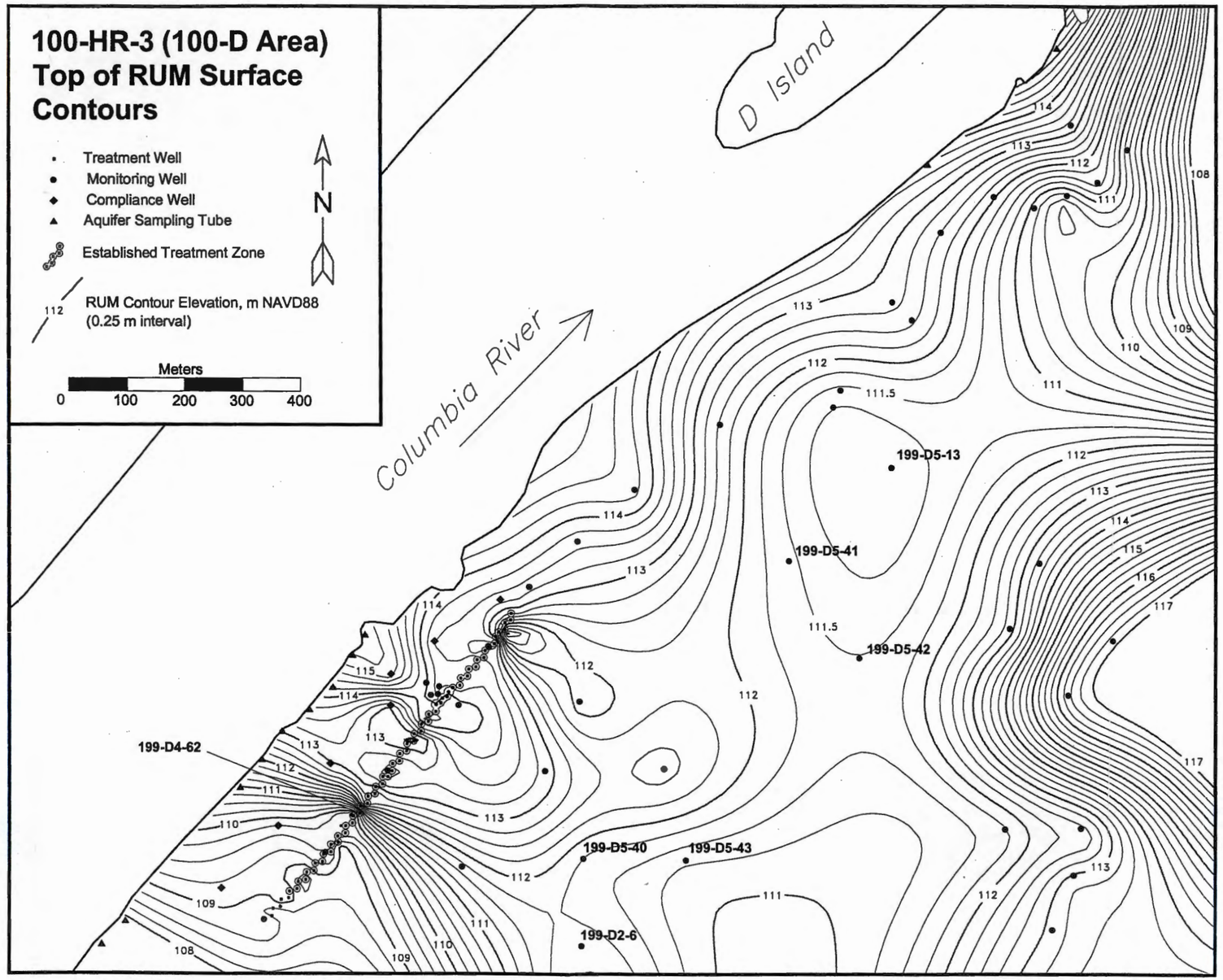
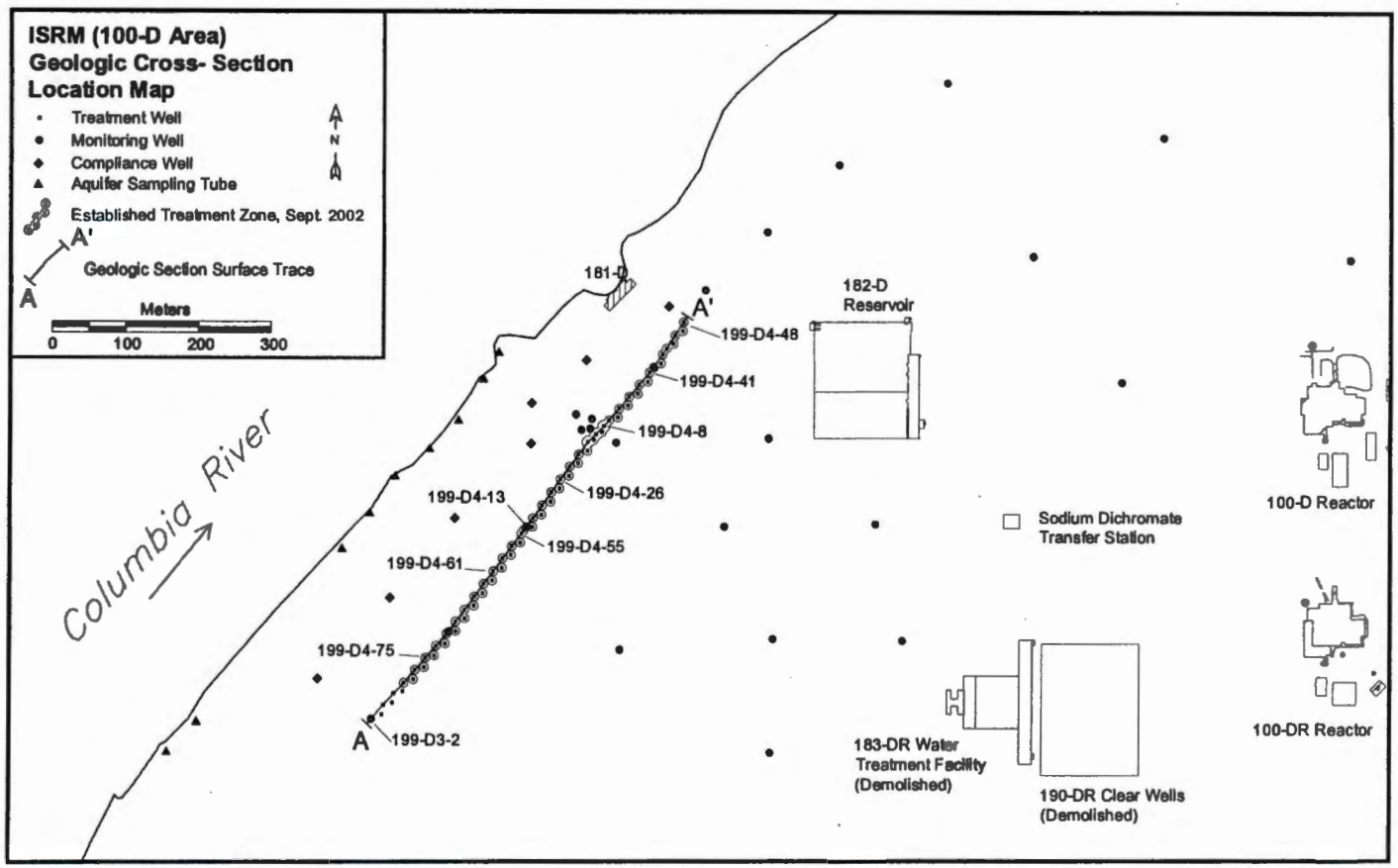


Figure 3-3. Location of Geologic Cross Section in the Area of the In Situ Redox Manipulation Treatment Zone.



This page intentionally left blank.

Figure 3-4. In Situ Redox Manipulation Treatment Zone Geologic Cross Section A-A.

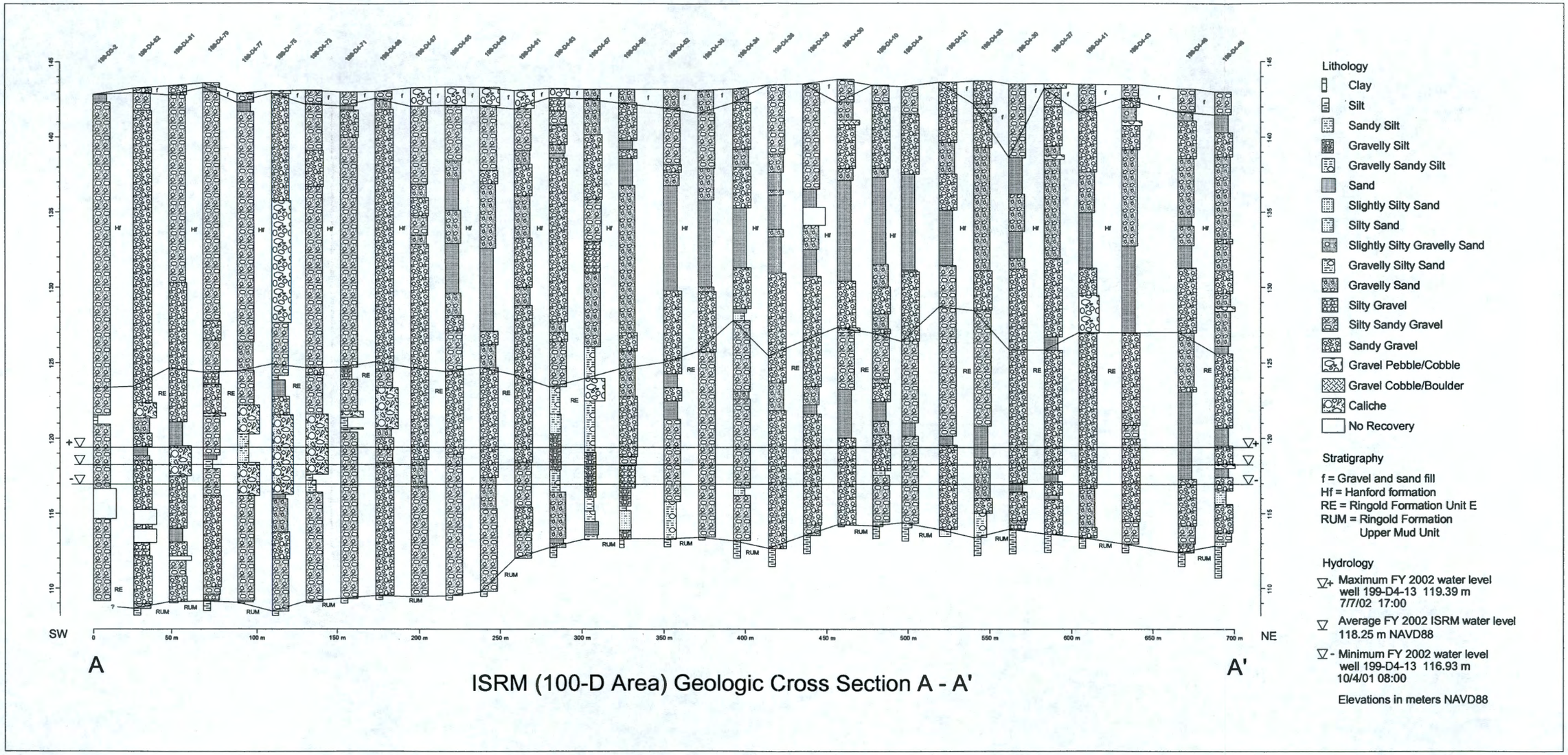
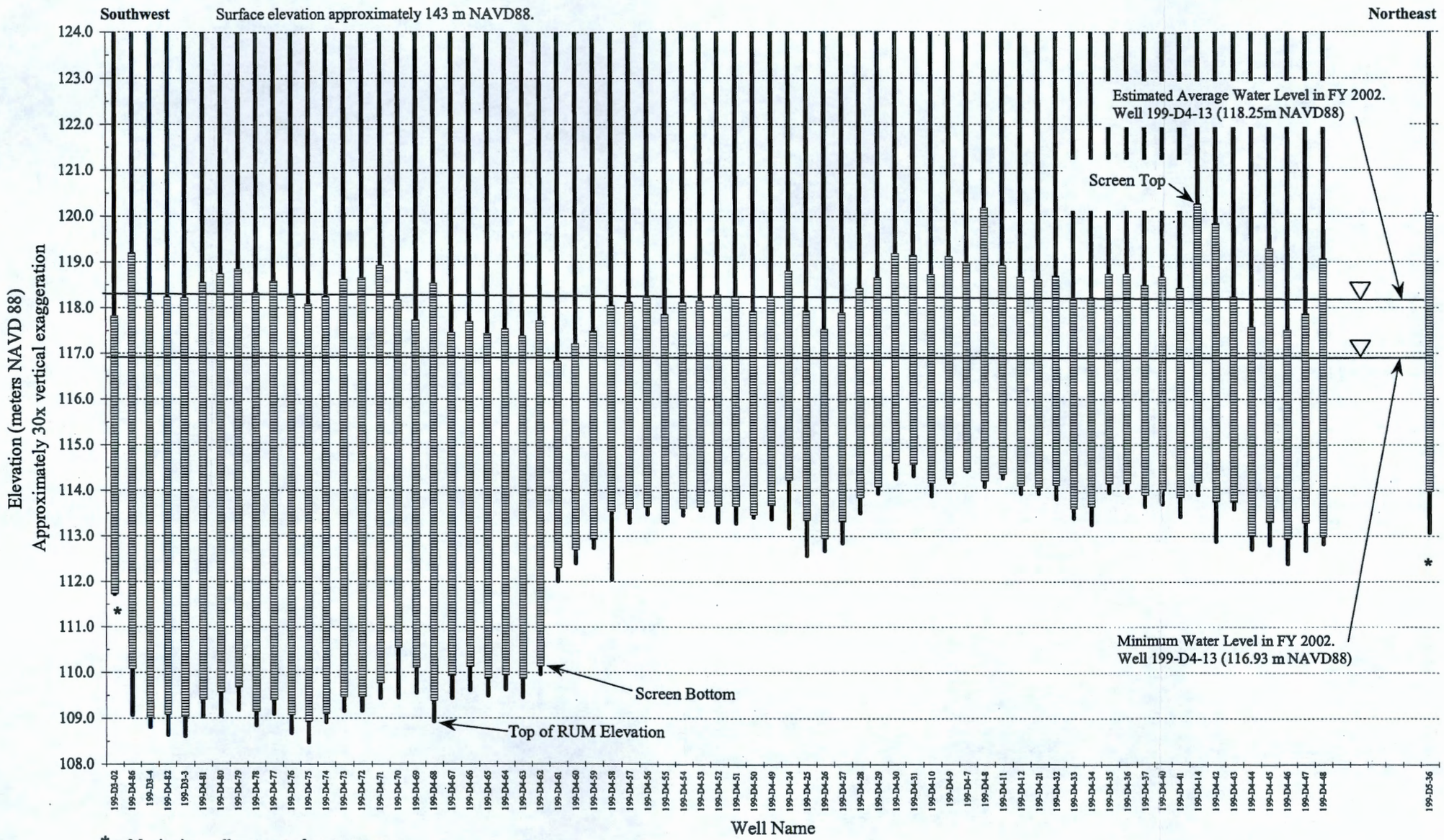


Figure 3-5. Relative Screened Interval Elevations for the In Situ Redox Manipulation Wells.



* = Monitoring well, not part of treatment zone.

Figure 3-6. Schematic of the 100-D Area In Situ Redox Manipulation Liquid Injection/Extraction System.

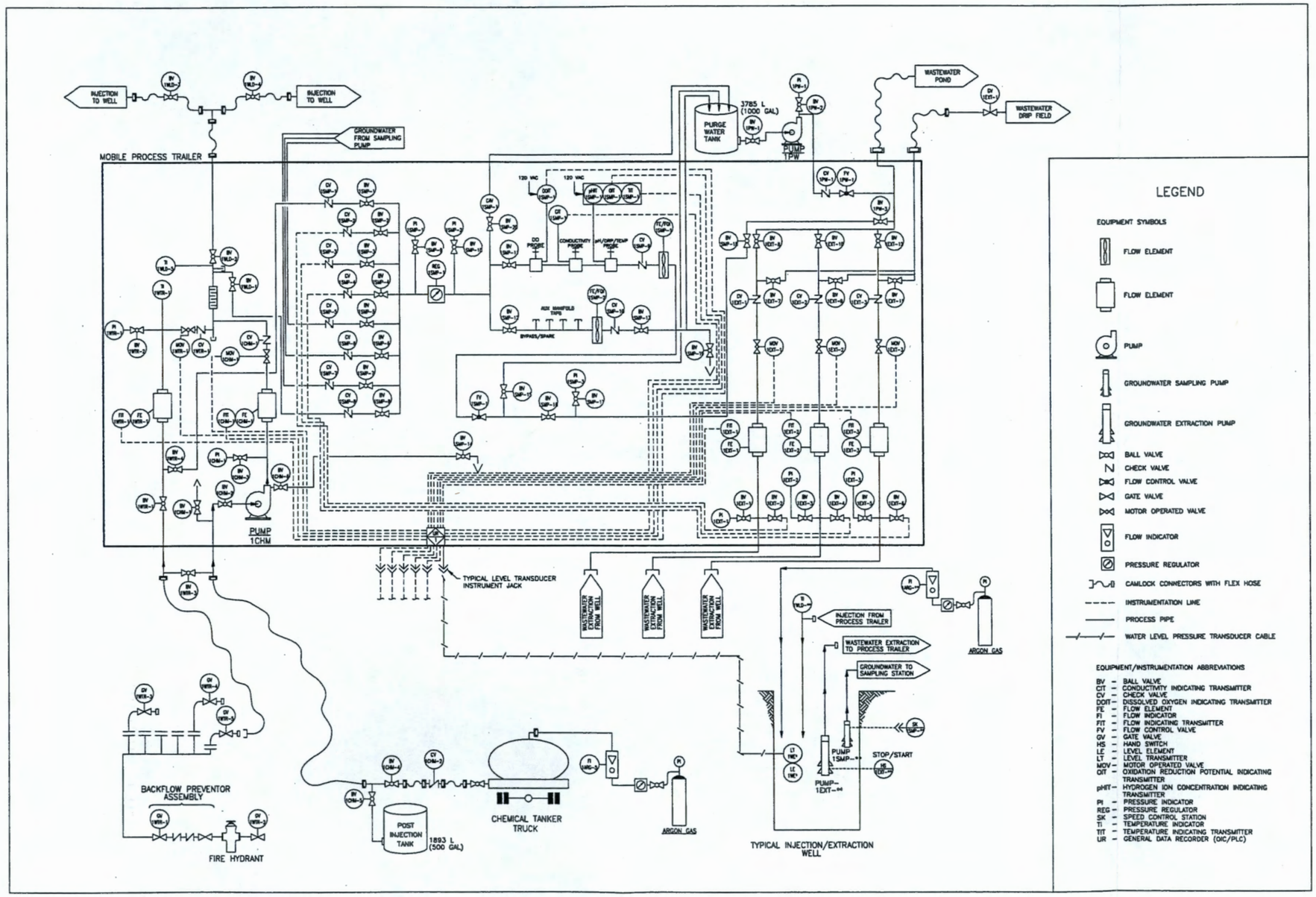


Table 3-1. In Situ Redox Manipulation Phase III Treatment Zone Well Construction Summary, Fiscal Year 2002.

Well Name	Well ID	Drilling Method	Drilling Start Date	Drilling Finish Date	Northing[a] (m)	Easting[a] (m)	Ground Surface Elevation[b] (Brass Cap)(m)	Total Depth (ft bgs[c])
Treatment Zone Injection / Extraction Wells								
199-D4-68	C3298	Cable tool	12/20/01	12/28/01	151299.838	572581.324	143.067	113.0
199-D4-69	C3299	Cable tool	01/07/02	01/11/02	151295.692	572568.997	143.084	111.0
199-D4-70	C3300	Cable tool	12/28/01	01/03/02	151282.677	572568.789	143.131	111.0
199-D4-71	C3301	Cable tool	01/30/02	02/04/02	151278.503	572556.286	143.119	111.6
199-D4-72	C3302	Cable tool	02/04/02	02/08/02	151265.778	572554.432	142.998	111.9
199-D4-73	C3303	Cable tool	02/11/02	02/14/02	151262.724	572542.167	143.148	112.0
199-D4-74	C3304	Cable tool	02/11/02	02/19/02	151249.798	572539.801	142.901	112.5
199-D4-75	C3305	Cable tool	02/19/02	02/26/02	151246.947	572527.758	143.069	114.5
199-D4-76	C3306	Cable tool	02/14/02	02/20/02	151234.236	572256.060	142.971	114.0
199-D4-77	C3307	Cable tool	01/20/02	02/25/02	151231.008	572513.333	142.929	111.2
199-D4-78	C3308	Cable tool	02/25/02	03/01/02	151218.263	572511.284	142.981	113.0
199-D4-79	C3309	Cable tool	03/04/02	03/12/02	151214.024	572498.237	143.627	115.1
199-D4-80	C3310	Cable tool	03/04/02	03/08/02	151202.591	572496.869	143.430	113.0
199-D4-81	C3311	Cable tool	02/26/02	03/04/02	151199.640	572484.362	143.329	112.8
199-D3-3	C3312	Cable tool	01/23/02	01/29/02	151186.957	572482.542	143.202	114.0
199-D4-82	C3313	Cable tool	01/17/02	01/23/02	151183.894	572470.262	143.229	115.0
199-D3-4	C3314	Cable tool	12/26/01	01/07/02	151170.973	572468.159	143.252	114.2
Boreholes Completed as Small-Diameter Groundwater Monitoring Wells								
199-D4-87	C3799	Sonic	03/05/02	03/08/02	151550.035	572757.049	143.444	100
199-D4-88	C3800	Sonic	03/08/02	03/11/02	151553.219	572758.674	143.399	98.0
199-D4-89	C3801	Sonic	03/12/02	03/14/02	151547.119	572759.624	143.529	97.5

[a] Northing and easting coordinates are based on Washington State Plane Coordinates (NAD83, *North American Datum of 1983*[91]), rounded to 0.001 m.

[b] NAVD88, *North American Vertical Datum of 1988*, values rounded to 0.001 m.

[c] Feet are used here because field measurements were reported and recorded in these units.

bgs = below ground surface.
ID = identification.

Table 3-2. In Situ Redox Manipulation Phase III Well Completion Summary for Fiscal Year 2002 Wells. (2 sheets)

Well Name	Well ID	Well Type	Water Level (ft bgs)	RUM Top (ft bgs)	Aquifer Thickness (ft)	Screen[ab]				Sandpack[c]	Seal[d]	Grout[e]	Riser[b]
						Screen Top (ft bgs)	Screen Bottom (ft bgs)	Screen Length (ft)	End Cap (ft)	Interval (ft bgs)	Seal (ft bgs)	Interval (ft bgs)	Riser Top (ft bgs)
Treatment Zone Injection / Extraction Wells													
199-D4-68	C3298	TZ	82.76	112.0	29.2	80.5	110.5	29.96	0.07	77.5-110.6	72.6-77.5 BP	0-72.6	+2.00
199-D4-69	C3299	TZ	81.79	110.0	28.2	83.2	108.2	25.02	0.06	79.4-111.0	74.4-79.4 BP	0-74.4	+2.00
199-D4-70	C3300	TZ	81.79	110.5	28.7	81.9	106.9	25.00	0.06	78.9-109.8	73.5-78.9 BP	0-73.5	+2.00
199-D4-71	C3301	TZ	82.05	110.5	28.5	79.4	109.4	30.03	WE	76.4-110.1	71.7-76.4 BP	0-71.7	+2.10
199-D4-72	C3302	TZ	81.83	111.0	29.2	79.9	110.0	30.03	WE	77.0-111.9	71.9-77.0 BP	0-71.9	+2.00
199-D4-73	C3303	TZ	80.40	111.5	31.1	80.5	110.5	30.00	0.06	77.5-112.0	72.5-77.5 BCC	0-72.5	+2.00
199-D4-74	C3304	TZ	81.44	111.5	30.1	80.9	110.9	30.00	WE	77.9-112.5	72.9-77.9 BP	0-72.9	+2.00
199-D4-75	C3305	TZ	82.25	113.5	31.3	82.0	112.0	30.03	WE	78.9-112.3	72.9-78.9 BP	0-72.9	+2.00
199-D4-76	C3306	TZ	81.70	112.5	30.8	81.1	111.2	30.02	0.06	78.6-112.2	72.6-78.6 BP	0-72.6	+1.90
199-D4-77	C3307	TZ	81.72	111.0	29.3	79.9	110.0	30.11	WE	76.9-110.0	71.2-76.9 BP	0-71.2	+2.00
199-D4-78	C3308	TZ	82.02	112.0	30.0	80.9	111.0	30.01	WE	77.0-113.0	72.0-77.0 BP	0-72.0	+2.00
199-D4-79	C3309	TZ	83.91	113.0	29.1	81.3	111.4	30.02	0.06	77.0-112.8	72.1-77.0 BP	0-72.1	+2.10
199-D4-80	C3310	TZ	83.45	112.8	29.4	81.0	111.1	30.03	WE	77.8-113.0	73.2-77.8 BP	0-73.2	+2.00
199-D4-81	C3311	TZ	83.11	112.5	29.4	81.3	111.3	30.05	0.06	77.6-112.6	72.2-77.6 BP	0-72.2	+2.00
199-D3-3	C3312	TZ	81.90	113.5	31.6	82.0	112.1	30.03	WE	79.1-113.6	74.2-79.1 BP	0-74.2	+2.10
199-D4-82	C3313	TZ	81.91	113.5	31.6	82.0	112.0	30.02	WE	79.0-115.0	74.0-79.0 BP	0-74.0	+2.00
199-D3-4	C3314	TZ	82.47	113.0	30.5	82.3	112.3	29.96	0.06	78.4-113.7	73.6-78.8 BP	0-73.6	+1.80

Table 3-2. In Situ Redox Manipulation Phase III Well Completion Summary for Fiscal Year 2002 Wells. (2 sheets)

Well Name	Well ID	Well Type	Water Level (ft bgs)	RUM Top (ft bgs)	Aquifer Thickness (ft)	Screen[ab]				Sandpack[c]	Seal[d]	Grout[e]	Riser[b]
						Screen Top (ft bgs)	Screen Bottom (ft bgs)	Screen Length (ft)	End Cap (ft)	Interval (ft bgs)	Seal (ft bgs)	Interval (ft bgs)	Riser Top (ft bgs)
Boreholes Completed as Small-Diameter (2 in.) Groundwater Monitoring Wells													
199-D4-87	C3799	TZ	83.71	97.2	13.56	87.3	89.5	2.20	WE	85.0-90.5	90.5-97.2 10.4-85.0[f]	0-10.4	1.90
199-D4-88	C3800	TZ	83.20	UNK	UNK	81.8	84.0	2.20	WE	79.7-85.1	85.1-95.0 11.0-79.7[f]	0-11.0	2.00
199-D4-89	C3801	TZ	83.90	97.0	13.1	93.2	95.4	2.22	WE	91.1-96.1	96.1-97.5 10.6-91.1[f]	0-10.6	1.60

[a]Screen slot size is 0.02 in.

[b]Screen and riser are stainless steel 316L alloy.

[c]Sandpack is Colorado silica sand (10-20 mesh).

[d]Bentonite seal consisted of 3/8-in. or 1/4 –in. bentonite pellets.

[e]Grout consisted of Portland cement with less than 5 percent by weight QUIK-GEL® (a registered trademark of Halliburton Energy Services, Inc., Carrollton, Texas) bentonite powder.

[f]Wells C3799, C3800, and C3801 had a coated bentonite seal in the bottom of the well. In addition, the upper seal consisted of +coated pellets, uncoated pellets, and/or granular bentonite (crumbles). Use of pellets is in accordance with WAC 173-160, "Minimum Standards for Construction and Maintenance of Wells," *Washington Administrative Code*, as amended, Olympia, Washington.

BCC = bentonite chip.
BP = bentonite pellet.
ID = identification.
RUM = Ringold Upper Mud.
TZ = treatment zone.
UNK = unknown.
WE = welded end.

Table 3-3. Stratigraphic Summary of Wells Drilled in Fiscal Year 2002.

Well Name	Well ID	Ground Surface Elevation (Brass Cap) (m)[a]	Groundwater Level When Drilled (ft bgs)[b]	Fill (ft bgs)[b]	Hanford/ Ringold Contact (ft bgs)[b]	Top of RUM (ft bgs)[b]	Total Depth (ft bgs)[b]	Top of RUM Elevation (m)[c]	Aquifer Thickness (m)
Treatment Zone Injection /Extraction Wells									
199-D4-68	C3298	143.067	82.76	3.0	60.0	112.0	113.0	108.913	9.34
199-D4-69	C3299	143.084	81.79	1.5	59.0	110.0	111.0	109.513	8.74
199-D4-70	C3300	143.131	81.79	2.5	61.0	110.5	111.0	109.394	8.86
199-D4-71	C3301	143.119	82.05	3.0	60.0	110.5	111.6	109.321	8.93
199-D4-72	C3302	142.998	81.83	1.5	59.0	111.0	111.9	109.116	9.13
199-D4-73	C3303	143.148	80.40	3.0	60.5	111.5	112.0	109.121	9.13
199-D4-74	C3304	142.901	81.44	1.0	60.0	111.5	112.5	108.910	9.34
199-D4-75	C3305	143.069	82.25	0.5	59.5	113.5	114.5	108.465	9.78
199-D4-76	C3306	142.971	81.70	3.0	60.5	112.5	114.0	108.698	9.55
199-D4-77	C3307	142.929	81.72	2.0	60.5	111.0	111.2	109.052	9.20
199-D4-78	C3308	142.981	82.02	2.0	61.0	112.0	113.0	108.803	9.45
199-D4-79	C3309	143.627	83.91	1.0	63.0	113.0	115.1	109.135	9.12
199-D4-80	C3310	143.430	83.45	2.0	61.0	112.8	113.0	109.004	9.25
199-D4-81	C3311	143.329	83.11	2.0	61.5	112.5	112.8	109.108	9.14
199-D3-3	C3312	143.202	81.90	3.0	64.0	113.5	114.0	108.659	9.59
199-D4-82	C3313	143.229	81.91	1.0	65.0	113.5	115.0	108.656	9.59
199-D3-4	C3314	143.252	82.47	1.0	67.6	113.0	114.2	108.926	9.32
Characterization/Small Diameter Groundwater Monitoring Wells									
199-D4-87	C3799	143.444	83.71	0	Unknown	97.2	100.0	113.817	4.43
199-D4-88	C3800	143.399	83.20	0	60.0	Unknown	98.0	Unknown	Unknown
199-D4-89	C3801	143.529	83.90	0	65.0	97.0	97.5	113.963	4.29

[a]Based on NAVD88.
[b]Feet are used here because field measurements were reported and recorded in this unit of measurement.
[c]Calculated from an average water table elevation of 118.25 m NAVD88.

ID = identification.
NAVD88 = *North American Vertical Datum of 1988.*
RUM = Ringold Upper Mud.

Table 3-4. In Situ Redox Manipulation Wells Treated and Sampled in Fiscal Year 2002.

Well Treated	Injection Start Date	Extraction Completion Date	Adjacent Wells	Samples Analyzed
199-D4-7[a]	27-Aug-02	14-Sep-02	199-D4-08, 199-D4-09	Laboratory, Field Parameter
199-D4-09[a]	12-Sep-02	28-Sep-02	199-D4-7, 199-D4-10	Field Parameter
199-D4-10[a]	4-Sep-02	18-Sep-02	199-D4-09, 199-D4-31	Field Parameter
199-D4-11[a]	10-Sep-02	10-Oct-02[c]	199-D4-08, 199-D4-12	Field Parameter
199-D4-12[a]	29-Aug-02	16-Sep-02	199-D4-11, 199-D4-21	Field Parameter
199-D4-24[b]	7-Sep-01	4-Oct-01	199-D4-25, 199-D4-49	Field Parameter
199-D4-35[a]	22-Aug-02	17-Sep-02	199-D4-34, 199-D4-36	Laboratory, Field Parameter
199-D4-50[b]	14-Sep-01	13-Nov-01	199-D4-49, 199-D4-51	Field Parameter
199-D4-52[b]	11-Sep-01	22-Oct-01	199-D4-51, 199-D4-53	Field Parameter
199-D4-54[b]	5-Sep-01	1-Nov-01	199-D4-53, 199-D4-55	Field Parameter
199-D4-57[b]	23-Aug-01	10-Oct-01	199-D4-56, 199-D4-58	Laboratory, Field Parameter
199-D4-58[b]	18-Sep-01	10-Oct-01	199-D4-57, 199-D4-59	Field Parameter
199-D4-60[b]	29-Aug-01	20-Nov-01	199-D4-59, 199-D4-61	Field Parameter
199-D4-61[b]	20-Sep-01	18-Oct-01	199-D4-60, 199-D4-62	Field Parameter
199-D4-62[b]	21-Aug-01	5-Oct-01	199-D4-61, 199-D4-63	Laboratory, Field Parameter
199-D4-63	20-Jun-02	22-Jul-02	199-D4-62, 199-D4-64	Field Parameter
199-D4-64	27-Mar-02	15-May-02	199-D4-63, 199-D4-65	Field Parameter
199-D4-65	17-Jun-02	21-Aug-02	199-D4-64, 199-D4-66	Field Parameter
199-D4-66	11-Apr-02	13-Jun-02	199-D4-65, 199-D4-67	Laboratory, Field Parameter
199-D4-67	13-Jun-02	17-Sep-02	199-D4-66, 199-D4-68	Field Parameter
199-D4-68	4-Apr-02	6-May-02	199-D4-67, 199-D4-69	Field Parameter
199-D4-69	11-Jun-02	17-Sep-02	199-D4-68, 199-D4-70	Field Parameter
199-D4-70	2-Apr-02	23-May-02	199-D4-69, 199-D4-71, 199-D4-19	Laboratory, Field Parameter
199-D4-71	6-Jun-02	04-Sep-02	199-D4-70, 199-D4-72	Field Parameter
199-D4-72	9-Apr-02	12-Jun-02	199-D4-71, 199-D4-73, 199-D4-19	Field Parameter
199-D4-73	30-May-02	9-Oct-02[c]	199-D4-72, 199-D4-74	Field Parameter
199-D4-74	14-May-02	8-Jul-02	199-D4-73, 199-D4-75	Laboratory, Field Parameter
199-D4-75	23-May-02	21-Aug-02	199-D4-74, 199-D4-76	Field Parameter
199-D4-76	16-May-02	7-Aug-02	199-D4-75, 199-D4-77	Field Parameter
199-D4-77	28-May-02	7-Aug-02	199-D4-76, 199-D4-78	Field Parameter
199-D4-78	21-May-02	21-Aug-02	199-D4-77, 199-D4-79	Laboratory, Field Parameter
199-D4-79	4-Jun-02	1-Oct-02[c]	199-D4-78, 199-D4-80	Field Parameter
Evaporation Pond	n/a	n/a	n/a	Laboratory

[a]These wells were previously treated.
[b]These wells were injected in fiscal year 2001, but the extractions were completed in fiscal year 2002.
[c]These extractions were completed during the first quarter of fiscal year 2003.
n/a = not available.

Table 3-5. Summary of Fiscal Year 2002 Trace Metals, Anion, Uranium, and Sulfate Concentrations.

Constituent	Fiscal Year 2002 Concentration Range[a]		
	Units	Baseline	Posttreatment
Silver	(μg/L)	0.5 (U) – 1.1 (U)	0.5 (U) – 3.8
Aluminum	(μg/L)	20.2 (U) – 3020	12.1 (U) – 84.6
Arsenic	(μg/L)	3.0 (U) – 3.9 (U)	3.1 – 80.1
Barium	(μg/L)	49.4 – 135.0	51.4 – 166.0
Calcium	(μg/L)	41,500 – 108,000	3,780 – 61,200
Cadmium	(μg/L)	0.3(U) – 0.35	0.1 (U) – 0.56
Total Chromium	(μg/L)	39.2 – 530.0	1.4 (U) – 172.0
Copper	(μg/L)	1.1 – 15.5	0.58 – 5.2
Total Iron	(μg/L)	14.5 (U) – 4740	90.8 – 5,470
Potassium	(μg/L)	4,900 – 149,000	299,000 – 8,490,000
Magnesium	(μg/L)	12,700 – 23,800	10,200 – 65,800
Manganese	(μg/L)	11.1 – 346.0	38.9 – 357.0
Molybdenum	(μg/L)	2.4 – 7.8	9.9 – 49.6
Sodium	(μg/L)	8,980 – 33,700	128,000 – 1,780,000
Lead	(μg/L)	1.7 (U) – 2.6	1.7 (U) – 2.4 (U)
Selenium	(μg/L)	3.2 (U) – 4.1 (U)	3.2 (U) – 5.7
Silicon	(μg/L)	12,500 – 39,700	4,990 – 16,500
Zinc	(μg/L)	4.1 – 233.0	3.3 – 66.1
Chloride	(μg/L)	23.0 – 36.1	10.8 – 28.4
Fluoride	(μg/L)	0.25 (U) – 2.5 (U)	0.5 (U) – 12.5 (U)
Nitrite	(μg/L)	0.53 – 1.69	1.25 (U) – 6.93
Nitrate	(μg/L)	14.0 – 53.6	0.72 – 17.2
Uranium	(μg/L)	0.687 – 3.08	0.076 – 0.680
Sulfate[b]	(mg/L)	81.0 – 254.7	381.0 – 4,380
Sulfate[c]	(mg/L)	79.9 – 245.0	324.0 – 716.0

[a]Baseline and posttreatment values shown represent range of concentrations based on samples collected from wells 199-D4-7, 199-D4-35, 199-D4-57, 199-D4-62, 199-D4-66, 199-D4-70, 199-D4-74, and 199-D4-78.

[b]Converted from sulfur data that were analyzed by unfiltered inductively coupled plasma metal analysis.

[c]Analyzed by anion method.

(U) = undetected at concentration shown.

Table 3-6. Summary of Fiscal Year 2002 Evaporation Pond Results.

Constituent and Units	Fiscal Year 2002 Concentrations			
	North End of Pond[a]		South End of Pond[b]	
	3rd Quarter[c]	4th Quarter[d]	3rd Quarter[c]	4th Quarter[d]
Total Uranium (µg/L)	3.61	6.94	3.93	7.08
Total Strontium (pCi/L)	-0.204	N/A	0.184	N/A
Tritium (pCi/L)	4940	10,900	3850	10,800
Sulfur (as S in µg/L)	2,220,000	2,170,000	1,920,000	2,180,000
Sulfur (as SO_4^{-2} in mg/L)	6660	6510	5760	6540
Alkalinity (mg/L)	5900	6540	6450	6620
Silver (µg/L)	0.50 (U)	1.1 (U)	0.5 (U)	1.1 (U)
Aluminum (µg/L)	20.6 (U)	39.1	25.0	40.7
Arsenic (µg/L)	75.6	65.9	79.6	61.7
Barium (µg/L)	194	235	191	234
Calcium (µg/L)	7970	8080	7610	8210
Cadmium (µg/L)	0.30 (U)	0.30 (U)	0.37	0.30 (U)
Hexavalent chromium (µg/L)	1.4	1.0 (U)	1.3	1.0 (U)
Copper (µg/L)	5.4	3.1	4.4	2.6
Iron (µg/L)	406	131	376	119
Potassium (µg/L)	6,460,000	7,190,000	6,750,000	7,280,000
Magnesium (µg/L)	64,800	77,600	67,800	77,000
Manganese (µg/L)	50.2	71.2	46.2	33.9
Molybdenum (µg/L)	74.8	85.6	75.7	85.4
Sodium (µg/L)	1,660,000	1,830,000	1,730,000	1,850,000
Lead (µg/L)	1.7 (U)	N/A	1.7 (U)	N/A
Selenium (µg/L)	3.5 (U)	4.1 (U)	3.5 (U)	4.6
Silicon (µg/L)	12,500	17,800	12,500	17,700
Zinc (µg/L)	13.2	21.1	67.3	43.0
Chloride (mg/L)	43.4	56.9	43.3	54.5
Fluoride (mg/L)	5.0 (U)	12.5 (U)	5.0 (U)	12.5 (U)
Nitrite (mg/L)	5.0 (U)	12.5 (U)	5.0 (U)	12.5 (U)
Nitrate (mg/L)	5.0 (U)	12.5 (U)	5.0 (U)	12.5 (U)

[a]Collected near discharge into pond.
[b]Collected opposite end of pond from discharge.
[c]Sample collected May 9, 2002. HEIS numbers are B14DR7 and B14DR8.
[d]Sample collected August 14, 2002. HEIS numbers are B154X9 and B154Y0.

HEIS = Hanford Environmental Information System
N/A = not applicable.
(U) = undetected at concentration shown.

This page intentionally left blank.

4.0 AQUIFER RESPONSE

The aquifer response to ISRM treatment zone establishment was monitored by the following four methods:

- Observing changes in water levels and chemical conditions within the treated portion of the aquifer during injection and extraction of the sodium dithionite reductant solution. (Section 4.1)
- Observing changes in water levels in monitoring wells surrounding the ISRM treatment zone. (Section 4.2)
- Groundwater analytical sample results from monitoring and barrier wells at the site. (Section 4.3)
- Groundwater analytical sample results from aquifer tubes. (Section 4.4).

4.1 MONITORING DURING ESTABLISHMENT OF THE TREATMENT ZONE

Conditions in the ISRM wells undergoing treatment and the adjacent wells were recorded to document establishment of the chemically reduced treatment zone within the aquifer. The conditions monitored during the treatment process included the following:

- Water level in the well being treated and in selected adjacent ISRM wells
- Temperature, Eh, pH, DO, and specific conductance
- Hexavalent chromium and sodium dithionite concentration.

In general and as expected, injection wells and nearby observation wells exhibited decreased Eh and DO, increased pH and specific conductance, decreasing hexavalent chromium concentration, detectable concentrations of sodium dithionite, and a rise in water table elevation during injection events. Table 4-1 presents a list of injection and corresponding monitoring wells where measurements were successfully obtained.

In a hydraulically connected aquifer system, a water-level increase would be expected in adjacent wells during injection. The magnitude of water-level responses observed was greatest in wells located on the eastern portion of the barrier, decreasing toward the western end of the barrier. Wells 199-D4-7 and 199-D4-10 located in the treatability test area had water-level responses 10 times greater than wells located in the western portion of the barrier (199-D4-73 through 199-D4-80). Injection wells 199-D4-63 and 199-D4-64 were designated as low producing wells with injection rates of three quarters of their designed values. This variability of water-level responses and pump rates reflects heterogeneity in the hydraulic conductivity of the aquifer and is consistent with conditions observed in the treatability test and the Phase I treatments where substantial variability in hydraulic response and transport of the treatment

solution was documented (Table 4-2). Graphs of the water-level responses during injection are presented in Appendix DD.

The appearance of sodium dithionite in adjacent wells during injection, along with other apparent impacts (e.g., changes in pH, Eh, DO, specific conductance) may indicate that injection activities resulted in treatment of larger volumes of the aquifer at specific locations than was planned in the system design, or may indicate that the treated portions of the aquifer are not cylinders of uniform size. The design used for establishment of the ISRM treatment zone was based on approximately 25 percent overlap of the treated portions of the aquifer. If the aquifer performed as anticipated and a 25 percent radius overlap was actually achieved, no treatment chemicals would have been observed in adjacent wells. Preferential flow paths may exist in the aquifer and may result in the appearance of sodium dithionite and changes in pH, Eh, DO, and specific conductance observed in adjacent wells.

4.2 HYDRAULIC MONITORING

Groundwater elevation in the unconfined aquifer was monitored in wells at the ISRM site. These measurements came from a long-term automated recording system and from semiannual manual measurements of water levels in wells. The groundwater elevation data were used to prepare water-level contour maps of the site and to develop a detailed assessment of apparent variations in groundwater flow direction and gradient across the ISRM site. These assessments are presented in the following subsections.

4.2.1 Groundwater Contours

Comparison of the seasonal fluctuation in water levels in monitoring wells indicates a seasonal shift in the groundwater flow direction as well as seasonal changes in the groundwater gradient across the site. Water levels are lowest in September through November and highest in June through August. The seasonal shift in general groundwater elevation relative to the river stage is demonstrated by comparison of the long-term monitoring data for the five monitored wells shown in Figure 4-1.

The automated water-level monitoring system collected continual long-term water-level data on an hourly basis in nine groundwater monitoring wells at the site. Wells included in this monitoring program are 199-D3-2, 199-D4-13, 199-D4-19, 199-D4-20, 199-D4-38, 199-D4-84, 199-D4-85, 199-D5-38, and 199-D5-43. The data from these wells indicate substantial seasonal and diurnal variations in water levels across the site. Wells located relatively close to the Columbia River exhibited diurnal fluctuations in a similar time frame to those observed in the river stage. The magnitude of fluctuation was attenuated in the monitoring wells near the river. Wells more distant from the river exhibited reduced diurnal fluctuation with increased attenuation of magnitude. Seasonal variations are pronounced at all well locations monitored and reflect variations in river stage, with high levels associated with high river stage in the summer and low levels associated with low river stage in the fall. Hydrographs for these nine wells for FY 2002 (October 2001 through September 2002) are shown in Appendix EE.

Water-level measurements were taken on a semiannual basis from all of the monitoring wells associated with the ISRM site. These measurements were used to establish groundwater elevation contours over a broad area of the site in June and in November. The groundwater contours for the site based on the spring and fall 2002 measurements are presented in Figures 4-2 and 4-3, respectively. The spring 2002 groundwater contours show a well-developed gradient from the Columbia River inland toward the 100-D Reactor areas because of high river stage. The difference in groundwater elevation from wells nearest the shoreline by the ISRM barrier to those east of the 100-D and 100-DR Reactors is 1.7 m. The contours also show changes in gradient, indicated by the spacing of the contours and the direction of groundwater flow along the axis of the ISRM barrier. There is a pronounced change in contour direction at well 199-D4-13.

The fall 2002 water table contours represent the groundwater flow regime when the Columbia River stage is low and groundwater is discharging to the river. A groundwater flow divide is shown in the southern part of the 100-D Area of Figure 4-3; flow is toward the northwest in the western part of the area, to the north in the central part, and to the northeast in the eastern part (i.e., east of the 100-D Reactors). In the northern part of the 100-D Area, flow is toward the north.

Water levels across the site increased in 2002 compared to measurements made for the same two periods in 2001. This sitewide increase is related to the more typical amount of spring runoff, which was much lower than usual in 2001. A comparison summary of water-level measurements taken in 2001 and 2002 is presented in Table 4-3. The average increase in water level between June 2001 and June 2002 across the 100-D Area site was 0.89 m. The average increase in water level between November 2001 and November 2002 across the 100-D Area site was 0.55 m.

4.2.2 Groundwater Flow Direction

Groundwater flow direction is a significant aspect in the treatment of the hexavalent chromium plume by the ISRM treatment zone. Ideally, the treatment zone should be oriented perpendicular to the groundwater flow direction and plume axis to intercept and treat the contaminant plume. The treatment zone appears to be situated to intercept the plume at a perpendicular orientation, 90 $\pm$ 30 degrees, for most of the year, based on the evaluation of water-level monitoring data.

To evaluate groundwater flow direction at the ISRM site, automated water-level data collected hourly by an automated data logger network from five wells were used to solve a series of three-point problems. These five wells are 199-D4-20, 199-D4-38, 199-D4-85, 199-D5-38, and 199-D5-43. Wells 199-D4-38 and 199-D4-85 are located between the Columbia River and the ISRM barrier. The other three wells are located further inland from the barrier, 199-D5-43 being the farthest from the Columbia River.

The principle behind the three-point problem is that, given the hydraulic head at three unique locations, it is possible to geometrically calculate the flow direction based on the relative magnitudes of each measurement. Briefly, the intermediate hydraulic head value is projected onto the maximum gradient line drawn between the maximum and minimum hydraulic heads. The line connecting the well where the intermediate head value was recorded and its equivalent

point along the line of maximum gradient is a line of constant head, much like a standard elevation contour line. Groundwater flow direction is perpendicular to this line in the direction of decreasing hydraulic head. Figure 4-4 presents the general layout of the three-point problem using wells 199-D4-20, 199-D5-38, and 199-D5-43. In this case, the line of maximum hydraulic gradient lies between wells 199-D5-38 and 199-D5-43, and the intermediate hydraulic head was measured at well 199-D4-20. Projecting the intermediate value onto the line between wells 199-D5-38 and 199-D5-43 and connecting it with the location of well 199-D4-20 produces the line of constant head (the dashed line in the figure). Groundwater flow direction is perpendicular to this line as shown in the direction of decreasing hydraulic head.

Data collected from three separate groupings of three wells were evaluated during FY 2002. Figure 4-5 shows the well locations and the three sets of three-point calculation charts. Wells 199-D4-20, 199-D4-38, and 199-D4-85 were used to evaluate flow direction near the treatment zone with wells that are strongly affected by river stage changes. Wells 199-D4-20, 199-D4-38, and 199-D5-38 were used to evaluate flow direction further inland from the river, recognizing that well 199-D4-38 is more strongly affected by river stage changes. Wells 199-D4-20, 199-D5-38, and 199-D5-43 were used to investigate groundwater flow direction farthest inland from the existing treatment zone.

The calculated flow directions are represented in azimuth degrees on the y-axis. North is at 360 and 0 degrees, south at 180 degrees, east at 90 degrees, and west at 270 degrees. A flow direction perpendicular to the axis of the treatment zone is 307 degrees, shown by the heavy black line on the charts. The charts also show the water levels for well sets used to calculate the flow direction curve. The river stage data also are included on the chart for wells 199-D4-20, 199-D5-38, and 199-D5-43.

The changes in flow direction during the course of the year are greatly influenced by the river stage. Water levels in wells 199-D4-38 and 199-D4-85 respond quickly to changes in river stage. Water levels in the other wells also respond but in an attenuated manner. This is shown by comparing the three-point solution data for wells 199-D4-20, 199-D4-38, and 199-D4-85 to the data for wells 199-D4-20, 199-D5-38, and 199-D5-43, which also include the river stage data.

The three-flow direction charts generally show flow directions of 330 $\pm$ 30 degrees azimuth for the period of fall through spring. Flow is roughly perpendicular to the axis of the treatment zone, the exception being February through March flow directions calculated from wells 199-D4-20, 199-D5-38, and 199-D5-43, which changed from 270 degrees (west) to 200 to 270 degrees (west).

The three-flow direction charts show mid-April azimuths of approximately 310 $\pm$ 20 degrees decreasing by 180 to 210 degrees to approximately 140 degrees azimuth by late April. The flow directions then show considerable variability through late May except for the wells farthest from the river, specifically 199-D5-20, 199-D5-38, and 199-D5-43.

The three-flow direction charts show that during high river stage the flow direction is from the Columbia River inland at approximate directions ranging from 120 to 90 degrees azimuth. The

flow directions returned to 300 ± 30 degrees, roughly perpendicular to the treatment zone axis, in late summer.

In conclusion, groundwater flow direction varies considerably near the ISRM area over the year. Changes in flow direction appear to be closely related to the river stage. The treatment zone is situated to intercept groundwater and the plume at approximate 90 degrees during August through mid-April. Near the treatment zone, flow directions during the early spring are quite variable. Flow directions are east to northeast during the highest river stage periods of mid-May through mid-July, and consequently the plume is not expected to be treated during this period. Flow directions for the area southwest of the 182-D Reservoir show variations of 180 degrees from late January to late May. The flow directions in this area after the period from late July to mid-September change from 90 to 330 degrees azimuth; from east to northwest. This suggests that part of the plume may be flowing toward, or by, the northern end of the treatment zone. To address this uncertainty, it is recommended that a monitoring well be installed on the north side of the 182-D Reservoir.

4.3 CONTAMINANT MONITORING

Chromium in groundwater previously has been described as distributed in two distinct plumes in the 100-D Area: a northern plume with sources near the former D Reactor and a southwestern plume with a source near the former 183-DR Water Treatment Facility (Figure 4-6). The area of low chromium concentrations between the plumes is believed to be the result of leakage of clean water from the 182-D Reservoir, which created an area of dilution and perhaps a groundwater mound. The 182-D Reservoir has been in use nearly continually since 1947 to store raw process water pumped from the Columbia River. In 1995, the reservoir was drained, repaired, and refilled. Changes in the distribution of chromium and other constituents (nitrate, sulfate, and specific conductance) suggest that a lower rate of leakage since the repairs is potentially allowing the northern and southwestern plumes to move into this clean area. Evaluation of hexavalent chromium concentrations in wells in the area suggests that the plumes may have merged in the vicinity north of the 182-D Reservoir, although very few monitoring wells are present in that area to confirm this conclusion.

The chromium plume near the ISRM treatment zone was oriented generally perpendicular to the Columbia River when it was first described. Investigations have been unable to identify with certainty the source of this plume. Possible sources include the former 183-DR Water Treatment Facility, where sodium dichromate was added to the water as a corrosion inhibitor, and a former transfer station where chromate stock solutions were unloaded from railcars and piped to the water treatment facilities. The transfer station was located north of the 183-DR Facility. Characterization of these areas failed to locate areas of high chromium contamination in the vadose zone (*Characterization Activities Conducted at the 183-DR Site in Support of an In Situ Gaseous Reduction Demonstration*, PNNL-13486).

Over the past 3 years, the configuration of the chromium plume has changed, with concentrations increasing in northern wells and remaining essentially unchanged or decreasing in southern wells (Figures 4-6 and 4-7). The most dramatic change in FY 2002 was a sharp decrease in chromium

concentrations in well 199-D5-39. The concentration in this well in August 2002 was 2,830 μg/L, which is about 40 percent lower than in August 2001.

Other wells located east of the ISRM treatment zone exhibiting increasing chromium concentration trends over the past 3 years are 199-D5-36, 199-D5-37, 199-D5-41, and 199-D5-20. The increased concentrations in these wells may coincide with the apparent movement of the plume to the north; toward the northern tip of the ISRM treatment zone and northeast from the sodium dichromate transfer station (Figure 4-7). A summary of hexavalent chromium concentrations and annual trends for monitoring wells near the ISRM facility is presented in Table 4-4. Trend plots for hexavalent chromium and sulfate in the monitoring wells are included in Appendix FF.

4.3.1 Downgradient Compliance Monitoring Wells

All seven downgradient compliance wells were characterized by decreasing or stable chromium concentrations in the fall of 2002, compared to the fall of 2001 (see Figure 4-7). Chromium concentrations in compliance wells near the south (west) end of the treatment zone decreased in well 199-D4-85 from 287 μg/L (fall 2001) to 157 μg/L (fall 2002). Similarly, chromium in well 199-D4-86 decreased from 47 μg/L in the fall of 2001 to 11 μg/L in the fall of 2002. The south end included wells among the last treated during FY 2002.

Chromium concentrations in the compliance wells along the north (east) end of the treatment zone decreased in 199-D4-39 from 640 μg/L (fall 2001) to 32 μg/L (fall 2002). Similarly, chromium in well 199-D4-83 decreased from 87 μg/L (fall 2001) to 45 μg/L (fall 2002). Treatment zone wells along this portion of the ISRM were characterized by uniformly lower or stable chromium concentrations.

Chromium concentrations in compliance wells along the central portion of the treatment zone were stable when comparing fall 2001 and fall 2002 results. These wells include 199-D4-84, 199-D4-38, and 199-D4-23. The fall 2002 chromium concentrations were 560, 93, and 144 μg/L, respectively. The stable concentrations may reflect the loss of reducing conditions that was noted and corrected in six wells that were re-treated and possibly by a loss of reducing conditions noted recently in wells 199-D4-26 and 199-D4-31.

4.3.2 Established Treatment Zone Monitoring

In December 2001, elevated hexavalent chromium concentrations were detected in treatment zone wells 199-D4-10, 199-D4-9, 199-D4-7, and 199-D4-11. The range in concentrations was from 70 μg/L in well 199-D4-10 to 700 μg/L in well 199-D4-9. Supplemental operational sampling and monitoring of treatment zone wells was conducted starting in January 2002. This sampling effort was limited to measuring field parameters and analyzing for hexavalent chromium. Results are presented in Table 4-5. The following is a brief discussion of results.

- Treatment zone wells 199-D4-7, 199-D4-9, 199-D4-10, 199-D4-11, and 199-D4-12 were installed and injected during the ISRM treatability test phase conducted in 1997 and

1998. Hexavalent chromium concentrations measured in December 2001 were above the RAO of 20 μg/L in four of five wells. No sample was collected from well 199-D4-12. Subsequent sampling results through May 2002 generally were well above 20 μg/L.

- June 2002 hexavalent chromium concentrations in these wells were 0 μg/L in all but 199-D4-9, which was at 40 μg/L. The cause of this uniform drop in hexavalent chromium is most likely the result of high river stage and flow of water from the Columbia River inland through the aquifer.

- Treatment zone well 199-D4-35 had concentrations of hexavalent chromium of 1,000 μg/L in January 2002 and 180 μg/L in June 2002.

- Five monitoring wells in the treatability test area were sampled. Monitoring well 199-D4-8 is located in the treatment zone. Monitoring wells 199-D4-2 and 199-D4-3 are located upgradient, and monitoring wells 199-D4-4 and 199-D4-5 are located downgradient of the treatment zone axis. These wells were sampled in January 2002, and the hexavalent chromium concentrations ranged from 1,720 μg/L in 199-D4-2 upgradient of the treatment zone to 40 μg/L in 199-D4-4 downgradient of the treatment zone.

Because of increasing chromium concentrations and as directed by the "ISRM Mitigation Plan" (CCN 091481, Attachment 1), treatment zone wells 199-D4-7, 199-D4-9, 199-D4-10, 199-D4-11, and 199-D4-12 were re-treated between August and September 2002. Treatment also was repeated in well 199-D4-35 in August 2002. These wells and five other monitoring wells were resampled on September 2, 2002. The following is a summary of the analytical results.

- Hexavalent chromium concentrations were non-detect at 0 μg/L in wells 199-D4-12 and 199-D4-35; 10 μg/L in wells 199-D4-9, 199-D4-10, and 199-D4-11; and 30 μg/L in well 199-D4-7.

- Hexavalent chromium concentrations in the monitoring wells were non-detect at 0 μg/L in wells 199-D-2, 199-D4-3, and 199-D4-5; and 10 μg/L in wells 199-D4-4 and 199-D4-8.

To qualitatively assess the effectiveness of the treatment zone, an estimate of the efficiency was made based on the results of the September 2, 2002, sampling. The purpose of the qualitative assessment of the treatment zone efficiency was to identify areas of the treatment zone that may be loosing treatment efficiency. To calculate the estimated percent effectiveness at each treated well, the September 2, 2002 sampling result was subtracted from the estimated proximal upgradient concentration, divided by the same estimated proximal upgradient concentration, and then multiplied by 100. Proximal upgradient concentrations were estimated from the plume contours (Figure 4-7) or from nearby upgradient monitoring wells if available, i.e., from well 199-D4-22. The treatment zone effectiveness is summarized as follows and is shown in Table 4-5.

- Forty-seven wells are estimated to be 100 percent effective.

- Sixteen wells are estimated to be 83 to 98 percent effective.
- Two wells, 199-D4-26 and 199-D4-37, are estimated to be 69 and 41 percent effective, respectively.

It should be noted that the RAO is 20 μg/L at the compliance monitoring wells, not at the treatment zone wells.

4.3.3 Sulfate and Other Reaction Byproducts

Sulfate is the primary byproduct of the sodium dithionite reduction reaction used to establish the ISRM treatment zone. The primary purpose of the extraction phase during the emplacement process is to capture and remove excess reagent and reaction products remaining after the reaction stage. Sulfate concentrations are monitored in wells downgradient and near the treatment zone to assess the performance of the extraction stage and to evaluate the distribution of sulfate levels with respect to the SDWS of 250 mg/L. Temporary elevated sulfate concentrations within and downgradient from the established treatment zone are an expected consequence of the deployment of the ISRM technology.

Figures 4-8 and 4-9 present the fall 2001 and fall 2002 sulfate plume maps, respectively.

A comparison of the fall 2001 and 2002 sulfate plume maps shows that in areas of recent treatment, sulfate concentrations have increased within and immediately adjacent to the treatment zone. A summary of sulfate concentrations and trend analysis for ISRM monitoring wells is presented in Table 4-6. The following presents a brief discussion of significant monitoring results.

- Compliance wells 199-D4-23 and 199-D4-38 exhibited decreasing sulfate concentrations for FY 2002. In the second quarter, both wells exceeded the SDWS of 250 mg/L. In the fourth quarter of FY 2002, the sulfate concentrations had dropped to 176 and 180 mg/L respectively, indicating that a slug of high-sulfate groundwater had dissipated or had passed these wells. A comparison of the FY 2001 and FY 2002 sulfate plume maps shows a shift of the >250 mg/L contour line to the northeast.
- Wells 199-D4-13, 199-D4-14, 199-D4-19, 199-D4-26, 199-D4-31, 199-D4-32, 199-D4-39, 199-D4-1, 199-D4-4, 199-D4-5, and 199-D4-7 had sulfate concentrations exceeding the SDWS of 250 mg/L in the fourth quarter of FY 2002. With the exception of well 199-D4-26, this increase exceeded sulfate concentrations for the prior three quarters and can be attributed to treatment activities conducted in the fourth quarter of FY 2002.
- Completed in mid- to late FY 2001, compliance wells 199-D4-83, 199-D4-84, 199-D4-85, and 199-D4-86 had insufficient data to calculate an annual comparison for FY 2002. However, based on quarterly sampling results and the FY 2002 average, sulfate concentrations appear to have increased slightly in the fourth quarter to 78, 92, and 102 mg/L for wells 199-D4-83, 199-D4-84, and 199-D4-85, respectively, while remaining stable in well 199-D4-86 at 60 mg/L.

Other effects of the ISRM technology on groundwater chemistry within the treated aquifer volume include decreases in dissolved oxygen and nitrate and increases in aluminum, iron, manganese, arsenic, and nitrite. Although iron, manganese, and arsenic are elevated in the treatment zone, they are not expected to be mobile downgradient from the zone because they will reoxidize and become immobile once they contact untreated sediment. However, the lack of trace metal analyses for downgradient wells does not allow this assumption to be verified. Trace metals should be added to the list of analytes for future sampling rounds. Increased sulfate in groundwater downgradient of the treatment zone is a result of incomplete recovery of the reaction products following the reduction treatment.

4.4 AQUIFER TUBES

Aquifer sampling tube DD-44 showed a stable hexavalent chromium concentration of 247 μg/L. The remaining aquifer sampling tubes exhibited significant decreases in hexavalent chromium concentrations. Hexavalent chromium and sulfate results from aquifer tubes sampled in December 2002 are presented in Table 4-7.

Aquifer sampling tube DD-44 showed stable sulfate concentrations of 100 mg/L. All the other aquifer sampling tubes exhibited decreasing sulfate concentrations.

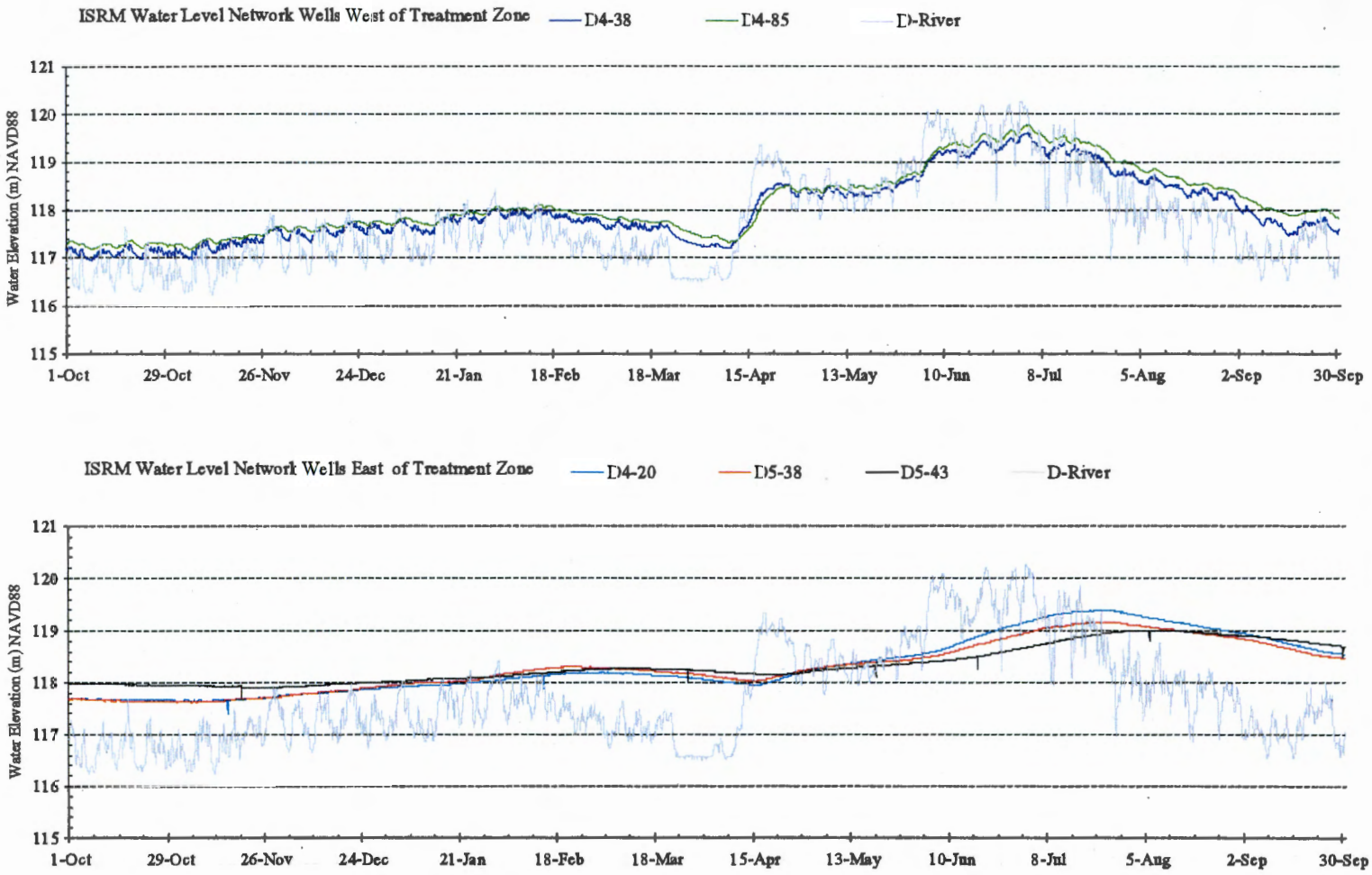


Figure 4-1. Comparison of Seasonal Water-Level Fluctuations in Five Wells at the In Situ Redox Manipulation Site.

This page intentionally left blank.

Figure 4-2. 100-D Area Water Table Map, Spring 2002.

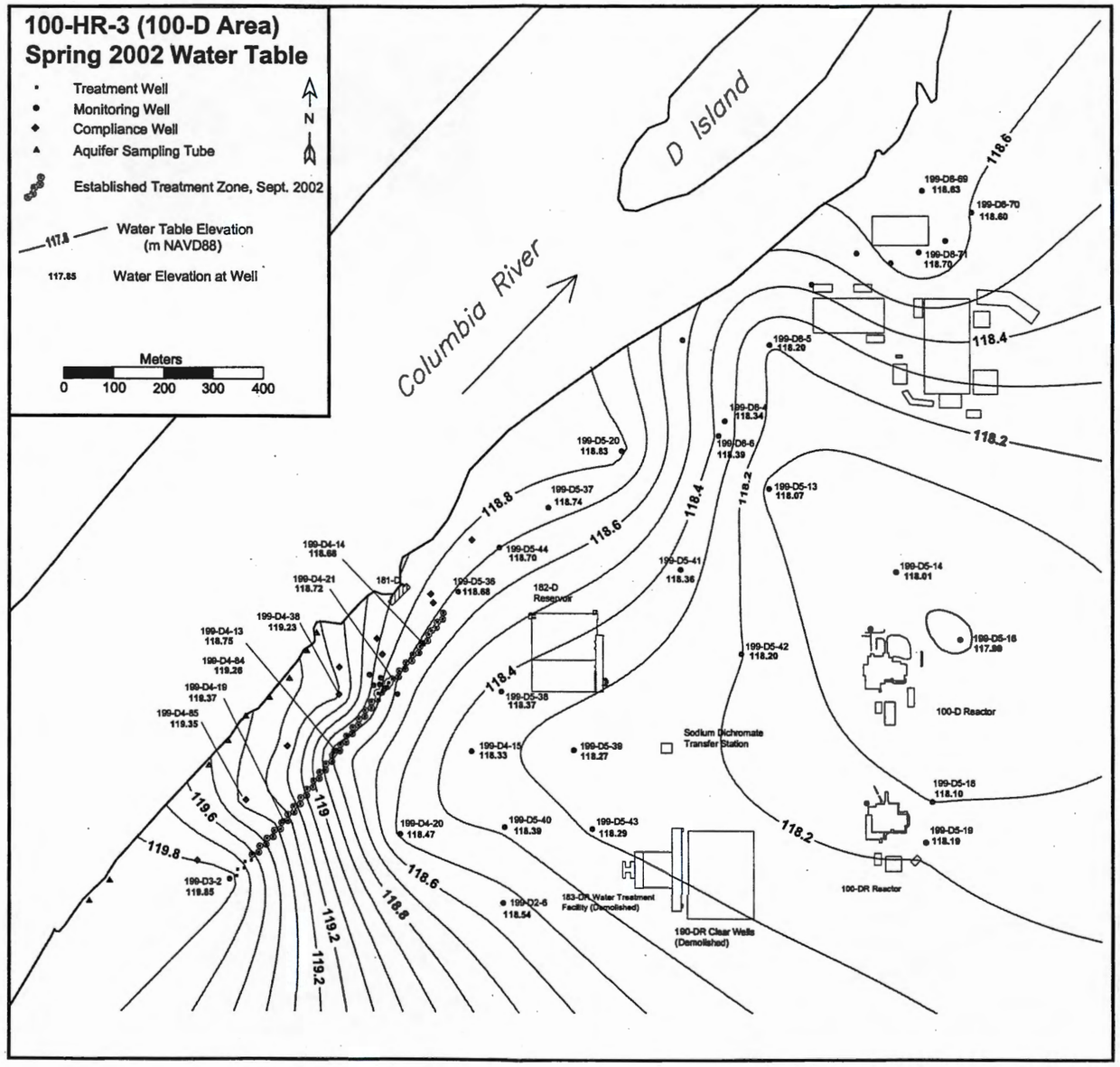


Figure 4-3. 100-D Area Water Table Map, Fall 2002.

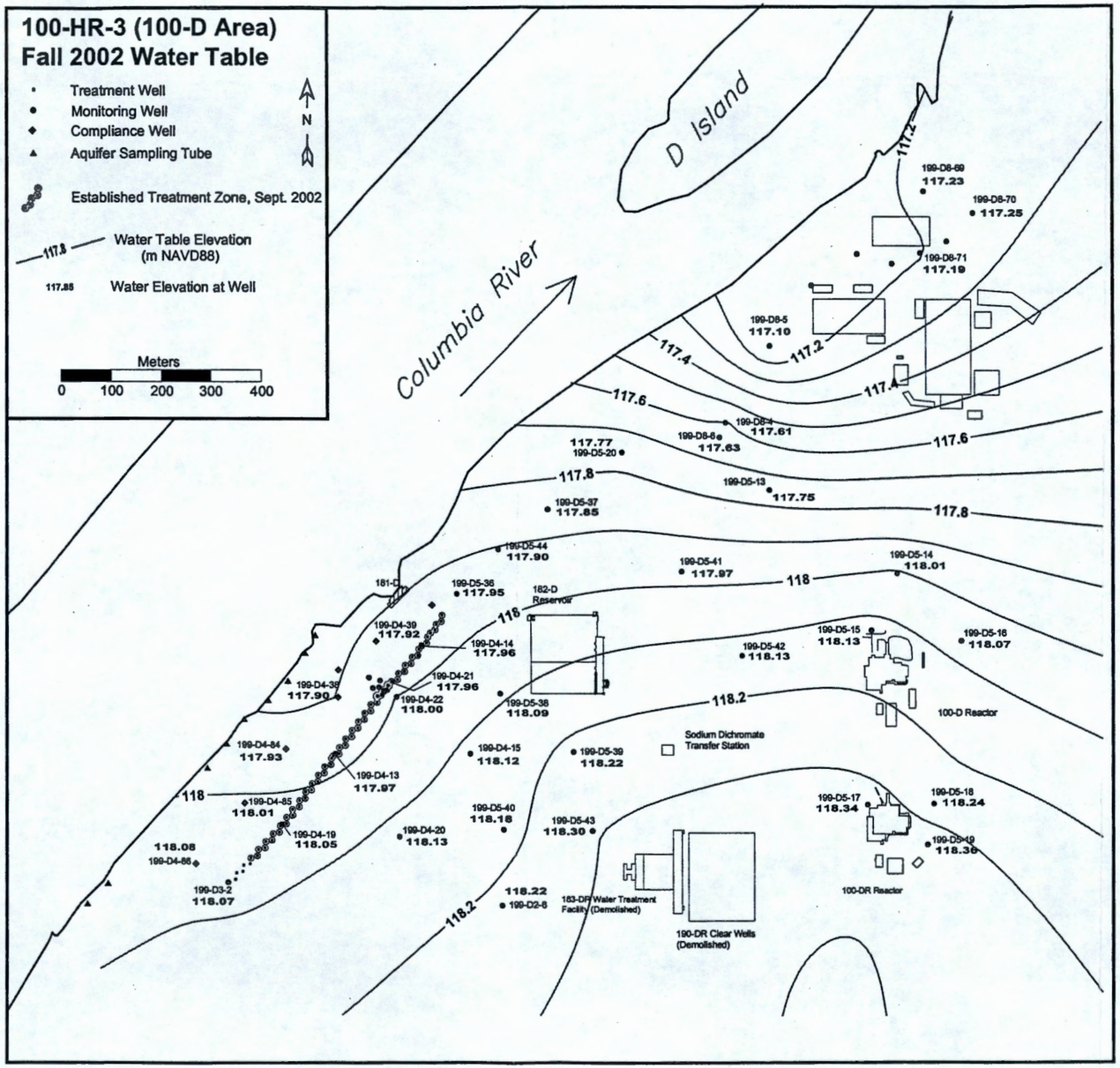
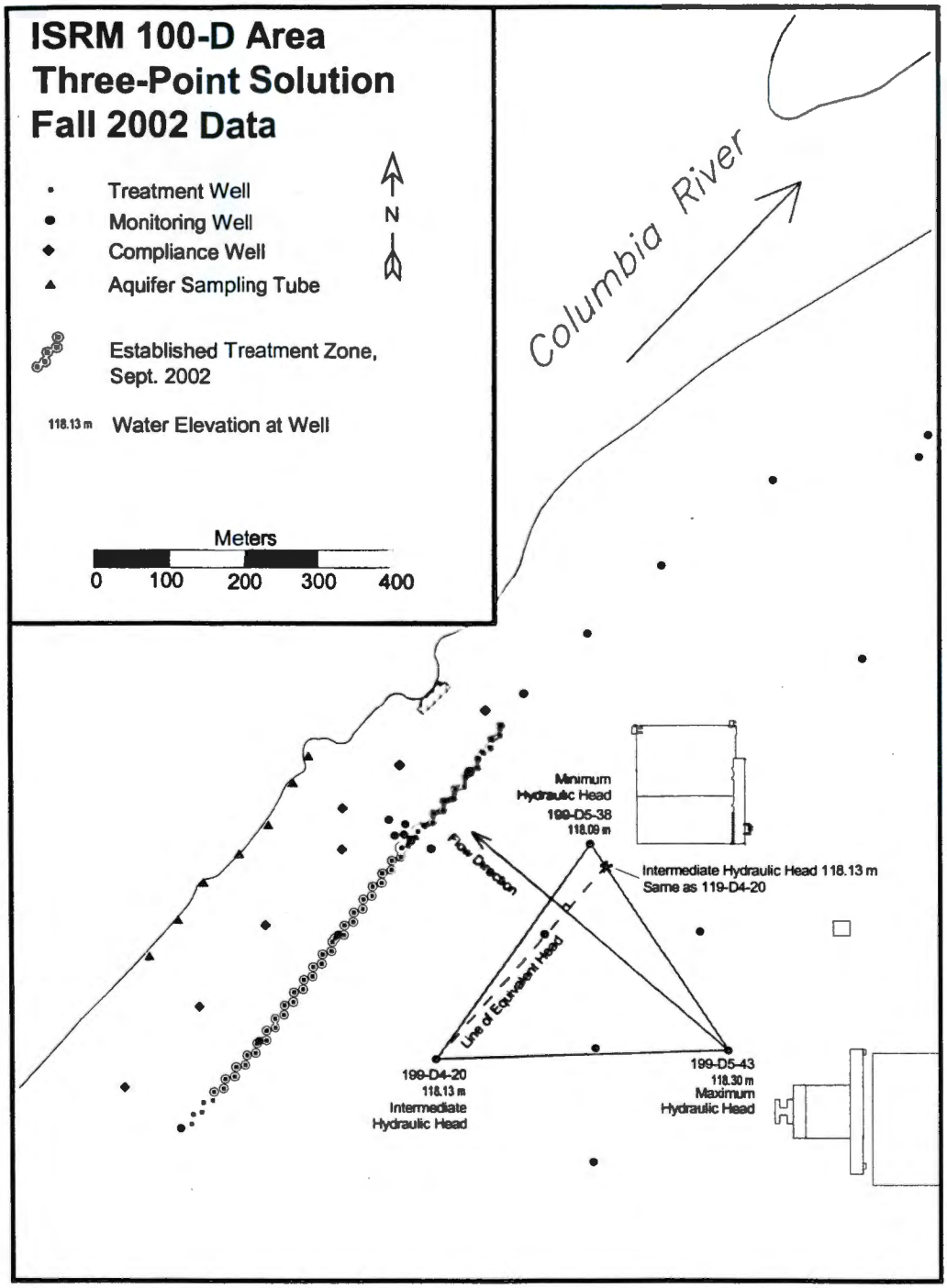
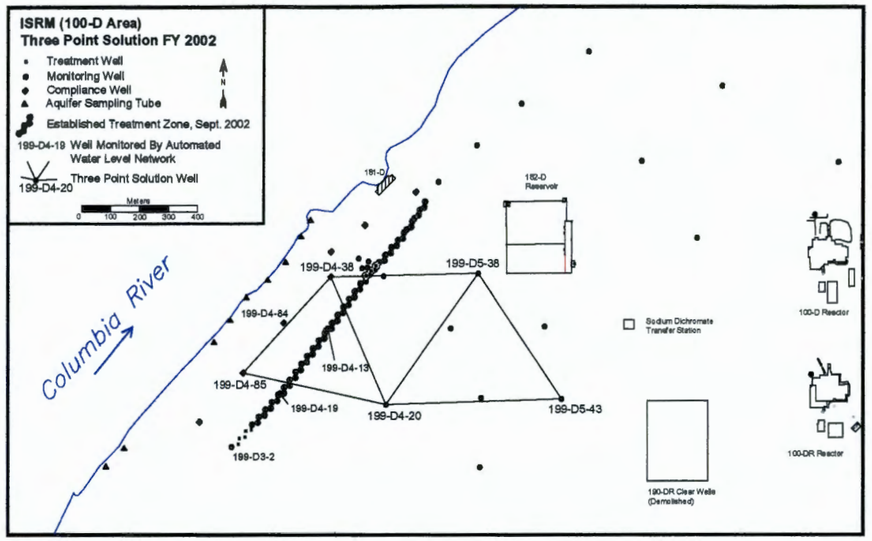


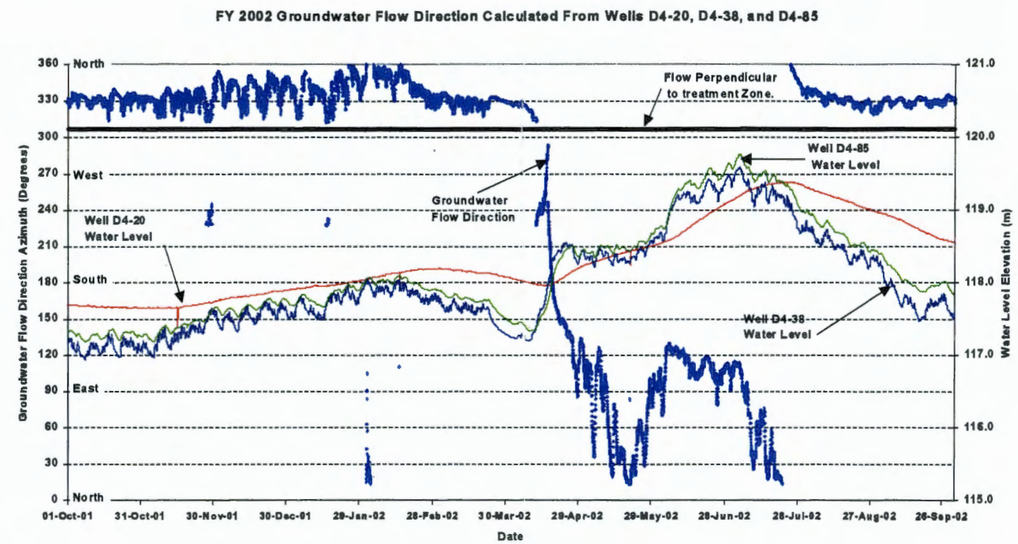
Figure 4-4. Layout of Three-Point Solution.

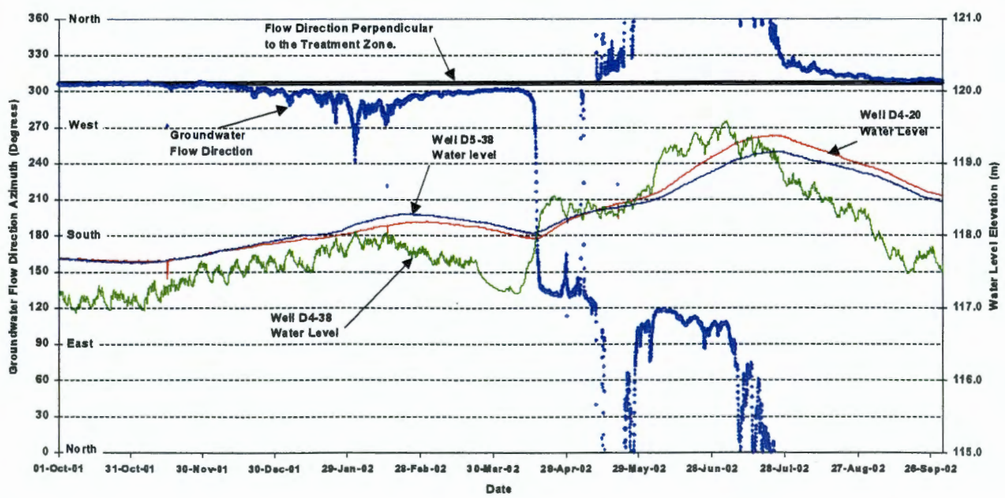


This page intentionally left blank.

Figure 4-5. Flow Direction Variations, In Situ Redox Manipulation and 100-D Area, Fiscal Year 2002.







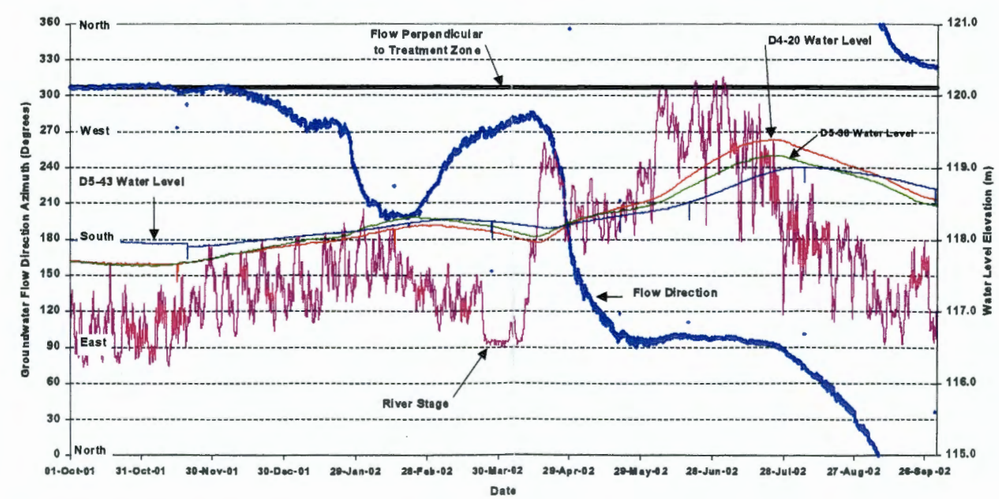


Figure 4-6. In Situ Redox Manipulation Hexavalent Chromium Plume Map, Fall 2001.

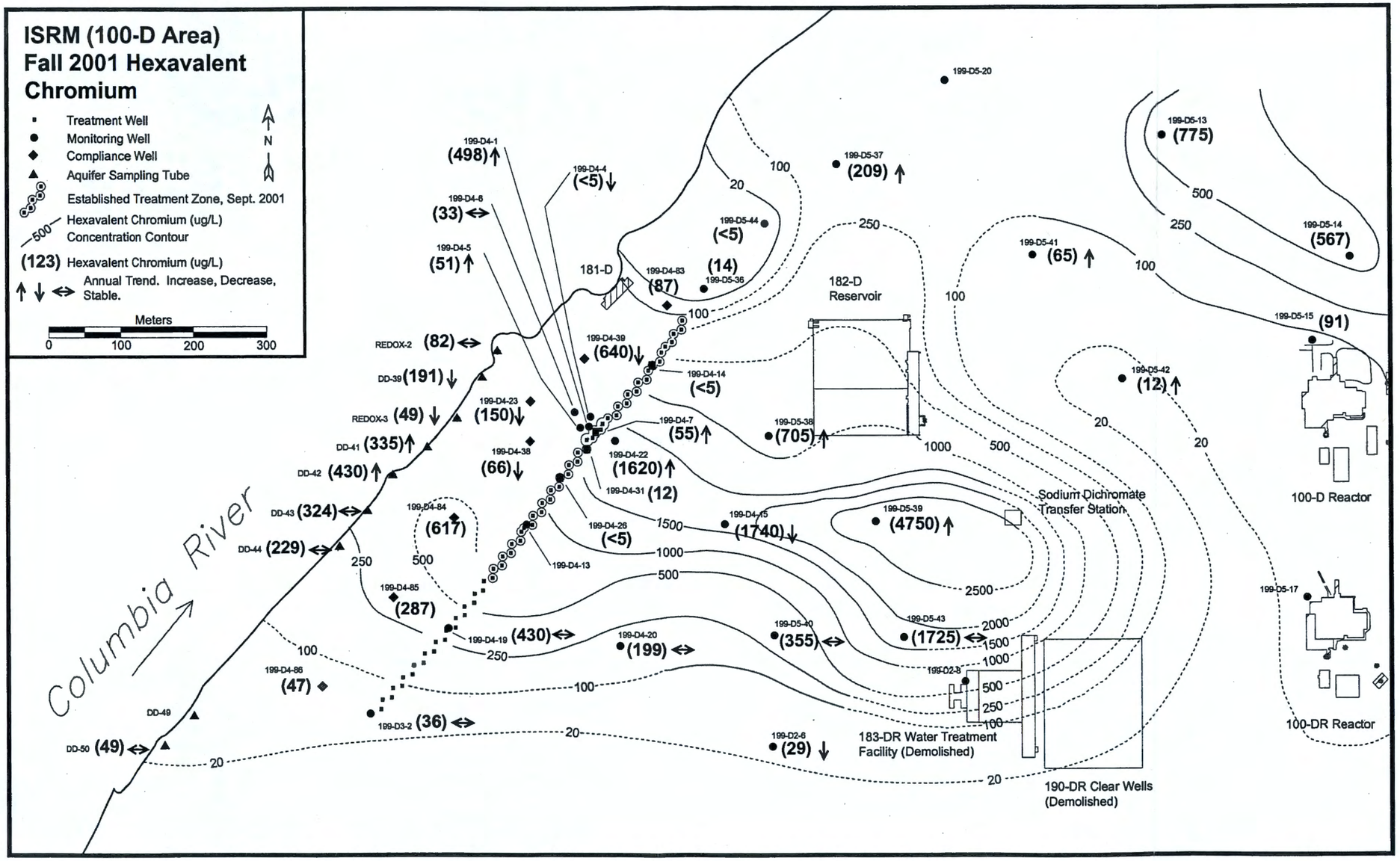


Figure 4-7. In Situ Redox Manipulation Hexavalent Chromium Plume Map, Fall 2002.

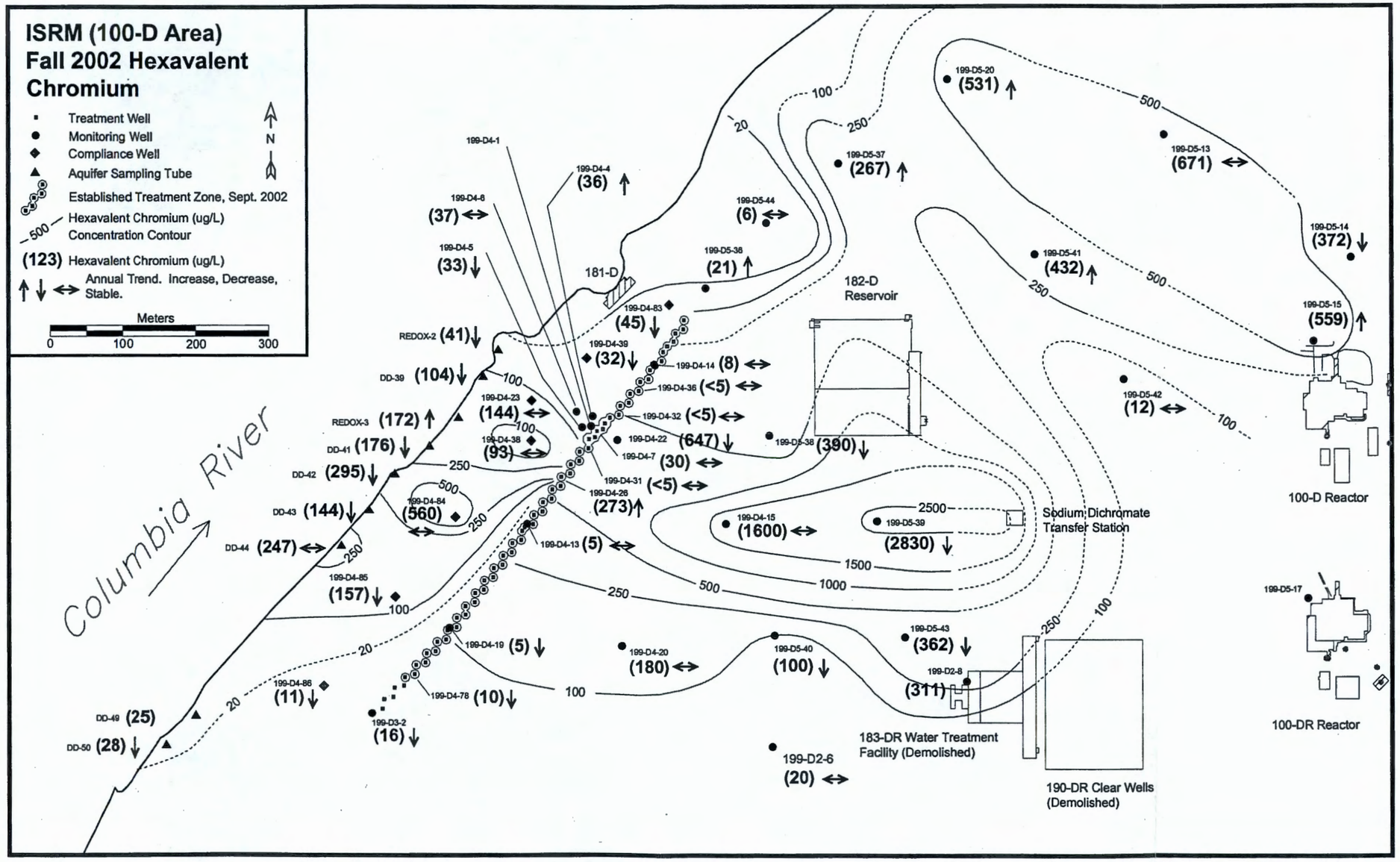


Figure 4-8. In Situ Redox Manipulation Sulfate Plume, Fall 2001.

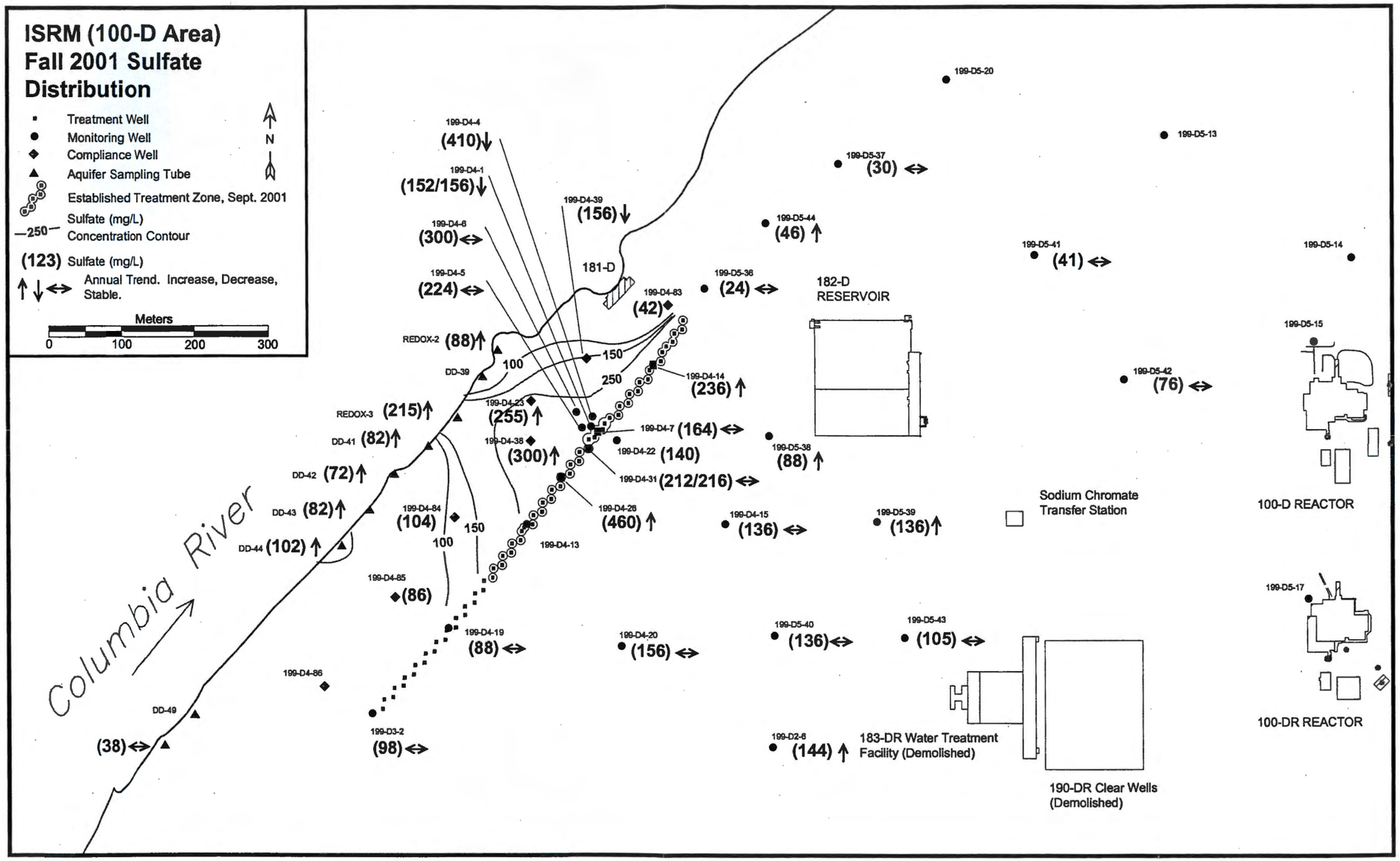


Figure 4-9. In Situ Redox Manipulation Sulfate Plume, Fall 2002.

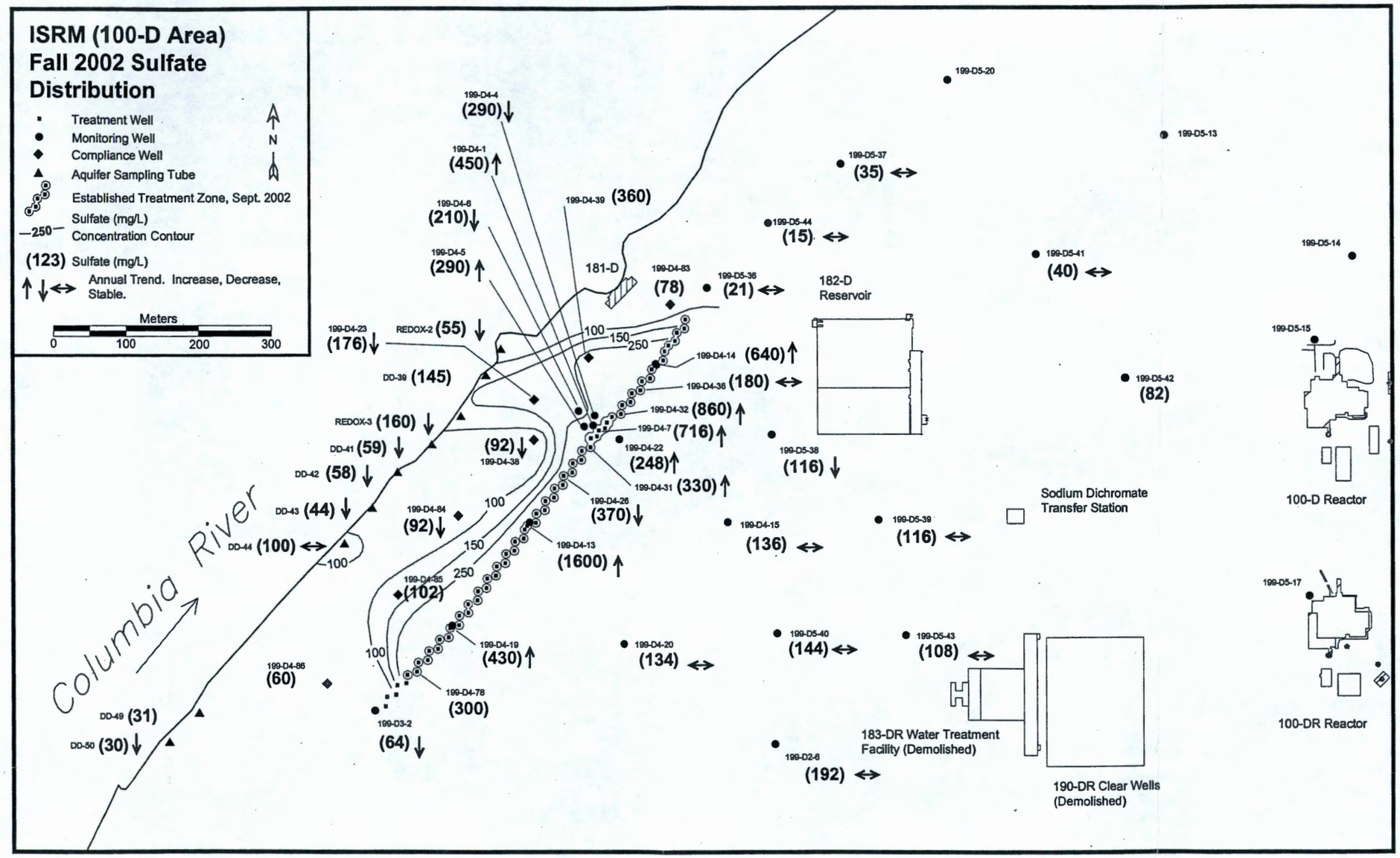


Table 4-1. Summary of Observations of Water-Level Effects During In Situ Redox Manipulation Injection. (2 sheets)

Injection Well			Adjacent Monitoring Wells	
Injection Well	Maximum Injection Head (ft)[a]	Injection Rate (gal/min)	Well Name	Maximum Head Increase (ft)[b]
199-D4-7	N/A	47.40	199-D4-08	n/a
			199-D4-09	n/a
199-D4-09	12.08	45.10	199-D4-7	8.56
			199-D4-10	10.93
199-D4-10	16.40	44.80	199-D4-09	2.36
			199-D4-31	2.18
199-D4-12	15.91	44.40	199-D4-11	3.18
			199-D4-21	1.95
199-D4-35	19.14	44.90	199-D4-34	1.11
			199-D4-36	1.10
199-D4-63	N/A	19.14[c]	199-D4-62	n/a
			199-D4-64	n/a
199-D4-64	N/A	17.6[c]	199-D4-63	n/a
			199-D4-65	n/a
199-D4-65	70.78	77.30	199-D4-64	4.62
			199-D4-66	4.40
199-D4-66	N/A	63.50	199-D4-65	n/a
			199-D4-67	n/a
199-D4-67	37.05	76.20	199-D4-66	n/a
			199-D4-68	2.49
199-D4-68	28.58	67.40	199-D4-67	2.00
			199-D4-69	1.95
199-D4-69	29.59	88.70	199-D4-68	2.47
			199-D4-70	1.76
199-D4-70	29.32	70.70	199-D4-69	1.96
			199-D4-71	1.59
199-D4-71	16.73	88.90	199-D4-70	1.80
			199-D4-72	n/a
199-D4-72	5.48	74.10	199-D4-71	1.23
			199-D4-73	1.26

Table 4-1. Summary of Observations of Water-Level Effects During In Situ Redox Manipulation Injection. (2 sheets)

Injection Well			Adjacent Monitoring Wells	
Injection Well	Maximum Injection Head (ft)[a]	Injection Rate (gal/min)	Well Name	Maximum Head Increase (ft)[b]
199-D4-73	N/A	88.00	199-D4-72	n/a
			199-D4-74	n/a
199-D4-74	26.88	86.50	199-D4-73	0.60
			199-D4-75	0.73
199-D4-75	19.42	84.50	199-D4-74	1.33
			199-D4-76	1.11
199-D4-76	10.89	79.20	199-D4-75	0.48
			199-D4-77	0.34
199-D4-77	14.73	86.80	199-D4-76	0.70
			199-D4-78	0.74
199-D4-78	54.30	88.60	199-D4-77	0.58
			199-D4-79	0.31
199-D4-79	6.00	89.10	199-D4-78	0.72
			199-D4-80	0.75

[a]Maximum measured head at injection well during injection phase.
[m]aximum measured head at adjacent monitoring wells during injection phase.
[c]Low-producing well.

N/A = not applicable.
n/a = not available.

Table 4-2. Summary of Observations of Chemical Effects During In Situ Redox Manipulation Injection and Extraction. (2 sheets)

Injection Well	Adjacent Wells*	Observations in Adjacent Wells
199-D4-7	199-D4-08 199-D4-09	A reducing condition for the main well was established. Both adjacent wells were impacted as all field parameter values matched the main well by the end of the injection. The main reason for this is that both adjacent wells are within 8.7 m of the main well.
199-D4-09	199-D4-7 199-D4-10	A reducing condition for the main well was established. Both adjacent wells were impacted as all field parameter values matched the main well by the end of the injection. Adjacent well D4-7 is within 8.7 m of the main well, while D4-10 is 11 m away.
199-D4-10	199-D4-09 199-D4-31	A reducing condition for the main well was established. Adjacent well D4-31 was not impacted. Well D4-9 was impacted as changes to pH, Eh, and conductivity noticed.
199-D4-11	199-D4-08 199-D4-12	A reducing condition for the main well was established. Adjacent well D4-08, which is 6 m from well D4-11, was highly impacted as observed by pH, Eh, and conductivity changes. Well D4-12, although treated before D4-11, was impacted as changes to Eh and conductivity observed.
199-D4-12	199-D4-11 199-D4-21	A reducing condition for the main well was established. Neither adjacent well was impacted.
199-D4-35	199-D4-34 199-D4-36	A reducing condition for the main well was established. Both adjacent wells were impacted as Eh and DO changes noticed.
199-D4-63	199-D4-62 199-D4-64	A reducing condition for the main well was not established because of lower-than-expected injection rates. Although the area immediately around the well showed changes, the low rates probably resulted in the targeted zone not being treated. There were no impacts on adjacent wells.
199-D4-64	199-D4-63 199-D4-65	A reducing condition for the main well was not established because of lower-than-expected injection rates. Although the area immediately around the well showed changes, the low rates probably resulted in the targeted zone not being treated. There were no impacts on adjacent wells.
199-D4-65	199-D4-64 199-D4-66	A reducing condition for the main well was established. Neither adjacent well was impacted.
199-D4-66	199-D4-65 199-D4-67	A reducing condition for the main well was established. Neither adjacent well was impacted.
199-D4-67	199-D4-66 199-D4-68	A reducing condition for the main well was established. Adjacent well D4-66 was not impacted. Well D4-68, although previously treated, was impacted as changes to pH, Eh, DO, dithionite, and conductivity were observed.
199-D4-68	199-D4-67 199-D4-69	A reducing condition for the main well was established. Adjacent well D4-67 was not impacted. Well D4-69, although previously treated, was impacted due to noticeable changes in pH, Eh, DO, dithionite, and conductivity.
199-D4-69	199-D4-68 199-D4-70	A reducing condition for the main well was established. Well D4-68, although previously treated, was impacted due to noticeable changes in pH, Eh, DO, dithionite, and conductivity. Adjacent well D4-67 had minimal changes to pH and Eh values.
199-D4-70	199-D4-69 199-D4-19 199-D4-71	A reducing condition for the main well was established. Adjacent well D4-71 was highly impacted as changes to all field parameter values were observed. For well D4-19, only a slight change to dithionite, but significant changes to pH, Eh, and conductivity (adjacent well D4-19 is within 6 m of the main well, while D4-71 is 11 m away). Adjacent well D4-69 was not impacted.

Table 4-2. Summary of Observations of Chemical Effects During In Situ Redox Manipulation Injection and Extraction. (2 sheets)

Injection Well	Adjacent Wells*	Observations in Adjacent Wells
199-D4-71	199-D4-70 199-D4-72	A reducing condition for the main well was established. Well D4-71, although previously treated, was slightly impacted as pH, Eh, dithionite, and conductivity changed. Well D4-72, although previously treated, was impacted as Eh, dithionite, and conductivity changes were observed.
199-D4-72	199-D4-71 199-D4-73 199-D4-19	A reducing condition for the main well was established. Adjacent well D4-71 was impacted as changes to pH, Eh, and conductivity were observed. Well D4-73 was slightly impacted as changes to pH and Eh were observed. Adjacent well D4-19 was not impacted (the higher numbers were the result of D4-70 injection). Adjacent well D4-19 was approximately 30 m from the main well.
199-D4-73	199-D4-72 199-D4-74	A reducing condition for the main well was established. Well D4-72, although previously treated, was impacted as pH, Eh, and conductivity changes were noticed. Only slight impacts were observed on well D4-74 as Eh and conductivity values changed.
199-D4-74	199-D4-73 199-D4-75	A reducing condition for the main well was established. Adjacent wells D4-73 and D4-75 were slightly impacted as pH, Eh, DO, and conductivity changes were noticed.
199-D4-75	199-D4-74 199-D4-76	A reducing condition for the main well was established. Adjacent well D4-74 was not impacted. Well D4-76, although previously treated, was highly impacted as changes to pH, Eh, dithionite, and conductivity were observed.
199-D4-76	199-D4-75 199-D4-77	A reducing condition for the main well was established. Adjacent well D4-77 was not impacted. Well D4-75 was slightly impacted due to changes in Eh and conductivity.
199-D4-77	199-D4-76 199-D4-78	A reducing condition for the main well was established. Adjacent wells D4-76 and D4-78, although previously treated, were slightly impacted as Eh and conductivity changed.
199-D4-78	199-D4-77 199-D4-79	A reducing condition for the main well was established. Adjacent well D4-79 was not impacted. Well D4-77 was impacted as changes to pH, Eh, dithionite, and conductivity were noticed.
199-D4-79	199-D4-78 199-D4-80	A reducing condition for the main well was established. Well D4-78, although previously treated, was slightly impacted as pH, Eh, dithionite, and conductivity changes were observed. Only slight impacts were observed to well D4-80 as pH, Eh, and conductivity values changed.

*Adjacent wells are typically located on opposite sides of the injection well at a distance of 10.7 m (35 ft). Some wells are located on opposite sides of the injection well at a distance of 6.1m (20 ft).

DO = dissolved oxygen.
Eh = reduction/oxidation potential.

Table 4-3. Comparison of 2001 and 2002 Semiannual Water-Level Measurements at 100-D Area. (2 sheets)

Well Name	June 2001 Water-Level Elevation NAVD88 (m)	June 2002 Water-Level Elevation NAVD88 (m)	Change (m)	November 2001 Water-Level Elevation NAVD88 (m)	November 2002 Water-Level Elevation NAVD88 (m)	Change (m)
199-D2-6	117.9	118.5	0.60	117.7	118.2	0.52
199-D3-2	117.7	n/a	n/a	117.4	118.1	0.67
199-D4-13	117.6	118.7	1.10	117.3	118.0	0.67
199-D4-14	117.4	118.7	1.30	117.3	118.0	0.66
199-D4-15	117.7	118.3	0.60	117.5	118.1	0.62
199-D4-19	117.7	119.4	1.70	117.4	118.0	0.65
199-D4-20	117.8	118.5	0.70	117.5	118.1	0.63
199-D4-21	117.5	118.7	1.20	117.3	118.0	0.66
199-D4-38	117.6	119.2	1.60	117.1	117.9	0.80
199-D5-13	117.6	118.1	0.50	117.3	117.8	0.45
199-D5-14	117.9	118.0	0.10	117.7	118.0	0.31
199-D5-15	118.0	n/a	n/a	117.8	118.1	0.33
199-D5-16	118.0	118.0	0.00	117.8	118.1	0.27
199-D5-17	118.2	n/a	n/a	118.0	118.3	0.34
199-D5-18	118.1	118.1	0.00	118.0	118.2	0.24
199-D5-19	118.3	118.2	-0.10	n/a	118.4	n/a
199-D5-20	117.6	118.8	1.20	117.1	117.8	0.67
199-D5-36	117.6	118.7	1.10	117.3	117.9	0.65
199-D5-37	117.6	118.7	1.10	117.2	117.8	0.65
199-D5-38	117.7	118.4	0.70	117.5	118.1	0.59
199-D5-39	117.9	117.7	-0.20	117.6	118.2	0.62
199-D5-40	117.8	118.4	0.60	117.6	118.2	0.56
199-D5-41	117.7	118.4	0.70	117.4	118.0	0.57
199-D5-42	117.8	118.2	0.40	117.6	118.1	0.53

Table 4-3. Comparison of 2001 and 2002 Semiannual Water-Level Measurements at 100-D Area. (2 sheets)

Well Name	June 2001 Water-Level Elevation NAVD88 (m)	June 2002 Water-Level Elevation NAVD88 (m)	Change (m)	November 2001 Water-Level Elevation NAVD88 (m)	November 2002 Water-Level Elevation NAVD88 (m)	Change (m)
199-D5-43	117.9	118.3	0.40	117.8	118.3	0.50
199-D5-44	117.6	118.7	1.10	117.3	117.9	0.61
199-D8-4	117.4	118.3	0.97	117.2	117.6	0.41
199-D8-5	117.3	118.2	0.87	116.8	117.1	0.30
199-D8-53	117.3	118.6	1.30	N/M	n/a	n/a
199-D8-54B	117.7	118.8	1.10	116.9	117.5	0.56
199-D8-6	117.4	118.4	1.00	117.1	117.6	0.53
199-D8-68	117.1	119.4	2.30	116.5	n/a	n/a
199-D8-69	117.1	118.6	1.50	116.6	117.2	0.63
199-D8-70	117.1	118.6	1.50	116.6	115.5	-1.12
199-D8-71	117.1	118.7	1.60	116.6	119.0	2.36
		Average Change	**0.89**		**Average Change**	**0.55**

n/a = not available.

NAVD88, *North American Vertical Datum of 1988.*

Table 4-4. Hexavalent Chromium Concentrations in In Situ Redox Manipulation Monitoring and Compliance Wells. (2 sheets)

Well Name	FY 2000 (Average)	FY 2001 (Average)	FY 2002					Annual Comparison[a]
			1st Quarter FY 2002	2nd Quarter FY 2002	3rd Quarter FY 2002	4th Quarter FY 2002	FY 2002 (Average)	
	Inductively Coupled Plasma/Hexavalent Chromium Concentration (µg/L)							
199-D2-6	92	41	77.8[b]	5.0 (U)	18/19	(21/19)	30.33	Decreasing
199-D3-2	27	32	n/a	21	21	16	19.33	Decreasing
199-D4-6	36	31	35	28	34	37	33.50	Stable
199-D4-13	150	555	5.8[b]	5	8	5	5.95	Decreasing
199-D4-14	524	N/A	5.8/5.8[b] (U)	5.0 (U)	5	8	5.95	N/A
199-D4-15	2,050	1655	1530[b]	1730	1590	1600	1612.50	Stable
199-D4-19	468	452	430[b]	431	235	5	275.25	Decreasing
199-D4-20	208	203	151[b]	147/149	(146/137)	181/179	155.13	Decreasing
199-D4-22	1,050	1467	1420	1570	(1340/1350)	647	1245.50	Stable
199-D4-23	673	365	175	159/160	199	143/145	169.38	Decreasing
199-D4-26	n/a	n/a	N/A	17	8	(267/279)	99.33	N/A
199-D4-31	n/a	n/a	5.8 (U)[b]	n/a	8	5	6.27	N/A
199-D4-32	n/a	n/a	5.8 (U)[b]	6	5	5	5.45	N/A
199-D4-36	n/a	n/a	5.8 (U)[b]	8/7	8/0 (U)	5 (U)	5.80	N/A
199-D4-38	731	253	29.8[b]	210	121	93	113.45	Decreasing
199-D4-39	512	148	944/958[b]	1170	908/911	32	765.63	Increasing
199-D5-20	113	206	180[b]	(423/429)	367	531	376.00	Increasing
199-D5-36	5.0 (U)	N/A	13.2[b]	7	7/6	21	13.73	Increasing
199-D5-37	47	152	230[b]	293	337	(264/270)	281.75	Increasing
199-D5-38	428	841	1050[b]	1060	919/1380	(389/392)	912.50	Stable
199-D5-39	1108	2707	5510/5660[b]	2020	2090	2830	3131.25	Stable
199-D5-40	289	337	352[b]	293/293	171	100	229.00	Decreasing
199-D5-41	78	107	48.8[b]	71	249	432	200.20	Increasing
199-D5-42	5.0 (U)	10	13.1[b]	13	(19/14)	12	13.65	Increasing
199-D5-43	2,132	2039	1350[b]	1410/1420	1380	360/364	1126.75	Decreasing
199-D5-44	5.0 (U)	N/A	6.3[b]	7	5 (U)	6	6.08	N/A
199-D4-1	5.0 (U)	278	426/416	282	148	n/a	283.67	Stable
199-D4-4	32	10	5.8 (U)[b]	16	57	37/38	29.08	Increasing
199-D4-5	41	102	324	(415/415)	327	33	274.75	Increasing

Table 4-4. Hexavalent Chromium Concentrations in In Situ Redox Manipulation Monitoring and Compliance Wells. (2 sheets)

Well Name	FY 2000 (Average)	FY 2001 (Average)	FY 2002					Annual Comparison[a]
			1st Quarter FY 2002	2nd Quarter FY 2002	3rd Quarter FY 2002	4th Quarter FY 2002	FY 2002 (Average)	
	Inductively Coupled Plasma/Hexavalent Chromium Concentration (µg/L)							
199-D4-7	48	242	339/354	(39/35)	23	n/a	135.50	Decreasing
199-D4-62	n/a	N/A	5.8 (U)[b]	6	5	n/a	5.60	N/A
199-D4-83	N/A	N/A	115[b]	25	68	45	63.25	N/A
199-D4-84	N/A	N/A	593[b]	558	562	559/562	568.38	N/A
199-D4-85	N/A	N/A	256[b]	345/337	277	157	257.75	N/A
199-D4-86	N/A	N/A	27[b]	24	8	11	17.50	N/A

[a]Annual comparison is the percent difference between FY 2002 and FY 2001 (or two most recent years) and is calculated by the following equation: (FY 2002-FY 2001)/FY 2001 x 100 percent. Wells are considered stable if there is less than a 20 percent change in concentration from FY 2001 to FY 2002.

[b]Reported concentrations are from inductively coupled plasma metals analysis.

(132/131) = Indicates sample results from splits. Values are averaged to calculate the FY 2002 annual average.
172/152 = Indicates sample results from duplicates. Values are averaged to calculate the FY 2002 annual average.

FY = fiscal year.
N/A= not applicable.
n/a = not available.
(U) = undetected.

Table 4-5. Fiscal Year 2002 In Situ Redox Manipulation Treatment Zone Operational Sampling Hexavalent Chromium Results. (2 sheets)

Well Name	Injection Date(s)	Hexavalent Chromium Concentrations (µg/L)						Estimated [a] Proximal Upgradient Concentrations	% Effective[b]
		Dec. 01	Jan. 02	Feb. 02	Apr. 02	June 02	Sept 02		
199-D4-79	2002	n/a	n/a	n/a	n/a	n/a	0	10	100
199-D4-78	2002	n/a	n/a	n/a	n/a	n/a	0	10	100
199-D4-77	2002	n/a	n/a	n/a	n/a	n/a	0	10	100
199-D4-76	2002	n/a	n/a	n/a	n/a	n/a	0	10	100
199-D4-75	2002	n/a	n/a	n/a	n/a	n/a	0	10	100
199-D4-74	2002	n/a	n/a	n/a	n/a	n/a	0	10	100
199-D4-73	2002	n/a	n/a	n/a	n/a	n/a	0	10	100
199-D4-72	2002	n/a	n/a	n/a	n/a	n/a	0	10	100
199-D4-71	2002	n/a	n/a	n/a	n/a	n/a	0	10	100
199-D4-70	2002	n/a	n/a	n/a	n/a	n/a	0	175	100
199-D4-69	2002	n/a	n/a	n/a	n/a	n/a	10	175	94
199-D4-68	2002	n/a	n/a	n/a	n/a	n/a	0	175	100
199-D4-67	2002	n/a	n/a	n/a	n/a	n/a	0	175	100
199-D4-66	2002	n/a	n/a	n/a	n/a	n/a	10	175	94
199-D4-65	2002	n/a	n/a	n/a	n/a	n/a	0	175	100
199-D4-64	2002	n/a	n/a	n/a	n/a	n/a	0	175	100
199-D4-63	2002	n/a	n/a	n/a	n/a	n/a	0	175	100
199-D4-62	2001	n/a	n/a	n/a	n/a	n/a	30	175	83
199-D4-61	2001	n/a	n/a	n/a	n/a	0	0	175	100
199-D4-60	2001	n/a	n/a	n/a	n/a	50	0	175	100
199-D4-59	2001	n/a	n/a	n/a	n/a	120	0	175	100
199-D4-58	2001	n/a	n/a	n/a	n/a	0	0	175	100
199-D4-57	2001	n/a	n/a	n/a	n/a	0	0	375	100
199-D4-56	2001	n/a	n/a	n/a	n/a	10	0	375	100
199-D4-55	2001	n/a	n/a	n/a	n/a	0	0	375	100
199-D4-54	2001	n/a	n/a	n/a	n/a	30	0	375	100
199-D4-53	2001	n/a	n/a	n/a	n/a	10	0	375	100
199-D4-52	2001	n/a	n/a	n/a	n/a	0	0	375	100
199-D4-51	2001	n/a	n/a	n/a	n/a	10	0	375	100
199-D4-50	2001	n/a	n/a	n/a	n/a	10	0	375	100
199-D4-49	2001	n/a	n/a	n/a	n/a	150	0	647	100
199-D4-24	2001	n/a	n/a	n/a	0	0	0	647	100
199-D4-25	2001	n/a	0	n/a	0	0	20	647	97
199-D4-26	2000	n/a	0	n/a	0	0	200	647	69
199-D4-27	2000	n/a	0	n/a	0	0	10	647	98

Table 4-5. Fiscal Year 2002 In Situ Redox Manipulation Treatment Zone Operational Sampling Hexavalent Chromium Results. (2 sheets)

Well Name	Injection Date(s)	Hexavalent Chromium Concentrations (µg/L)						Estimated [a] Proximal Upgradient Concentrations	% Effective[b]
		Dec. 01	Jan. 02	Feb. 02	Apr. 02	June 02	Sept 02		
199-D4-28	2000	n/a	0	n/a	0	0	0	647	100
199-D4-29	2000	n/a	10	n/a	0	0	0	647	100
199-D4-30	2000	n/a	10	n/a	0	0	10	647	98
199-D4-31	2000	n/a	n/a	n/a	0	0	0	647	100
199-D4-10	1998, 2002	70	20	83	10	0	10	647	98
199-D4-9	1998, 2002	700	660	558	960	40	10	647	98
199-D4-7	1997, 2002	530	n/a	n/a	620	0	30	647	95
199-D4-8	Not treated	140	230	n/a	210	0	10	647	98
199-D4-3	Not treated	n/a	1320	n/a	1240	105	0	647	100
199-D4-2	Not treated	n/a	1720	n/a	1480	95	0	647	100
199-D4-11	1998, 2002	310	340	416	540	0	10	647	98
199-D4-5	Not treated	n/a	670	n/a	410	0	0	647	100
199-D4-4	Not treated	n/a	40	n/a	300	10	10	647	98
199-D4-12	1998, 2002	n/a	140	0	270	0	0	647	100
199-D4-21	1998	n/a	0	n/a	0	0	0	647	100
199-D4-32	2000	n/a	n/a	n/a	0	0	0	375	100
199-D4-33	2000	n/a	0	n/a	0	0	0	375	100
199-D4-34	2000	n/a	10	n/a	n/a	0	0	375	100
199-D4-35	2000, 2002	n/a	1000	n/a	760	180	0	375	100
199-D4-36	2000	n/a	n/a	n/a	0	20	0	375	100
199-D4-37	2001	n/a	0	n/a	0	0	220	375	41
199-D4-40	2001	n/a	n/a	n/a	n/a	40	20	375	95
199-D4-41	2001	n/a	n/a	n/a	n/a	20	20	375	95
199-D4-42	2001	n/a	n/a	n/a	n/a	10	10	375	97
199-D4-43	2001	n/a	n/a	n/a	n/a	10	0	175	100
199-D4-44	2001	n/a	n/a	n/a	n/a	0	0	175	100
199-D4-45	2001	n/a	n/a	n/a	n/a	0	20	175	89
199-D4-46	2001	n/a	n/a	n/a	n/a	10	0	175	100
199-D4-47	2001	n/a	n/a	n/a	n/a	10	0	375	100
199-D4-48	2001	n/a	n/a	n/a	n/a	10	0	375	100

[a] Estimated Proximal Upgradient Concentrations are estimated from the plume contours (Figure 4-7) or from upgradient monitoring well if available, i.e., well 199-D4-22

[b] % Effective = ((Estimated Proximal Upgradient Concentration – Sept 02 Concentration) / Estimated Proximal Upgradient Concentration) x 100

Table 4-6. Sulfate Concentrations in In Situ Redox Manipulation Monitoring and Compliance Monitoring Wells. (2 sheets)

Well Name	FY 2000 (Average)	FY 2001 (Average)	FY 2002					Annual Comparison*
			1st Quarter FY 2002	2nd Quarter FY 2002	3rd Quarter FY 2002	4th Quarter FY 2002	FY 2002 (Average)	
	Sulfate Concentration (mg/L)							
199-D2-6	183	121.3	139	140	152/152	192	155.8	Increasing
199-D3-2	74	80.1	n/a	(62/62.8)	31	64	52.5	Decreasing
199-D4-6	455	282.7	298	156	280	210	236.0	Stable
199-D4-13	150	106	636	700	580	1600	879.0	Increasing
199-D4-14	56	127.3	178/174	168	172	640	289.0	Increasing
199-D4-15	133	119	130	132	132	144	134.5	Stable
199-D4-19	78	84.6	89.3	92	160	430	192.8	Increasing
199-D4-20	118	129	135	128/136	136	132/136	134.3	Stable
199-D4-22	n/a	110.7	(132/131)	144	(144/141)	248	166.5	Increasing
199-D4-23	144	226.3	248/250	288/280	244	176/176	238.3	Stable
199-D4-26	n/a	308	n/a	(630/690)	440	370	490.0	Increasing
199-D4-31	n/a	206.5	174	n/a	260	330	254.7	Increasing
199-D4-32	N/A	N/A	227	276	236	860	399.8	N/A
199-D4-36	n/a	n/a	105	330/330	200	180	203.8	N/A
199-D4-38	205	231	314	148	128	92	170.5	Decreasing
199-D4-39	230	162.5	142/144	152	172/152	360	204.3	Decreasing
199-D5-36	17	17.6	20.9	16	1	21	17.2	Stable
199-D5-37	35	31.5	35.1	33	35	(35/32.4)	34.2	Stable
199-D5-38	77	94.9	101	114	72	64	87.8	Stable
199-D5-39	84	121.3	(110/104)	140	108	144	124.8	Stable
199-D5-40	117	116.7	123	112/120	132	144	128.8	Stable
199-D5-41	40	41.1	42.3	45	37	40	41.1	Stable
199-D5-42	69	81.2	62	64	(60/71.3)	82	68.4	Stable
199-D5-43	101	115	95.2	98/94	100	100/100	97.8	Stable
199-D5-44	15	21.3	13.6	11	15	15	13.7	Decreasing
199-D4-1	n/a	169.8	150/152	156	192	450	166.3	Increasing
199-D4-4	n/a	521.8	349	300	240	290/290	294.8	Decreasing
199-D4-5	n/a	210	186	160	200	290	209.0	Stable
199-D4-7	n/a	153	(152/156)	152	248	716	317.5	Increasing

Table 4-6. Sulfate Concentrations in In Situ Redox Manipulation Monitoring and Compliance Monitoring Wells. (2 sheets)

Well Name	FY 2000 (Average)	FY 2001 (Average)	FY 2002					Annual Comparison*
			1st Quarter FY 2002	2nd Quarter FY 2002	3rd Quarter FY 2002	4th Quarter FY 2002	FY 2002 (Average)	
	Sulfate Concentration (mg/L)							
199-D4-62	N/A	N/A	619	650	410	n/a	559.7	N/A
199-D4-83	N/A	N/A	46.7	18	21	78	40.9	N/A
199-D4-84	N/A	N/A	99.4	94	72	92/92	89.4	N/A
199-D4-85	N/A	N/A	88.3	86	70	102	86.6	N/A
199-D4-86	N/A	N/A	89.2	n/a	46	60	65.1	N/A

*Annual comparison is the percent difference between FY 2002 and FY 2001 (or two most recent years) and is calculated by the following equation: (FY 2002-FY 2001)/FY 2001 x 100 percent. Wells are considered stable if there is less than a 20 percent change in concentration from FY 2001 to FY 2002.

(132/131) = Indicates sample results from splits. Values are averaged to calculate the FY 2002 annual average.

172/152 = Indicates sample results from duplicates. Values are averaged to calculate the FY 2002 annual average.

FY = fiscal year.
N/A = not applicable.
n/a = not available.

Table 4-7. Summary of Hexavalent Chromium and Sulfate in Aquifer Tubes Downgradient of the In Situ Redox Manipulation Treatment Zone.

Tube Name	Hexavalent Chromium Concentration (µg/L)					Annual Comparison*
	Fall 1998	Fall 1999	Fall 2000	Fall 2001	Fall 2002	
DD-39	783	641	437	191	104	Decreasing
DD-41	234	n/a	n/a	335	176	Decreasing
DD-42	n/a	n/a	276	430	295	Decreasing
DD-43	n/a	n/a	304	324	144	Decreasing
DD-44	309	330	253	229	247	Stable
DD-49	n/a	n/a	n/a	n/a	25	N/A
DD-50	41	34	42	49	28	Decreasing
Redox-1	n/a	n/a	420	n/a	n/a	N/A
Redox-2	n/a	n/a	78	82	41	Decreasing
Redox-3	n/a	n/a	521	119	172	Increasing
Tube Name	**Sulfate Concentration (mg/L)**					**Annual Comparison***
	Fall 1998	**Fall 1999**	**Fall 2000**	**Fall 2001**	**Fall 2002**	
DD-39	118	130	90	n/a	145	N/A
DD-41	28	n/a	44	82	59	Decreasing
DD-42	n/a	n/a	52	72	58	Decreasing
DD-43	n/a	n/a	62	82	44	Decreasing
DD-44	70	90	69	102	100	stable
DD-49	n/a	n/a	n/a	n/a	31	N/A
DD-50	30	36	35	38	30	Stable
Redox-1	n/a	n/a	66	n/a	n/a	N/A
Redox-2	n/a	n/a	68	88	55	Decreasing
Redox-3	n/a	n/a	110	215	160	Decreasing

*Annual comparison is the percent difference between FY 2002 and FY 2001 and is calculated by the following equation: (FY 2002-FY 2001)/FY 2002 x 100 percent. Values are considered stable if there is less than a 20 percent change in concentration from FY 2001 to FY 2002.

FY = fiscal year.
N/A = not applicable.
n/a = not available.

This page intentionally left blank.

5.0 QUALITY ASSURANCE/QUALITY CONTROL

Field replicates, offsite laboratory replicates, and field/offsite laboratory splits are quality control samples used to assess the precision of chemical analyses.

Establishing the precision of analyses by field screening consisted of comparing analyses 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.

5.1 CHROMIUM

Results of the quality control analyses performed during FY 2002 are included in Table 5-1 for hexavalent chromium and total chromium by well number, sample date, sample number, result, and RPD.

The RPD of 15 field replicates analyzed for hexavalent chromium ranged from 0.0 to 15.4 percent. The U.S. Environmental Protection Agency functional guideline is ±20 percent for these types of analyses (*Laboratory Data Validation Functional Guidelines for Evaluating Inorganics Analyses,* EPA/540/R-94/083). All 15 replicate analyses fell within the guideline.

Similarly, three pairs of offsite laboratory replicates were analyzed for total chromium with an RPD range of 0.0 to 1.4 percent.

In addition, 23 filtered/unfiltered sample pairs were collected and analyzed for total chromium in an offsite laboratory. The RPD range when comparing filtered results to unfiltered results was 0.0 to 34.3 percent. Only one of the 22 pairs had an RPD greater than 20 percent. These results suggest that there is very little difference in total chromium results between filtered and unfiltered samples from these wells.

Thirteen replicate samples were split and analyzed in the field using field method COLOR_TK_FIELD[2] and then in an offsite laboratory using method 7196_CR6.[2] The RPD range was from 0.8 to 30.3 percent. Eleven of 13 replicate RPDs were less than 20 percent. There was no consistent bias between field and offsite laboratory analyses in that seven field analyses were higher than the corresponding offsite laboratory split.

Finally, 15 sample pairs were collected and split. The field samples were filtered and analyzed for hexavalent chromium using method COLOR_TK_FIELD.[2] The offsite samples were

---

[2] Methods are taken from the Hanford Environmental Information System database.

analyzed in the Pacific Northwest National Laboratory without filtering using method Cr6_Hatch_M. The range of the RPDs was from 0.6 to 48.6 percent; 12 of 16 RPDs were less than 20 percent. Additionally, 11 of 15 filtered field results were higher than the corresponding unfiltered offsite laboratory result, which is reasonable considering the quick degradation of hexavalent chromium with time.

5.2 SULFATE

Results of the quality control analyses performed during FY 2002 are included in Table 5-2 for sulfate by well number, sample date, sample number, result, and RPD. The precision for the sulfate analyses is quite good, as summarized below.

Sixteen pairs of unfiltered field replicates were analyzed. The RPDs ranged from 0.0 to 12.3 percent. Fifteen of the 16 pairs had RPDs less than 6.9 percent.

Five pairs of unfiltered offsite laboratory replicates were analyzed. The RPDs ranged from 0.8 to 2.3 percent.

Three pairs of unfiltered field and offsite laboratory splits were analyzed. The RPDs ranged from 2.1 to 17.2 percent.

Two pairs of unfiltered offsite laboratory splits were analyzed. The RPDs were 0.8 and 5.6 percent.

Table 5-1. Fiscal Year 2001 Quality Control Sample Analyses for Hexavalent Chromium in 100-D Area Wells. (3 sheets)

Well Name	Sample Date	Constituent	Reported Value #1 (µg/L)	Sample Number	Reported Value #2 (µg/L)	Sample Number	RPD
Field Replicates							
199-D2-6	15-May-2002	Hexavalent chromium	18	B14F59	21	B14F61	15.4%
199-D4-15	22-May-2002	Hexavalent chromium	1670	B14F43	1660	B14F45	0.6%
199-D4-20	14-Feb-2002	Hexavalent chromium	147	B13XL2	149	B13XL0	1.4%
199-D4-20	29-Aug-2002	Hexavalent chromium	181	B14YV3	179	B14YV5	1.1%
199-D4-23	22-Feb-2002	Hexavalent chromium	159	B13XD7	160	B13XD5	0.6%
199-D4-23	27-Aug-2002	Hexavalent chromium	143	B15051	145	B15053	1.4%
199-D4-36	19-Feb-2002	Hexavalent chromium	8	B13XM2	7	B13XM4	13.3%
199-D4-39	15-May-2002	Hexavalent chromium	911	B14F75	908	B14F77	0.3%
199-D4-4	3-Sep-2002	Hexavalent chromium	37	B15067	38	B15069	2.7%
199-D4-84	5-Sep-2002	Hexavalent chromium	559	B15085	562	B15087	0.5%
199-D5-36	30-Apr-2002	Hexavalent chromium	7	B14F87	6	B14F89	15.4%
199-D5-38	18-Jun-2002	Hexavalent chromium	444	B14N09	445	B14N07	0.2%
199-D5-40	20-Feb-2002	Hexavalent chromium	293	B13XH2	293	B13XH0	0.0%
199-D5-43	20-Feb-2002	Hexavalent chromium	1410	B13XT1	1420	B13XT3	0.7%
199-D5-43	29-Aug-2002	Hexavalent chromium	360	B14YX2	364	B14YX4	1.1%
Offsite Laboratory Replicates							
199-D4-1	15-Nov-2001	Total chromium	422	B13DM2	416	B13DM4	1.4%
199-D4-39	15-Nov-2001	Total chromium	944	B13DP1	958	B13DP3	1.5%
199-D4-7	26-Nov-2001	Total chromium	324	B13CX2	324	B13CX6	0.0%
Offsite Laboratory Filtered vs Unfiltered Pairs							
			Filtered		**Unfiltered**		
199-D4-22	30-Nov-2001	Hexavalent chromium	1420	B13CV8	1430	B13D88	0.7%
199-D4-23	27-Nov-2001	Hexavalent chromium	175	B13CW2	176	B13D90	0.6%
199-D4-5	28-Nov-2001	Hexavalent chromium	324	B13CW6	326	B13D92	0.6%
199-D4-6	15-Nov-2001	Hexavalent chromium	35	B13CW8	33	B13D93	5.9%
199-D4-7	26-Nov-2001	Hexavalent chromium	339	B13CX0	321	B13CX1	5.5%
199-D4-7	26-Nov-2001	Hexavalent chromium	354	B13CX4	329	B13CX5	7.3%
199-D2-6	15-Nov-2001	Total chromium	77.8	B13B32	110	B13B33	34.3%
199-D3-2	30-Jan-2002	Total chromium	17.4	B13Y38	18.1	B13Y37	3.9%
199-D4-13	19-Nov-2001	Total chromium	5.8 (U)	B13B38	5.8 (U)	B13B39	N/A
199-D4-14	19-Nov-2001	Total chromium	5.8 (U)	B13B42	5.8 (U)	B13B41	N/A
199-D4-14	19-Nov-2001	Total chromium	5.8 (U)	B13B40	5.8 (U)	B13B43	N/A
199-D4-15	15-Nov-2001	Total chromium	1530	B13B44	1550	B13B45	1.3%

Table 5-1. Fiscal Year 2001 Quality Control Sample Analyses for Hexavalent Chromium in 100-D Area Wells. (3 sheets)

Well Name	Sample Date	Constituent	Reported Value #1 (µg/L)	Sample Number	Reported Value #2 (µg/L)	Sample Number	RPD
199-D4-19	20-Nov-2001	Total chromium	430	B13B46	429	B13B47	0.2%
199-D4-20	15-Nov-2001	Total chromium	151	B13B48	153	B13B49	1.3%
199-D4-22	30-Nov-2001	Total chromium	1340	B13B50	1370	B13B51	2.2%
199-D4-22	30-Nov-2001	Total chromium	1400	B13B52	1410	B13B53	0.7%
199-D4-23	27-Nov-2001	Total chromium	177	B139J6	176	B139J7	0.6%
199-D4-23	27-Nov-2001	Total chromium	163	B139K7	175	B139L3	7.1%
199-D5-20	20-Nov-2001	Total chromium	180	B139X8	189	B139X9	4.9%
199-D5-36	19-Nov-2001	Total chromium	14.3	B139Y1	13.2	B139Y0	8.0%
199-D5-37	20-Nov-2001	Total chromium	230	B139Y2	228	B139Y3	0.9%
199-D5-38	19-Nov-2001	Total chromium	1050	B13B36	1060	B13B37	0.9%
199-D5-39	19-Nov-2001	Total chromium	5510	B139W2	5650	B139W3	2.5%
199-D5-39	19-Nov-2001	Total chromium	5660	B139W4	5690	B139W5	0.5%
199-D5-40	20-Nov-2001	Total chromium	352	B139W0	352	B139W1	0.0%
199-D5-41	26-Nov-2001	Total chromium	48.8	B139V8	46.7	B139V9	4.4%
199-D5-42	26-Nov-2001	Total chromium	13.1	B139V6	11	B139V7	17.4%
199-D5-43	19-Nov-2001	Total chromium	1350	B139V4	1330	B139V4	1.5%
199-D5-44	26-Nov-2001	Total chromium	6.3	B139V2	5.8 (U)	B139V3	N/A
Filtered Field (COLOR_TK_ FIELD) vs Filtered Offsite (7196_CR6) Laboratory Splits							
			Field		**Offsite**		
199-D2-6	27-Aug-2002	Hexavalent chromium	21	B15039	19	B15041	10.0%
199-D4-20	20-May-2002	Hexavalent chromium	146	B14F63	137	B14F65	6.4%
199-D4-26	4-Sep-2002	Hexavalent chromium	267	B15055	279	B15057	4.4%
199-D4-36	20-May-2002	Hexavalent chromium	8	B14F71	0 (U)	B14F73	N/A
199-D4-7	21-Feb-2002	Hexavalent chromium	39	B13XP2	35	B13XP4	10.8%
199-D4-85	20-Feb-2002	Hexavalent chromium	345	B13XR0	337	B13XR2	2.3%
199-D5-20	30-Jan-2002	Hexavalent chromium	423	B13XF3	429	B13XF4	1.4%
199-D5-37	29-Aug-2002	Hexavalent chromium	264	B14YW3	270	B14YW5	2.2%
199-D5-38	29-Aug-2002	Hexavalent chromium	389	B15095	392	B15097	0.8%
199-D5-42	20-May-2002	Hexavalent chromium	19	B14F17	14	B14F19	30.3%
199-D5-43	20-May-2002	Hexavalent chromium	1270	B14F79	1220	B14F81	4.0%
199-D5-43	18-Jun-2002	Hexavalent chromium	850	B14N13	887	B14N15	4.3%
199-D5-43	6-Aug-2002	Hexavalent chromium	392	B14TW2	365	B14TW4	7.1%
199-D5-38	29-Aug-2002	Hexavalent chromium	389	B15095	392	B15097	0.8%

Table 5-1. Fiscal Year 2001 Quality Control Sample Analyses for Hexavalent Chromium in 100-D Area Wells. (3 sheets)

Well Name	Sample Date	Constituent	Reported Value #1 (µg/L)	Sample Number	Reported Value #2 (µg/L)	Sample Number	RPD
Filtered Field (COLOR_TK_ FIELD) vs Unfiltered Offsite (Cr6_Hach_M) Laboratory Splits							
			Field		**Offsite**		
199-D4-22	22-Feb-02	Hexavalent chromium	1570	B13XL4	2020	B140C2	25.1%
199-D4-22	20-May-02	Hexavalent chromium	1350	B14F35	1365	B14FD7	1.1%
199-D4-22	27-Aug-02	Hexavalent chromium	647	B15049	642	B151D4	0.8%
199-D4-23	22-Feb-02	Hexavalent chromium	159	B13XD7	158	B140C3	0.6%
199-D4-23	20-May-02	Hexavalent chromium	199	B14F67	185	B14FD8	7.3%
199-D4-23	27-Aug-02	Hexavalent chromium	143	B15051	136	B151D5	5.0%
199-D4-4	25-Feb-02	Hexavalent chromium	16	B13XN0	23	B140C4	35.9%
199-D4-4	21-May-02	Hexavalent chromium	57	B14FB9	53	B14FF0	7.3%
199-D4-5	25-Feb-02	Hexavalent chromium	415	B13XN4	397	B140C5	4.4%
199-D4-5	21-May-02	Hexavalent chromium	327	B14FB5	323	B14FD9	1.2%
199-D4-5	3-Sep-02	Hexavalent chromium	33	B15073	37	B151D8	11.4%
199-D4-6	21-Feb-02	Hexavalent chromium	28	B13XN8	25	B140C6	11.3%
199-D4-6	20-May-02	Hexavalent chromium	34	B14FB3	26	B14FF4	26.7%
199-D4-6	3-Sep-02	Hexavalent chromium	37	B15075	41	B151D9	10.3%
199-D4-7	20-May-02	Hexavalent chromium	23	B14F99	14	B14FF1	48.6%

N/A = not applicable.
RPD = relative percent difference.
(U) = not detected at concentration shown.

Table 5-2. Fiscal Year 2002 Quality Control Sample Analyses for Sulfate 100-D Area Wells. (2 sheets)

Well Name	Sample Date	Constituent	Reported Value #1 (µg/L)	Sample Number	Reported Value #2 (µg/L)	Sample Number	RPD
Unfiltered Field Replicates							
199-D2-6	15-May-2002	Sulfate	152000	B14F60	152000	B14F62	0.0%
199-D4-15	22-May-2002	Sulfate	124000	B14F44	128000	B14F46	3.2%
199-D4-20	14-Feb-2002	Sulfate	136000	B13XL3	128000	B13XL1	6.1%
199-D4-20	29-Aug-2002	Sulfate	132000	B14YV4	136000	B14YV6	3.0%
199-D4-23	22-Feb-2002	Sulfate	280000	B13XD8	288000	B13XD6	2.8%
199-D4-23	27-Aug-2002	Sulfate	176000	B15054	176000	B15052	0.0%
199-D4-36	19-Feb-2002	Sulfate	330000	B13XM3	330000	B13XM5	0.0%
199-D4-39	15-May-2002	Sulfate	172000	B14F76	152000	B14F78	12.3%
199-D4-4	3-Sep-2002	Sulfate	290000	B15068	290000	B15070	0.0%

Table 5-2. Fiscal Year 2002 Quality Control Sample Analyses for Sulfate 100-D Area Wells. (2 sheets)

Well Name	Sample Date	Constituent	Reported Value #1 (µg/L)	Sample Number	Reported Value #2 (µg/L)	Sample Number	RPD
199-D4-84	5-Sep-2002	Sulfate	92000	B15086	92000	B15088	0.0%
199-D5-36	30-Apr-2002	Sulfate	11000	B14F88	11000	B14F90	0.0%
199-D5-38	18-Jun-2002	Sulfate	80000	B14N08	80000	B14N10	0.0%
199-D5-38	30-Sep-2002	Sulfate	118000	B15766	116000	B15768	1.7%
199-D5-40	20-Feb-2002	Sulfate	120000	B13XH1	112000	B13XH3	6.9%
199-D5-43	20-Feb-2002	Sulfate	94000	B13XT2	98000	B13XT4	4.2%
199-D5-43	29-Aug-2002	Sulfate	100000	B14YX3	100000	B14YX5	0.0%
Unfiltered Offsite Laboratory Replicates							
199-D4-1	15-Nov-2001	Sulfate	152000	B13DM3	150000	B13DM5	1.3%
199-D4-14	19-Nov-2001	Sulfate	178000	B13B41	174000	B13B43	2.3%
199-D4-23	27-Nov-2001	Sulfate	248000	B139J7	250000	B139L3	0.8%
199-D4-39	15-Nov-2001	Sulfate	144000	B13DP4	142000	B13DP2	1.4%
199-D4-7	26-Nov-2001	Sulfate	152000	B13CX3	155000	B13CX7	2.0%
Unfiltered Field-Offsite Laboratory Splits							
199-D4-26	26-Feb-2002	Sulfate	630000	B141D8	690000	B13XL7	9.1%
199-D5-42	20-May-2002	Sulfate	60000	B14F18	71300	B14F20	17.2%
199-D4-22	20-May-2002	Sulfate	144000	B14F36	141000	B14F38	2.1%
Unfiltered Offsite Laboratory Splits							
199-D4-22	30-Nov-2001	Sulfate	131000	B13B51	132000	B13B53	0.8%
199-D5-39	19-Nov-2001	Sulfate	104000	B139W3	110000	B139W5	5.6%

RPD = relative percent difference.

6.0 100-D AND 100-DR AREAS IN SITU REDOX MANIPULATION COST DATA

Actual costs for the 100-D Area ISRM interim remedial action were recorded in Bechtel Hanford, Inc., and Fluor Hanford, Inc., 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 (construction of new wells and an evaporation pond), and modifications to the system. This includes all Fluor Hanford, Inc., 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.

All projected costs are burdened and are based on costs through September 30, 2002. These costs are inclusive of the design, construction, operation, and performance monitoring of the ISRM as discussed in the "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). These costs are summarized in Figure 6-1 and Table 6-1.

Figure 6-1. Cost Breakdown for 100-D Area In Situ Redox Manipulation Operations, Fiscal Year 2002.

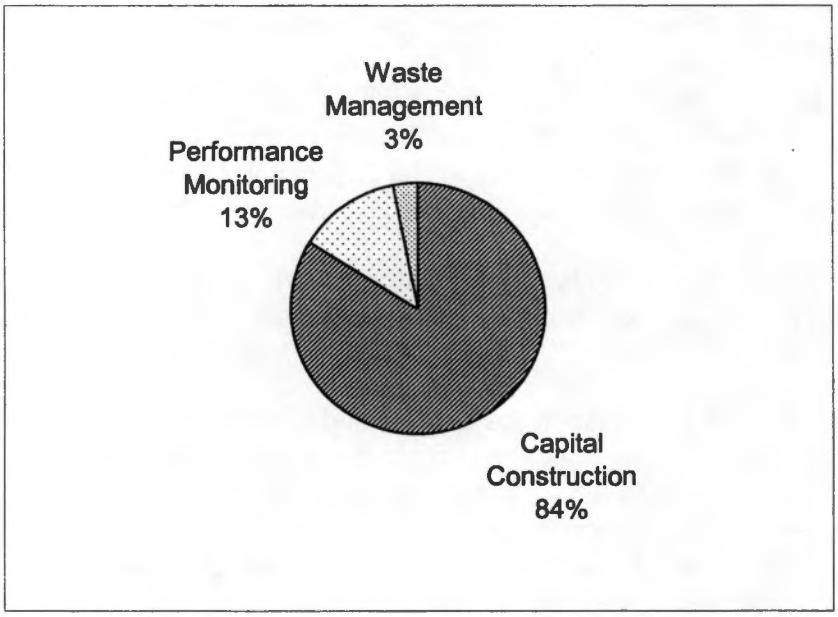


Table 6-1. 100-D Area In Situ Redox Manipulation Operating Cost Breakdown.

Description	Costs for 100-D Area ISRM Actual Costs x 1,000			
	1999	2000	2001	2002
Remedial Design	$669.60	$ 1.60	--	--
Capital Construction	--	$2,076.10	$3,034.10	$2,793.80
Performance Monitoring	--	--	$ 312.00[a]	$ 430.00
Waste Management	--	*	$ 48.90	$ 106.10
Total	$669.60	$2,077.70	$ 3,395.00	$3,329.90

*These costs were included in capital construction in fiscal year 2000.

[a] The FY 2001 costs in the *Fiscal Year 2001 Annual Summary Report for the In Situ Redox Manipulation Operations* (DOE/RL-2002-01) combined mitigation sampling and analysis in the Performance Monitoring cost category. These costs for FY 2001 are subtracted out so that the costs assigned to FY 2001 Performance Monitoring would be representative of the ISRM operation.

ISRM = in situ redox manipulation.

7.0 MITIGATION PLAN IMPLEMENTATION

The following sections describe the development and implementation of a mitigation plan in FY 2001 to address a significant trend of increasing hexavalent chromium concentrations observed in five wells. These concentration increases indicate a breakdown in the performance of the treatment zone. Section 7.1 summarizes background information and the mitigation plan option selected in FY 2001. Section 7.2 addresses results from implementation of the mitigation plan in FY 2002.

7.1 MITIGATION PLAN

Five wells within the central part of the treatability test area of the ISRM treatment zone exhibited increasing concentrations of hexavalent chromium in groundwater during FY 2001 (i.e., wells 199-D4-7, 199-D4-9, 199-D4-10, 199-D4-11, and 199-D4-12). The first well to exhibit increasing chromium was 199-D4-7, which also was the first ISRM well to be treated during the treatability study phase of the interim action. Increases in chromium concentrations also were observed in wells 199-D4-5 and 199-D4-23, both of which are located downgradient of the treatability study area (Figure 7-1). Well 199-D4-26, which was treated in late FY 2000, exhibited rising hexavalent chromium concentrations in FY 2001. Hexavalent chromium concentrations in the five treatability test area wells continued to increase, with concentrations in well 199-D4-9 rising to 900 μg/L, close to baseline (i.e., pre-ISRM treatment zone levels of approximately 1,000 μg/L) (Figures 7-1 and 7-2).

The "ISRM Mitigation Plan" (CCN 091481, Attachment 1) was prepared to evaluate the path forward for addressing the breakthrough in the treatability study portion of the ISRM treatment zone, including advantages/disadvantages and a schedule for implementation. Although no clear cause of the apparent reduced longevity of the treatment zone was identified during FY 2001, the following potential causes of the premature 100-D Area ISRM treatment zone breakthrough were identified:

- Heterogeneities (rapid reoxygenation of high-permeability zones and/or low residual reduction capacity of high-permeability zones)
- Fluctuating water table
- Variability in reduced iron content and other geochemical indicators (e.g., presence of manganese oxides that may oxidize trivalent chromium)
- Reoxygenation of the reduced zone during air rotary drilling
- Formation disturbance (fracturing)/trapped air from air rotary drilling
- Natural reoxygenation rates higher than used in the barrier longevity calculations (DO content in the natural groundwater)
- Groundwater flow velocity in excess of the design basis.

The "ISRM Mitigation Plan" (CCN 091481, Attachment 1) provided three options for a path forward to address this trend in the treatability test study portion of the ISRM treatment zone. The three options included (1) immediately reinjecting the treatability test wells, (2) collecting data and reinjecting treatability test wells and Phase I well(s) in the fall of 2001, and (3) reinjecting the wells in the spring of 2002. All three options include reestablishing the treatability test zone of the ISRM treatment zone by reinjection of sodium dithionite. The third option was identified as the preferred option and was added to the Groundwater/Vadose Zone Integration Project's work scope in the *Richland Environmental Restoration Project Fiscal Year 2002 Detailed Work Plan* (BHI-01581).

Activities to be performed as part of Option 3 included soil sampling investigative tasks before reinjection, evaluating the results, and reestablishing reducing conditions in the five treatability test treatment zone wells in the summer of 2002 (at a time when higher yearly aquifer water levels were expected).

7.2 2002 MITIGATION PLAN ACTIONS

The "ISRM Mitigation Plan" (CCN 091481, Attachment 1) actions specified in Option 3 included collection and analysis of samples from the treatability test area of the treatment zone, chemical treatment of the aquifer, and barrier monitoring.

7.2.1 Analysis of Treatment Zone Samples

Core samples of the treated aquifer in the central treatability test area of the ISRM barrier were collected at wells 199-D4-87, 199-D4-88, and 199-D4-89 using anoxic sampling protocols to preserve the in situ oxidation-reduction characteristics of the treatment zone. The wells are shown in Figure 3-1 and are near well 199-D4-7. The samples were collected to evaluate local heterogeneities and the reductive capacity of the aquifer materials. To assess the vertical variability of Redox capacity, the core was visually inspected to locate depth intervals where higher permeability areas might exist. The color of the sediments was logged carefully, because color is a qualitative indicator of the state of reduction in the sediment. Selected samples were analyzed for reduced iron and other parameters by Pacific Northwest National Laboratory to measure the mass fraction <4 mm in size, bulk density, porosity, field, and laboratory-reduced iron. Descriptions of the cores, analytical methods, analytical results, and interpretation of the results from the study are presented in Appendix GG.

The analytical results show that most of the samples had significant remaining reductive capacity, but there is a zone of oxidation at 116 m elevation in two of the three wells. The scale of aquifer heterogeneity is difficult to determine but was evident in the three wells, which are spaced 3.75 to 5 m apart. The laboratory results also show little correlation between the amount of field-reduced iron and porosity, or between porosity and sediment properties noted in well logs.

The other "ISRM Mitigation Plan" (CCN 091481, Attachment 1) actions are discussed below.

7.2.2 Chemical Treatment

Six wells that showed evidence of treatment zone breakdown were re-treated in FY 2002. These wells were 199-D4-7, 199-D4-9, 199-D4-10, 199-D4-11, 199-D4-12, and 199-D4-35. Re-treatment of well 199-D4-35 was not required by the "ISRM Mitigation Plan" (CCN 091481, Attachment 1). However, hexavalent chromium concentrations in the well of 1,000 and 760 μg/L in January and April 2002, respectively, indicated that re-treatment was necessary.

Chemical treatment protocols used for Phase III FY 2002 were similar to those used for Phase II FY 2001 activities. A 2-hour, postinjection "push stage" was included for Phase III activities. Injections were performed when groundwater levels were within a 20 percent range of the average water level at the injection well, as advised by Pacific Northwest National Laboratory based on knowledge gained during ISRM development and deployment. This 20 percent criterion was a general rule-of-thumb established as an interim hold point for Phase III emplacements; further evaluation is required if the 20 percent rule-of-thumb is breached.

7.2.3 Barrier Monitoring Activities

Monitoring of treatment zone wells for hexavalent chromium was expanded to include all the treated wells in FY 2002. Most of the wells were monitored on a quarterly frequency; wells that had significant hexavalent chromium concentrations were monitored monthly. Section 4.3.2 describes the results of the monitoring.

Figure 7-1. Hexavalent Chromium in Wells 199-D4-5, 199-D4-7, and 199-D4-23.

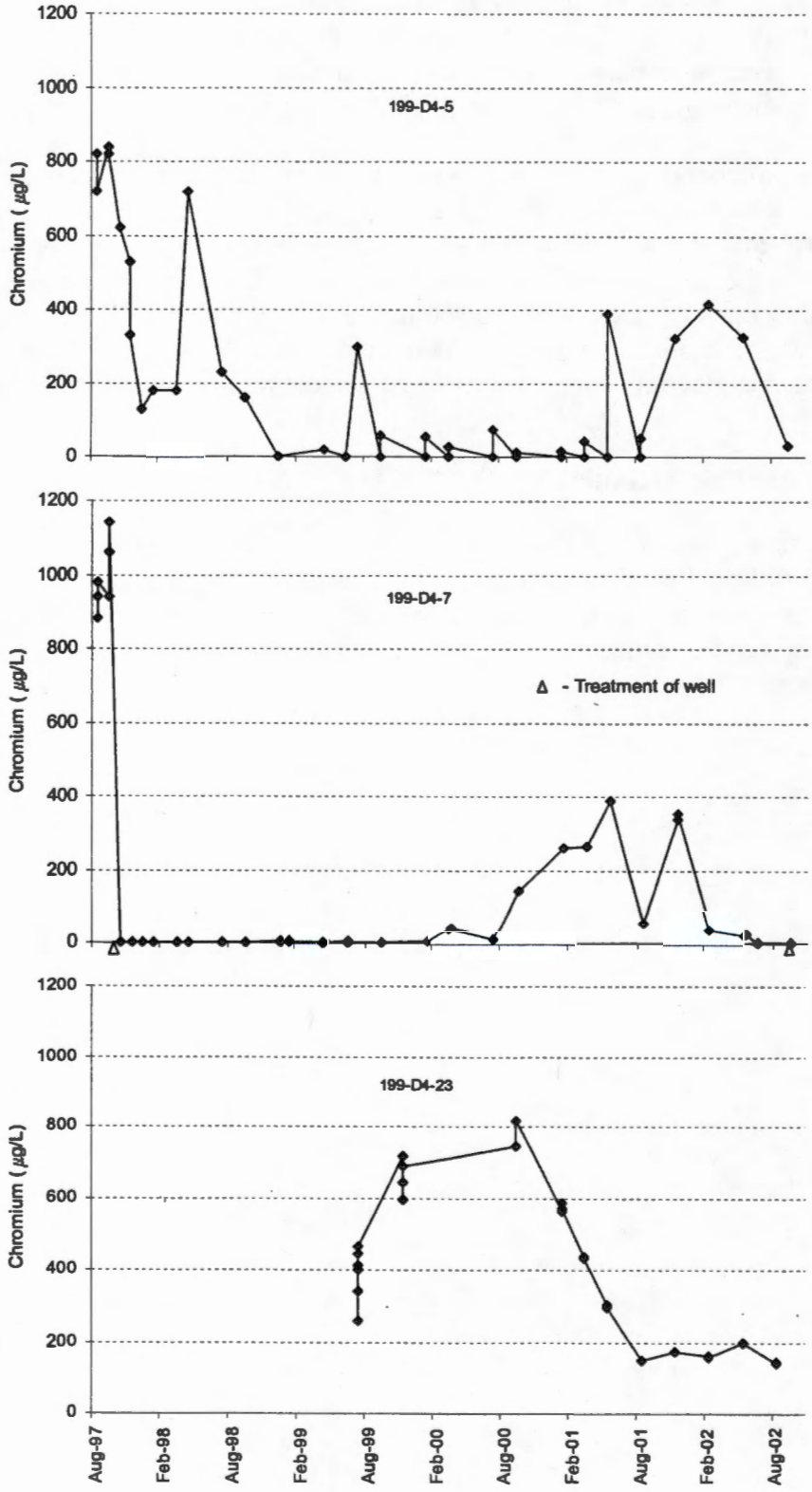
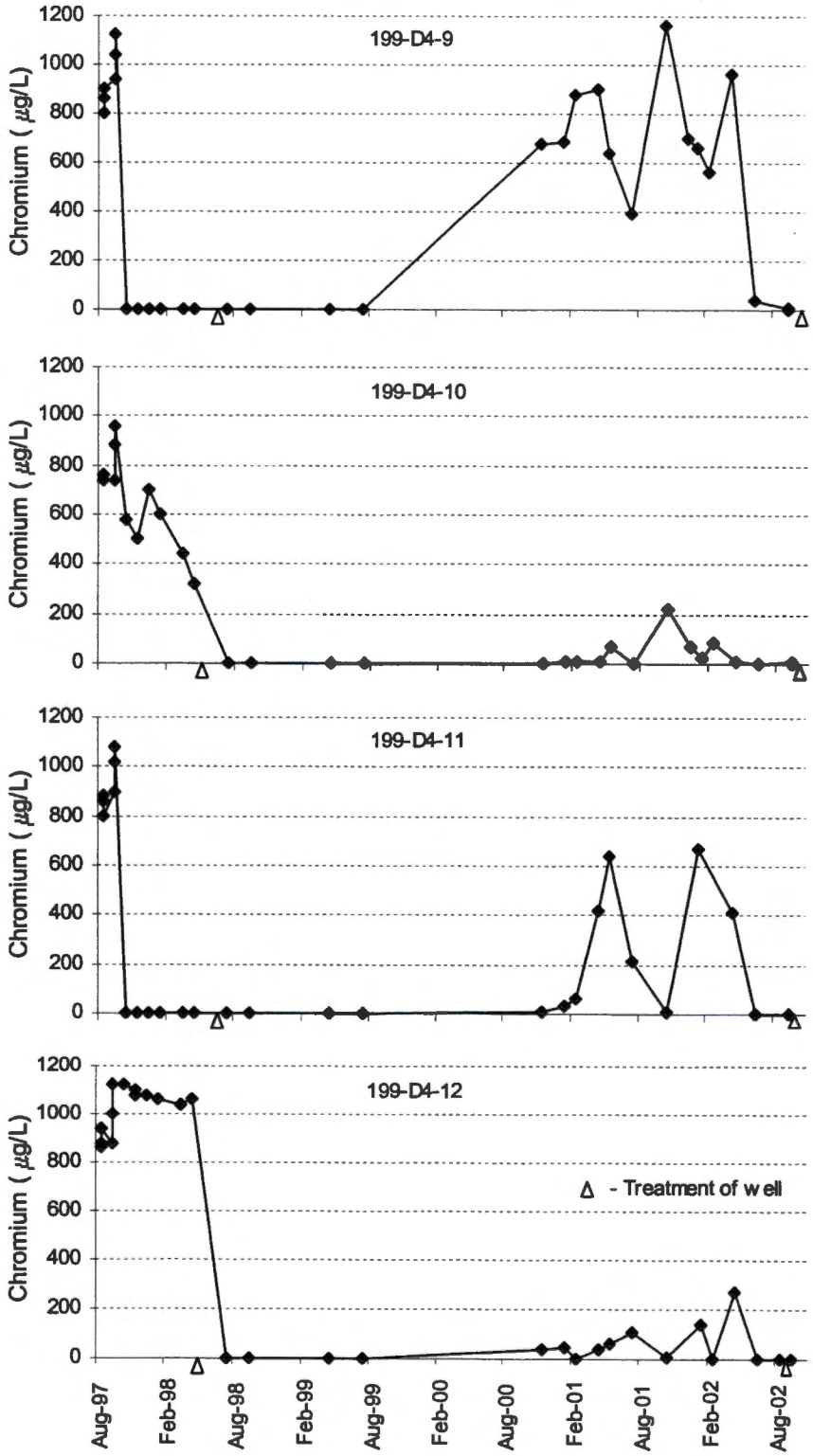


Figure 7-2. Hexavalent Chromium in Wells 199-D4-9, 199-D4-10, 199-D4-11, and 199-D4-12.



This page intentionally left blank.

8.0 CONCLUSIONS

Emplacement of the ISRM treatment zone is nearly completed, and data have been collected that allow a preliminary performance evaluation in relation to the RAOs (EPA et al. 1996). Hexavalent chromium concentration exceeds the RAO in six of seven compliance wells; the exception is 199-D4-86. Specific progress for FY 2002 toward meeting each RAO is discussed below.

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

  Result: The ISRM Phase III construction and treatment zone emplacement activities have been almost completed. The extraction phase was completed in early FY 2003 in the last three of the 32 wells being treated in FY 2002. The final five Phase III wells are scheduled to be completed before June 30, 2003. This will complete Phase III ISRM construction. Operational monitoring of treatment zone wells indicates successful development of reducing conditions throughout most of the ISRM barrier. However, in FY 2001 five treated treatment zone wells located in the highest concentration areas of the hexavalent chromium plume exhibited increasing concentrations, indicating a loss of reducing conditions.

  The "ISRM Mitigation Plan" (CCN 091481, Attachment 1) was prepared to provide a path forward to address these trends in increasing concentrations within the ISRM treatment zone. The "ISRM Mitigation Plan" (CCN 091481, Attachment 1) was implemented in FY 2002 and included soil sampling investigative tasks, evaluation of the results before reinjections in these wells, and reestablishment of reducing conditions in the five treatment zone wells. Treatment of the five wells and in well 199-D4-35 appears to have reestablished reducing conditions. However, in late FY 2002, hexavalent chromium concentrations were found to be increasing in two other wells, 199-D4-26 and 199-D4-37, to levels well above the RAO. It appears that a loss of reducing conditions has occurred in these wells. These wells are being monitored on a monthly basis.

- **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 the development and implementation of a final remedy. The treatment zone was reestablished during Phase III (FY 2002) in the six wells that exhibited increasing concentrations. In addition, there will be continued monitoring of the treated wells and further evaluation of data.

The ROD Amendment (EPA et al. 1999) and RDR/RAWP (DOE/RL-99-51) 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 FY 2001.

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

  Result: During Phase III (FY 2002), the treatment zone was extended to a total length of 630 m by the treatment of 17 additional wells. At the end of FY 2002, the ISRM treatment zone consisted of 61 wells. When the last five Phase III wells are treated in FY 2003, the total length of the treatment zone will be 680 m, and it will consist of 66 wells.

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

  Result: Construction and implementation of the treatment zone is following the design principles and schedule outlined in the RDR/RAWP (DOE/RL-99-51).

- **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: Compliance wells have average FY 2002 hexavalent chromium concentrations ranging from 18 μg/L in well 199-D4-86 to 821 μg/L in well 199-D4-39. Most compliance well concentrations are well above the RAO of 20 μg/L. The western end of the treatment zone is still under construction, and concentrations measured in the compliance wells do not yet reflect treatment zone performance. Concentrations also may reflect heterogeneous areas of the ISRM treatment zone with low hydraulic conductivities.

- **Compliance monitoring wells will monitor chromium and dissolved oxygen 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. The treatment zone is still under construction, and concentrations measured in the compliance wells do not yet reflect treatment zone performance.

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

  Result: Monitoring wells are sampled on a quarterly basis for these field parameters. Currently, the trends in these wells are inconclusive.

- **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: Currently there are seven compliance wells for the ISRM treatment zone, the last four of which were installed during FY 2001. These designated compliance wells are located approximately midway between the treatment zone and the Columbia River. The wells are oriented parallel to the treatment zone and span its entire length. All seven compliance wells were characterized by decreasing or stable chromium concentrations in the fall of 2002, compared to the fall of 2001.

Treatment zone breakthrough was indicated by concentrations measured in eight wells, six of which were treated again in FY 2002. The highest concentration portion of the hexavalent chromium plume may be spreading somewhat to the northeast in a direction generally parallel to the axis of the ISRM treatment zone. This situation will be monitored and evaluated in FY 2003. Additional monitoring wells may be required in FY 2003 to evaluate this contingency.

- **The installation of the treatment barrier shall be initiated within 15 months after signing the ROD Amendment and shall be fully implemented by the end of FY 2002, 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 FY 2000, Phase II was completed, and Phase III is on schedule. In accordance with an approved *Hanford Federal Facility Agreement and Consent Order* (Ecology et al. 1989) change request, the date for Phase III completion has been extended to June 30, 2003.

- **If barrier breakthrough is identified, the Washington State Department of Ecology and the U.S. Environmental Protection Agency will determine alternative action to be taken.**

  Result: Treatment zone breakthrough at the treatability test area was identified and confirmed during FY 2001. The Washington State Department of Ecology and the U.S. Environmental Protection Agency were notified, and they concurred with the path forward. The "ISRM Mitigation Plan" (CCN 091481, Attachment 1) was implemented during Phase III (FY 2002) activities and includes soil sampling investigative tasks before reinjection, evaluation of the results, and reestablishment of reducing conditions in six treatment zone wells.

- **Posttreatment extraction purgewater shall be collected and disposed to an evaporation pond constructed at the ISRM site. High-concentration purgewater generated during posttreatment 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 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: During FY 2002, approximately 28,500,000 L (500,000 gal) were extracted and sent to the evaporation pond. Approximately 6,250,000 L (1,650,000 gal) were processed to the dripfield in accordance with the requirements established in the RDR/RAWP (DOE/RL-99-51).

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

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

- **Applicable or relevant and appropriate requirements set forth in EPA et al. (1996) are unchanged, with the exception of WAC 173-218, "Underground Injection Control Program," and 40 CFR 144, "Underground Injection Control Program," 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 primary DWS 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 the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980.***

  Result: Sulfate concentrations in wells treated during FY 2002, including compliance well 199-D4-39, exceeded the SDWS of 250 mg/L. However, sulfate concentrations in the other compliance wells were below the SDWS.

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

- Treatment residuals arsenic and nitrate exceed DWS in some of the eight wells treated in FY 2002. Treatment residuals iron, manganese, sulfate, and pH exceed the SDWS in many of the eight wells treated in FY 2002.
- A plume of elevated sulfate concentration was detected downgradient of the established ISRM treatment zone.
- The injection/extraction, process controls, and mechanical systems performed as expected. No major shutdowns or operational delays were caused by this equipment.

9.0 RECOMMENDATIONS

Based on observations made during FY 2002, the following recommendations are made.

- Continue operational monitoring of treatment zone wells for hexavalent chromium. All treatment zone wells should be sampled quarterly, unless significant increases in hexavalent chromium, e.g., >30 μg/L, are detected. Treatment zone wells showing significant increases in hexavalent chromium should be sampled monthly.

- Review groundwater data from downgradient and compliance wells for nitrate to assess compliance with DWS.

- Include As, Mn, and Fe in the list of analytes in groundwater samples collected from downgradient wells, compliance wells, and aquifer sampling tubes to assess compliance with DWS and SDWS.

- Install additional monitoring well(s) in the vicinity of the 182-D Reservoir to assess possible northward movement of the plume.

This page intentionally left blank.

10.0 REFERENCES

40 CFR 141, "National Primary Drinking Water Standards," Title 40, *Code of Federal Regulations,* Part 141, as amended.

40 CFR 143, "National Secondary Drinking Water Standards," Title 40, *Code of Federal Regulations*, Part 143, as amended.

40 CFR 144, "Underground Injection Control Program," Title 40, *Code of Federal Regulations*, Part 144, as amended.

BHI, 2002, *Exhibit D, Scope of Work 100-D In-Situ Redox Electrical Power Upgrades,* Bechtel Hanford, Inc., Richland, Washington.

BHI-01516, 2001, *Sampling and Analysis Instruction to Support Operation of the 100-D Area In Situ Redox Manipulation Process*, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

BHI-01581, 2001, *Richland Environmental Restoration Project Fiscal Year 2002 Detailed Work Plan*, Rev. 0, vols. 1-7, Bechtel Hanford, Inc., Richland, Washington.

BHI-01638, 2001, *ISRM Barrier Well Completion Report for the 100-HR-3 Groundwater Operable Unit, Fiscal Year 2002*, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

CCN 091481, 2001, "Transmittal of In Situ Redox Manipulation (ISRM) Mitigation Plan," Attachment (1), "ISRM Mitigation Action Plan," (letter to A. C. Tortoso, U.S. Department of Energy, Richland Operations Office, from M. J. Graham), Bechtel Hanford, Inc., Richland, Washington, August 3.

Comprehensive Environmental Response, Compensation, and Liability Act of 1980, 42 U.S.C. 9601, et seq.

DOE/RL-99-51, 2000, *Remedial Design Report and Remedial Action Work Plan for the 100-HR-3 Groundwater Operable Unit In Situ Redox Manipulation*, Rev. 1, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2002-01, 2002, *Fiscal Year 2001 Annual Summary Report for the In Situ Redox Manipulation Operations*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Ecology, EPA, and DOE, 1989, *Hanford Federal Facility Agreement and Consent Order*, 2 vols., as amended, Washington State Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Olympia, Washington.

EPA, Ecology, and DOE, 1996, *Declaration of the Record of Decision for the 100-HR-3 and 100-KR-4 Operable Units at the Hanford Site (Interim Remedial Actions)*, U.S. Environmental Protection Agency, Washington State Department of Ecology, and U.S. Department of Energy, Olympia, Washington.

EPA, Ecology, and DOE, 1999, *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)*, U.S. Environmental Protection Agency, Washington State Department of Ecology, and U.S. Department of Energy, Olympia, Washington.

EPA-540/R-94/083, 1998, *Laboratory Data Validation Functional Guidelines for Evaluating Inorganics Analyses*, Hazardous Site Evaluation Division, U.S. Environmental Protection Agency, Washington, D.C.

Henderson, T., 1994, "Geochemical Reduction of Hexavalent Chromium in the Trinity Sand Aquifer," in *Groundwater*, Vol. 32, No. 3, May-June 1994.

NAD83, 1983, *North American Datum of 1983*, National Geodetic Survey, Federal Geodetic Control Committee, Silver Spring, Maryland.

NAVD88, 1988, *North American Vertical Datum of 1988*, National Geodetic Survey, Federal Geodetic Control Committee, Silver Spring, Maryland.

PNNL-12153, 1999, *100-D Area In Situ Redox Treatability Test for Chromate-Contaminated Groundwater: FY 1998 Year-End Report*, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13349, 2000, *100-D Area In Situ Redox Treatability Test for Chromate-Contaminated Groundwater, September 2000*, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13486, 2001, *Characterization Activities Conducted at the 183-DR Site in Support of an In Situ Gaseous Reduction Demonstration*, Pacific Northwest National Laboratory, Richland, Washington.

Price, John B., 2003, "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)" (letter to Arlene Tortoso, U.S. Department of Energy) Washington State Department of Ecology, Olympia, Washington, April 21.

Resource Conservation and Recovery Act of 1976, 42 U.S.C. 6901, et seq.

WAC 173-160, "Minimum Standards for Construction and Maintenance of Wells," *Washington Administrative Code*, as amended, Olympia, Washington.

WAC 173-218, "Underground Injection Control Program," *Washington Administrative Code*, as amended, Olympia, Washington.

APPENDICES ON CD IN POCKET, ATTACHED

This page intentionally left blank.

APPENDIX A

INJECTION DATA FOR WELL 199-D4-58

IN SITU REDOX MANIPULATION ANNUAL SUMMARY REPORT FISCAL YEAR 2002

This page intentionally left blank.

This page intentionally left blank.

APPENDIX B

INJECTION DATA FOR WELL 199-D4-59

IN SITU REDOX MANIPULATION ANNUAL SUMMARY REPORT FISCAL YEAR 2002

This page intentionally left blank.

This page intentionally left blank.

APPENDIX C

INJECTION DATA FOR WELL 199-D4-60

IN SITU REDOX MANIPULATION ANNUAL SUMMARY REPORT FISCAL YEAR 2002

This page intentionally left blank.

APPENDIX D

INJECTION DATA FOR WELL 199-D4-61

IN SITU REDOX MANIPULATION ANNUAL SUMMARY REPORT FISCAL YEAR 2002

This page intentionally left blank.

This page intentionally left blank.

APPENDIX E

INJECTION DATA FOR WELL 199-D4-62

IN SITU REDOX MANIPULATION ANNUAL SUMMARY REPORT FISCAL YEAR 2002

This page intentionally left blank.

APPENDIX F

INJECTION DATA FOR WELL 199-D4-07

IN SITU REDOX MANIPULATION ANNUAL SUMMARY REPORT FISCAL YEAR 2002

This page intentionally left blank.

This page intentionally left blank.

APPENDIX G

INJECTION DATA FOR WELL 199-D4-09

IN SITU REDOX MANIPULATION ANNUAL SUMMARY REPORT FISCAL YEAR 2002

This page intentionally left blank.

This page intentionally left blank.

APPENDIX H

INJECTION DATA FOR WELL 199-D4-10

IN SITU REDOX MANIPULATION ANNUAL SUMMARY REPORT FISCAL YEAR 2002

This page intentionally left blank.

This page intentionally left blank.

APPENDIX I

INJECTION DATA FOR WELL 199-D4-11

IN SITU REDOX MANIPULATION ANNUAL SUMMARY REPORT FISCAL YEAR 2002

This page intentionally left blank.

This page intentionally left blank.

APPENDIX J

INJECTION DATA FOR WELL 199-D4-12

IN SITU REDOX MANIPULATION ANNUAL SUMMARY REPORT FISCAL YEAR 2002

This page intentionally left blank.

This page intentionally left blank.

APPENDIX K

INJECTION DATA FOR WELL 199-D4-35

IN SITU REDOX MANIPULATION ANNUAL SUMMARY REPORT FISCAL YEAR 2002

This page intentionally left blank.

This page intentionally left blank.