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Phase II Investigation Report for Sandia Canyon



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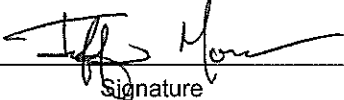
Phase II Investigation Report for Sandia Canyon

September 2012

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EXECUTIVE SUMMARY

This Phase II investigation report for Sandia Canyon presents the results of studies conducted from August 2009 to June 2012 to investigate contamination in sediment, surface water, shallow perched alluvial groundwater, perched-intermediate groundwater, and regional groundwater potentially impacted by solid waste management units (SWMUs) and areas of concern (AOCs) located within the Sandia Canyon watershed. The domain of the investigation is larger than the area encompassed by and beneath the Sandia Canyon watershed; it extends south beneath Mortandad Canyon to define the nature and extent of chromium and associated contaminants in groundwater. This report synthesizes the results from the investigations conducted to date for chromium and other contaminants originating from Sandia Canyon.

The Phase I and Phase II investigations indicate inorganic, organic, and radionuclide chemicals of potential concern (COPCs) are present in sediment, surface water, and groundwater in the Sandia Canyon watershed at concentrations above screening levels and federal and/or New Mexico groundwater standards. These COPCs are derived from several sources, including SWMUs and AOCs within Los Alamos National Laboratory (the Laboratory), runoff from developed areas, and natural sources such as noncontaminated soils, sediments, and bedrock. The nature and extent of these COPCs are defined in sediment, surface water, the vadose zone, and regional groundwater.

The studies indicate that SWMUs and AOCs within Technical Area 03 (TA-03) are the most important sources of contamination with respect to potential human health risks, ecological risks, and groundwater impacts. The most important sources for COPCs released from SWMUs or AOCs are the former outfall for the power plant cooling towers in upper Sandia Canyon, a former polychlorinated biphenyl (PCB) transformer storage area along the south fork of Sandia Canyon, and the former asphalt batch plant along the north fork of Sandia Canyon. In groundwater, contamination is present in wells beneath both Sandia and Mortandad Canyons. Groundwater samples from these wells indicate the former outfall for the TA-03 power plant cooling towers and Outfall 051, which has historically released effluent from the TA-50 radioactive liquid waste treatment facility into the Mortandad Canyon watershed, are the key sources of groundwater contamination.

Contaminants in sediment originally released from TA-03 extend for approximately 10 km to 12 km (6 mi to 7 mi) downcanyon from the sources. The most important historical sediment deposition area is in the upper canyon where a broad wetland exists (reach S-2). A single sediment reach, S-5EC, was sampled for the Phase II investigation. The distribution and concentrations of COPCs were compared with those in bounding Phase I reaches S-5C and S-5E for evaluating potential human health and ecological risks. With the exception of zinc, the average concentrations of COPCs in sediments in reach S-5EC are bounded by those in reaches S-5C and S-5E. The average zinc concentration in S-5EC is slightly higher than in S-5C, possibly from runoff from the adjacent roadway. Concentrations in this supplemental reach are generally much less than the maximum concentrations measured during Phase I. The inventory estimates for chromium and PCBs in Sandia Canyon sediments were updated based on data from reach S-5EC; these slightly revised Phase I results. Approximately 85% of the inventory of chromium is located in wetland reach S-2; an estimated 81% to 99.6% of PCBs is located in reach S-2, depending on the PCB congener.

Supplemental data collection relevant to risk assessments included sediment investigation reach S-5EC and 3 yr of surface water sampling. The conclusions of the Phase I risk assessments are not significantly changed by the Phase II investigation results, and updates or recalculation of risks are not warranted for this Phase II investigation report. Briefly, the Phase I investigation report concluded the following for human health and ecological risk. The human health risk assessment results indicate no areas in Sandia Canyon have contaminant concentrations greater than target risk levels, with one exception. Potential carcinogenic risk is estimated to be 2×10^{-5} , compared with a target incremental cancer risk criterion of

1×10^{-5} in reach S-1N, primarily from polycyclic aromatic hydrocarbons in sediment, some of which is likely from SWMUs and AOCs. The Phase I baseline ecological risk assessment indicated exposures to chemicals of potential ecological concern (COPECs) may cause potential adverse effects to terrestrial and aquatic receptors in the upper part of Sandia Canyon, including the Sandia wetland. However, other non-COPEC factors related to habitat quality also correlated to decreased growth or survival from the bioassay measures and may be the cause of the findings. The conclusions of the ecological and human health risk assessments are not changed based from those presented in the Phase I report based on the additional Phase II sediment and surface water sampling results.

Investigations of surface water and groundwater have better constrained the nature and extent of contaminants released into Sandia Canyon. The COPCs in surface water and alluvial groundwater relate closely to those identified for sediment but generally extend for a shorter distance downcanyon from the source than do the sediment COPCs. Other more mobile constituents are found in the underlying vadose zone, perched-intermediate groundwater, and regional groundwater. A conceptual model informed by multiple lines of evidence indicates these mobile groundwater constituents are present along a migration pathway dominated by infiltration into the vadose zone over a short segment in the middle portion of Sandia Canyon. Contaminants that infiltrate Sandia Canyon may be partly transported laterally via mixing with perched-intermediate groundwater that flows generally southward on top of and within the Cerros del Rio basalts before breaking through to the regional aquifer. These waters mix with perched-intermediate groundwater that infiltrates generally more vertically beneath Mortandad Canyon.

Dissolved-phase chromium [chromium (VI)] is present within the regional aquifer at concentrations exceeding the 50 $\mu\text{g/L}$ New Mexico groundwater standard. Perchlorate is also present in the regional aquifer beneath Mortandad Canyon at concentrations exceeding the Compliance Order on Consent screening level of 4 $\mu\text{g/L}$. The analyte 1,4-dioxane is present in perched-intermediate groundwater beneath Mortandad Canyon at concentrations exceeding its groundwater standard. The footprint of the breakthrough locations from the vadose zone into the regional groundwater is estimated based on groundwater data and calibrated groundwater models used to support the conceptual model. The potential spatial distribution and magnitude of flux in the estimated breakthrough locations are interpreted from a series of model analyses. Groundwater modeling indicates contaminant transport in the regional aquifer is expected to occur predominantly east-southeast from the primary infiltration window near regional wells R-42 and R-28 (toward wells R-44 and R-45), which is consistent with the observed hydraulic gradients along the regional water table.

Data from groundwater monitoring wells and the groundwater model provide information on the extent of chromium contamination in the regional aquifer. The installation of new regional wells R-50, R-61, and R-62 have further refined information on the extent of the chromium plume along the southern (R-50 and R-61) and western (R-62) boundaries. Perchlorate is also present in the aquifer from a Mortandad Canyon source, and its distribution is defined by observations in wells R-15, R-61, and R-50 and wells to the north.

Groundwater will continue to be monitored for potential changes in concentrations or distribution of contaminants within wells in the Chromium Investigation monitoring group. The monitoring plan will be included in the Laboratory's annual Interim Facility-Wide Groundwater Monitoring Plan. The information on the nature and extent of contamination originating from Sandia (and Mortandad) Canyons supports proceeding to the corrective measures evaluation phase to evaluate and recommend a final remedy for groundwater contamination.

CONTENTS

1.0	INTRODUCTION	1
1.1	Purpose and Scope	1
1.2	Organization of Investigation Report	2
1.3	Watershed Description	3
1.4	Current Land Use	3
2.0	BACKGROUND	3
2.1	Effluent Releases.....	4
2.1.1	Sandia Canyon.....	4
2.1.2	Mortandad Canyon.....	5
2.2	Previous Investigations of Contamination in Canyons Media	5
2.2.1	Consent Order Investigations.....	5
2.3	Site-Stabilization Activities.....	6
2.3.1	Stormwater Management.....	6
2.3.2	Planned Stabilization of the Sandia Canyon Wetland.....	6
3.0	SCOPE OF ACTIVITIES	7
3.1	Sediment Investigations	7
3.2	Surface Water and Groundwater Investigations.....	7
3.2.1	Perched-Intermediate Monitoring Well Installations.....	8
3.2.2	Regional Aquifer Monitoring Well Installations.....	9
3.2.3	R-28 Cross-Hole Pumping Test	9
3.2.4	Well Redevelopment	9
3.2.5	Surface Water and Groundwater Sampling	10
3.2.6	Water-Level Measurements	10
3.2.7	Surface Geophysics	10
3.2.8	Geochemical Data Analyses	11
3.2.9	Simulations of Contaminant Transport.....	11
3.3	Deviations from Planned Activities	11
4.0	FIELD AND LABORATORY INVESTIGATIONS	11
4.1	Sediment.....	11
4.2	Surface Water and Groundwater	12
4.2.1	Perched-Intermediate Monitoring Well Installations.....	12
4.2.2	Regional-Aquifer Monitoring Well Installations	12
4.2.3	R-28 Cross-Hole Pumping Test	13
4.2.4	Well Redevelopment	13
4.2.5	Surface Water and Groundwater Sampling	13
4.2.6	Water-Level Measurements	13
4.2.7	Surface Geophysics	13
5.0	REGULATORY CRITERIA	14
5.1	Regulatory Context.....	14
5.2	Water Quality Standards and Comparison Values.....	15

6.0	CANYONS CONTAMINATION.....	16
6.1	Data Preparation.....	16
6.2	Sediment COPCs	16
6.2.1	Identification of Sediment COPCs.....	17
6.2.2	Comparison of Phase II Sediment COPC Concentrations to Phase I Concentrations	17
6.3	Surface Water COPCs	17
6.3.1	Stormwater Screen against Comparison Values	17
6.3.2	Identification of Nonstorm-Related Surface-Water COPCs	18
6.4	Groundwater COPCs.....	18
6.4.1	Identification of Groundwater COPCs	18
6.4.2	Comparison of Water COPC Concentrations to Comparison Values	19
6.5	Summary	19
7.0	PHYSICAL SYSTEM CONCEPTUAL MODEL	19
7.1	Contaminants in Sediment	20
7.1.1	Inorganic Chemicals in Sediment.....	22
7.1.2	Organic Chemicals in Sediment.....	24
7.1.3	Summary of Sources and Distribution of Key Sediment COPCs.....	26
7.1.4	Contaminant Inventory	27
7.1.5	Relations between Particle Size and Contaminant Concentration	28
7.1.6	Flood Attenuation and Downcanyon Extent of Contamination.....	28
7.1.7	Temporal Trends in Sediment Contamination.....	29
7.2	Conceptual Model for Hydrology and Contaminant Transport in Groundwater	29
7.2.1	Surface Water	30
7.2.2	Alluvial Groundwater	31
7.2.3	Vadose-Zone Hydrology.....	32
7.2.4	Perched-Intermediate Groundwater.....	32
7.2.5	Regional Aquifer	34
8.0	RISK ASSESSMENTS.....	38
8.1	Baseline Ecological Risk Assessment.....	38
8.2	Human Health Risk Assessment Synopsis	39
8.3	Phase II Investigations	39
9.0	CONCLUSIONS AND RECOMMENDATIONS	40
10.0	ACKNOWLEDGMENTS	42
11.0	REFERENCES	43

Figures

Figure 1.1-1	Sandia Canyon watershed showing technical area boundaries	51
Figure 3.1-1	Sandia Canyon watershed showing reach boundaries.....	52
Figure 3.2-1	Sandia Canyon watershed showing water sampling locations.....	53
Figure 3.2-2	Chromium Investigation monitoring group	54
Figure 4.1-1	Schematic cross-sections showing post-1942 coarse-facies and fine-facies sediment deposits in reach S-5EC	55

Figure 4.1-2	Schematic cross-sections showing post-1942 coarse-facies and fine-facies sediment deposits in reaches (a) S-5C, and (b) S-5E.....	56
Figure 7.0-1	Conceptual hydrogeologic cross-section for Sandia Canyon that includes potential chromium transport pathways and dissolved hexavalent chromium for surface water, monitoring wells, and water-supply wells.....	57
Figure 7.1-1	Estimated average concentrations of select inorganic chemicals in fine facies sediment in Reach S-5EC and other Sandia Canyon reaches.....	58
Figure 7.1-2	Estimated average concentrations of select PCBs in fine facies sediment in Reach S-5EC and other Sandia Canyon reaches	59
Figure 7.1-3	Estimated average concentrations of benzo(a)pyrene in fine facies sediment in Reach S-5EC and other Sandia Canyon reaches	60
Figure 7.1-4	Estimated average concentrations of TPH-DRO in fine facies sediment in Reach S-5EC and other Sandia Canyon reaches	60
Figure 7.1-5	Estimated anthropogenic chromium inventory in Sandia Canyon; (a) normalized inventory (kg/km); (b) cumulative inventory (kg).....	61
Figure 7.1-6	Estimated Aroclor-1254 inventory in Sandia Canyon; (a) normalized inventory (kg/km); (b) cumulative inventory (kg).....	61
Figure 7.1-7	Estimated Aroclor-1260 inventory in Sandia Canyon; (a) normalized inventory (kg/km); (b) cumulative inventory (kg).....	62
Figure 7.2-1	Projected chromium and perchlorate plumes beneath Sandia and Mortandad Canyons, including chromium concentrations	63
Figure 7.2-2	Conceptual model for mixing of groundwater types beneath various canyons, including major ion chemistry and chromium concentrations	64
Figure 7.2-3	Major ion chemistry and chromium concentrations of perched-intermediate and regional groundwaters in the Chromium Investigation monitoring group wells	65

Tables

Table 2.3-1	Baseline and Augmented BMPs to Control Runoff and Erosion in Sandia Canyon under the Laboratory's Individual Permit	67
Table 3.2-1	Phase II Investigation Surface and Groundwater Sampling Locations and Rationale	68
Table 6.1-1	Phase II Water Screening Location, Synonym, and Reach.....	70
Table 6.2-1	Phase II Samples Collected and Analyses Performed for Sediment from Sandia Canyon.....	72
Table 6.2-2	Inorganic COPCs in Sandia Canyon Phase II Sediment Samples.....	73
Table 6.2-3	Organic COPCs in Sandia Canyon Phase II Sediment Samples	75
Table 6.3-1	Phase II Samples Collected and Analyses Performed for Surface Water Associated with Sandia Canyon	77
Table 6.3-2	Stormwater Screen for Phase II Samples from Sandia Canyon.....	80
Table 6.3-3	Inorganic COPCs in Phase II Filtered Nonstorm-Related Surface-Water Samples from Sandia Canyon	81
Table 6.3-4	Inorganic COPCs in Phase II Nonfiltered Nonstorm-Related Surface-Water Samples from Sandia Canyon	82

Table 6.3-5	Organic COPCs in Phase II Nonfiltered Nonstorm-Related Surface-Water Samples from Sandia Canyon	83
Table 6.3-6	Radionuclide COPCs in Phase II Nonfiltered Nonstorm-Related Surface-Water Samples from Sandia Canyon	83
Table 6.4-1	Phase II Samples Collected and Analyses Performed for Groundwater Associated with Sandia Canyon	84
Table 6.4-2	Inorganic COPCs in Filtered Alluvial Groundwater from the Sandia Canyon Watershed	123
Table 6.4-3	Inorganic COPCs in Nonfiltered Alluvial Groundwater from the Sandia Canyon Watershed	124
Table 6.4-4	Organic COPCs in Nonfiltered Alluvial Groundwater from the Sandia Canyon Watershed	125
Table 6.4-5	Radionuclide COPCs in Nonfiltered Alluvial Groundwater from the Sandia Canyon Watershed	125
Table 6.4-6	General Inorganic COPCs in Filtered Alluvial Groundwater from the Sandia Canyon Watershed	126
Table 6.4-7	General Inorganic COPCs in Nonfiltered Alluvial Groundwater from the Sandia Canyon Watershed	127
Table 6.4-8	Inorganic COPCs in Filtered Intermediate Groundwater from the Sandia Canyon Watershed	129
Table 6.4-9	Inorganic COPCs in Nonfiltered Intermediate Groundwater from the Sandia Canyon Watershed	130
Table 6.4-10	Organic COPCs in Nonfiltered Intermediate Groundwater from the Sandia Canyon Watershed	131
Table 6.4-11	Radionuclide COPCs in Nonfiltered Intermediate Groundwater from the Sandia Canyon Watershed	132
Table 6.4-12	General Inorganic COPCs in Filtered Intermediate Groundwater from the Sandia Canyon Watershed	133
Table 6.4-13	General Inorganic COPCs in Nonfiltered Intermediate Groundwater from the Sandia Canyon Watershed	134
Table 6.4-14	Inorganic COPCs in Filtered Regional Groundwater and Springs from the Sandia Canyon Watershed	135
Table 6.4-15	Inorganic COPCs in Nonfiltered Regional Groundwater and Springs from the Sandia Canyon Watershed	136
Table 6.4-16	Organic COPCs in Nonfiltered Regional Groundwater and Springs from the Sandia Canyon Watershed	138
Table 6.4-17	Radionuclide COPCs in Nonfiltered Regional Groundwater and Springs from the Sandia Canyon Watershed	141
Table 6.4-18	General Inorganic COPCs in Filtered Regional Groundwater and Springs from the Sandia Canyon Watershed	144
Table 6.4-19	General Inorganic COPCs in Nonfiltered Regional Groundwater and Springs from the Sandia Canyon Watershed	147
Table 6.5-1	Sandia Canyon Watershed COPC Summary	150
Table 6.5-2	Summary of Water COPCs Greater than Comparison Values	159

Table 7.2-1	Reductive Capacity of the Sandia Canyon Wetland and the Rock Units within the Chromium Area	160
Table 8.4-1	Maximum Phase II Sediment COPC Concentrations Compared with Screening Levels	161

Appendixes

Appendix A	Acronyms and Abbreviations, Metric Conversion Table, and Data Qualifier Definitions
Appendix B	Field Investigation Methods and Results
Appendix C	Analytical Data
Appendix D	Contaminant Trends and Inventory
Appendix E	Geophysics Report from Contractor
Appendix F	Perched-Intermediate Groundwater Level Responses
Appendix G	Analysis of Regional Aquifer Water Levels Observed at Monitoring Wells Near Sandia Canyon
Appendix H	Chromium Isotope Investigation
Appendix I	Investigations of Light Stable Isotopes
Appendix J	Analytical Simulation of Chromium Contaminant Transport in the Regional Aquifer and Estimation of the Potential Zones of Contaminant Arrival at the Top of the Regional Aquifer
Appendix K	Numerical Simulation of Groundwater Flow and Chromium Transport in the Regional Aquifer beneath Sandia and Mortandad Canyons
Appendix L	Hydrogeologic Analysis of the Aquifer Pumping Test at Regional Well R-28
Appendix M	Hydrogeologic Cross-Sections along and across Sandia Canyon
Appendix N	Cross-Reference of New Mexico Environment Department Approvals with Modifications to the Sandia Canyon Phase II Investigation Report

Plates

Plate 1	Sandia Canyon Watershed
Plate 2	Sandia Canyon Geomorphology Reach S-5EC

1.0 INTRODUCTION

Los Alamos National Laboratory (LANL or the Laboratory) is a multidisciplinary research facility operated by the U.S. Department of Energy (DOE). The Laboratory is located in north-central New Mexico, approximately 90 km (60 mi) northeast of Albuquerque and 30 km (20 mi) northwest of Santa Fe. The Laboratory consists of a 103 km² (40 mi²) area, mostly on the Pajarito Plateau, which is a series of mesas separated by eastward-draining canyons. It also includes part of White Rock Canyon along the Rio Grande to the east. The Laboratory is currently investigating sites potentially contaminated by past operations, both inside and outside the current Laboratory boundary, to ensure contaminants do not threaten human health or the environment. The sites under investigation are designated as solid waste management units (SWMUs), areas of concern (AOCs), and consolidated units. Contamination in canyon bottoms and in groundwater is being investigated on a watershed basis between the possible sources and the Rio Grande, the master drainage in the region, in addition to investigations at SWMUs and AOCs. Canyons investigations at the Laboratory are subject to the March 1, 2005, Compliance Order on Consent (the Consent Order).

1.1 Purpose and Scope

This Phase II investigation report presents the results of studies conducted from August 2009 to June 2012 to assess contamination in affected media in, beneath, and surrounding Sandia Canyon. The area encompassed by this investigation is shown in Figure 1.1-1. The investigation reported herein addresses sediment, surface water, shallow perched alluvial groundwater, perched-intermediate groundwater, and regional groundwater potentially impacted by SWMUs and AOCs located within the watershed. These media are collectively referred to as canyons media in this report.

The Phase II investigation builds on investigations conducted from 1998 to July 2009 presented in the Investigation Report for Sandia Canyon (hereafter, the Phase I IR) (LANL 2009, 107453). The Phase II investigation was conducted to fulfill the requirements set forth in the Phase II Investigation Work Plan for Sandia Canyon (hereafter, the Phase II Work Plan) (LANL 2010, 110480). The Phase II Work Plan was written in response to the New Mexico Environment Department's (NMED's) approval with modification for the Investigation Report for Sandia Canyon (NMED 2010, 108683). NMED approved the Phase II Work Plan with modifications in 2011 (NMED 2011, 111518).

The investigations conducted under the Phase II Work Plan also followed the technical strategy presented in the Core Document for Canyons Investigations (hereafter "the canyons core document") (LANL 1997, 055622). The canyons core document was prepared after a pilot study in Los Alamos and Pueblo Canyons was implemented in 1996, with the goal of standardizing the technical strategy for work in canyons. In 1998, NMED approved the core document (LANL 1998, 057666; NMED 1998, 058638).

This report synthesizes the results from the investigations conducted to date for chromium and other contaminants originating from Sandia Canyon. The domain of the discussions contained in this report is larger than the area encompassed by and beneath the Sandia Canyon watershed. The domain extends toward the south beneath the Mortandad Canyon watershed to include wells that are defined as part of the Chromium Investigation monitoring group, as defined in the 2011 Interim Facility-wide Groundwater Monitoring Plan (LANL 2011, 208811). Data from and beneath adjacent watersheds are incorporated into the conceptual model (CM) as a result of hydrologic and contaminant pathways identified during the investigations. Data collected during the investigations included in this report are used to (1) further define the nature and extent of contamination; (2) update the CM for contaminant distribution and transport; and (3) determine and recommend potential remedial actions, if needed, that may be appropriate to achieve or maintain site conditions at an acceptable risk level. The assessments in this report primarily present

data the Laboratory collected since 2009 under the Phase II Work Plan. However, the CMs and risk assessment presented in the report are inclusive of the previous studies.

This report addresses characterization and risk assessment on the spatial scale of an entire canyon system, encompassing a large area downcanyon and downgradient of SWMUs and AOCs. The characterization and assessment approach used in this investigation provides an integrating perspective on historical and current contaminant releases to the canyon floor and subsequent contaminant redistribution resulting from various transport processes. This approach facilitates the development of CMs that describe expected spatial and temporal trends in contaminant concentrations, thus supporting recommendations for long-term monitoring or remediation. The results also support the Laboratory's watershed approach by providing information on the extent of contamination associated with SWMUs, AOCs and aggregate areas in the Sandia Canyon watershed and by helping identify and prioritize remedial activities within the watershed.

1.2 Organization of Investigation Report

This investigation report follows the outline used in the NMED-approved Mortandad Canyon Investigation Report (LANL 2006, 094161; NMED 2007, 095109), and is organized as follows. Section 1 is an introduction to the report and to the Sandia watershed. Section 2 provides background information on the sources and history of contaminant releases, previous investigations of canyons media, and remediation and stabilization activities that have occurred in the watershed. Section 3 describes the scope of activities in this investigation. Section 4 introduces the field and laboratory investigations. Section 5 describes the regulatory context of this investigation. Section 6 presents screening level assessments that identify chemicals of potential concern (COPCs) and that help focus subsequent sections on the subset of the most important COPCs for evaluating potential human health risk. Section 7 presents a physical system CM, including discussions of the nature, sources, extent, fate, and transport of select COPCs that are most relevant for evaluating contaminant distributions, and the fate and transport of chromium and other COPCs. Section 8 discusses new sediment and surface water data and relates those to the full ecological risk-screening assessments and human health risk-screening assessments performed in the Phase I IR (LANL 2009, 107453). Section 9 presents the conclusions and recommendations. Acknowledgements of those who contributed to this report are listed in section 10. Section 11 presents the references cited in this report.

This report includes the following appendixes. Appendix A presents a list of acronyms and abbreviations, a table showing conversion of metric units to U.S. customary units, and data qualifier definitions. Appendix B presents field-investigation methods and results. Appendix C presents analytical results from sediment and water samples and summarizes data quality. Data packages are included as attachments on DVD. Appendix D presents supporting information on spatial contaminant trends. Appendix E is a report detailing a geophysical survey of the wetland in upper Sandia Canyon. Appendix F presents a study of perched-intermediate water-level responses. Appendix G provides an updated map of the water table beneath the Laboratory based on new wells and an analysis of transient, regional water levels. Appendixes H and I present the results from the chromium isotope and light stable isotope investigations, respectively. Appendixes J and K describe numerical simulations of chromium transport in the regional aquifer using analytical and three-dimensional (3-D) models. Appendix L provides the results of an aquifer pumping test at regional well R-28. Appendix M presents geologic cross-sections along and perpendicular to Sandia Canyon. Finally, Appendix N includes cross-walk tables that address comments received in NMED's approval with modification for the Investigation Report for Sandia Canyon (NMED 2010, 108683), and NMED's approval with modifications on the Phase II Work Plan (NMED 2011, 111518).

1.3 Watershed Description

Sandia Canyon heads on the Pajarito Plateau in Technical Area 03 (TA-03), has a maximum elevation of approximately 2320 m (7600 ft) above sea level (asl), and extends approximately 17.6 km (10.9 mi) to the Rio Grande at an elevation of approximately 1660 m (5445 ft) asl (Figure 1.1-1). The watershed has a drainage area of 14.2 km² (5.5 mi²), of which 45% is on Laboratory land, 39% is on Pueblo de San Ildefonso land, 15% is within Bandelier National Monument, and 1% is on private land. The part of the watershed upcanyon from state highway NM 4 and White Rock, the primary focus of this investigation, has a drainage area of 6.7 km² (2.6 mi²), of which 96% is on Laboratory land, 3% is on Pueblo de San Ildefonso land, and 1% is on private land.

Bedrock geologic units exposed within the Sandia Canyon watershed consist largely of the Tshirege Member of the Bandelier Tuff and basaltic rocks of the Cerros del Rio volcanic field (Griggs and Hem 1964, 092516; Smith et al. 1970, 009752; Dethier 1997, 049843). Geologic units within this watershed are discussed in more detail in section 7 of this report.

A comprehensive overview of the biological setting of the Sandia Canyon watershed is provided in the Sandia Canyon Biota Investigation Work Plan (LANL 2007, 099152), and results of the ecological risk assessment are included in the Phase I IR (LANL 2009, 107453). Details about the hydrology of the watershed are discussed in section 7 of this report.

1.4 Current Land Use

The portion of the Sandia Canyon watershed downcanyon from SWMUs and AOCs is located on DOE land, private land at the Royal Crest trailer park, Bandelier National Monument land, and Pueblo de San Ildefonso land. Laboratory activities in the canyon bottom are largely restricted to environmental work, such as sediment and water sampling, except for the Protective Force firing range in TA-72. Currently, some public access to the watershed is available on Laboratory land downcanyon from SWMUs and AOCs, east of the firing range, and other parts of the canyon may be used by Laboratory personnel for recreational activities, such as hiking. The Pueblo land supports various traditional uses.

2.0 BACKGROUND

Inorganic chemicals, organic chemicals, and radionuclides have been released into Sandia Canyon from a variety of sources, primarily Laboratory operations and Laboratory physical support (i.e., power and steam generation, sanitary effluent treatment) in several TAs, since the Laboratory began operation in 1943. Section 2 of the Phase I IR summarizes known releases of inorganic chemicals, organic chemicals, and radionuclides that have contributed to contamination in the Sandia watershed (LANL 2009, 107453). Liquid wastes from industrial and sanitary systems have been discharged to Sandia Canyon since the early 1950s. The canyon was also the location of a brief operation of a small-charge implosion and initiator experiment site in the 1940s and in recent years has served as the location of the Laboratory's security force firing range. These operations, conducted in and next to Sandia Canyon, may have impacted Sandia Canyon and its tributaries. Discharges are associated with outfalls, surface runoff, and firing site activities located at TA-03, which is the current location of the Laboratory administration complex, and former TA-20, which briefly operated in the 1940s as a firing site. A former asphalt batch plant (LANL 2008, 100693), former polychlorinated biphenyl- (PCB-)containing transformers, and former PCB spills (LANL 2008, 100693) were also located at TA-03. Additional discharges began with the continued expansion of Laboratory operations to include accelerator technology research and a firing range in the 1960s, specifically at TA-53 and TA-72. In addition, near the head of the watershed, several

large paved parking lots and roads drain into the canyon. Runoff from developed areas can transport various contaminants into the canyon.

Much of the contamination related to Laboratory releases is associated with effluent discharges. The contamination has been dispersed into the watershed in sediment, surface water, and alluvial groundwater from release sites. Subsequently, waterborne constituents have percolated into the subsurface and are observed in vadose-zone pore water. Hexavalent chromium from cooling tower discharge and other constituents are present in intermediate-perched water and in regional groundwater. SWMUs and AOCs that may contribute contaminants to the Sandia watershed are described in various work plans and historical investigation reports (LANL 1999, 064617; LANL 2008, 100692; LANL 2008, 100693; LANL 2009, 105079; LANL 2009, 105078) and are summarized in the Phase I IR (LANL 2009, 107453). In addition, releases associated with the TA-03 Power Plant cooling towers are discussed in documents related to the chromium investigations (LANL 2006, 091987; LANL 2006, 094431; LANL 2007, 098938; LANL 2008, 102996).

The following sections provide background and updated information on the more significant effluent releases, both in terms of contaminant mass and effluent volumes, to Sandia and Mortandad Canyons that are relevant to this Phase II IR. In addition, stabilization efforts conducted in the Sandia watershed are discussed.

2.1 Effluent Releases

2.1.1 Sandia Canyon

Liquid effluents have been released from TA-03 to Sandia Canyon since the early 1950s and continue today. The highest volume releases include treated sanitary wastewater, steam plant effluent, and cooling tower blowdown from the TA-03 power plant (building 03-0022, Plate 1). From 1951 to 1985, treated effluent generated by the TA-03 waste water treatment plant (WWTP) [Consolidated Unit 03-014(a)-99, discussed in section 2.1.1.4] was recycled and used for cooling at the TA-03 power plant (LANL 2008, 100692). The water was further treated before it was used as cooling water, and the history of water treatment chemicals used at the power plant is provided in the Interim Measures Report for Chromium Contamination (LANL 2006, 094431). In particular, potassium dichromate usage from 1956 to 1972 resulted in an estimated total release of approximately 31,000 to 72,000 kg (69,000 to 160,000 lb) of hexavalent chromium into the south fork of upper Sandia Canyon [SWMU 03-012(b)] (LANL 2007, 098938). Phosphate, zinc, and sulfuric acid were other common additives used during this time period. Since 1985, the Laboratory uses the Los Alamos County power grid for its electrical power needs, and the TA-03 power plant is used only for backup or emergency power, at most a few times a month. Municipal water rather than recycled waste water is used for cooling. Chlorine, bromine, sodium molybdate, zinc chloride, other inorganic salts, and acrylate polymers have been used as cooling water additives during this period of low power generation (LANL 2006, 094431).

In 1976 and 1977, a monitoring program detected tritium in effluent from sanitary sewage treatment facilities at the Laboratory (Stoker 1977, 037377). The study noted that there was apparently recurring tritium contamination entering the TA-03 treatment facility in upper Sandia Canyon. Effluent tritium concentrations measured approximately monthly from June 1976 to January 1977 ranged between 4200 pCi/L and 38,500 pCi/L.

Currently, three National Pollutant Discharge Elimination System (NPDES) outfalls release to upper Sandia Canyon in the TA-03 area (EPA 2007, 099009). NPDES Outfall 001 (formerly designated as NPDES Outfall 01A001 and shown on Plate 1 with this designation) discharges effluent, predominantly from the Laboratory's TA-46 Sanitary Wastewater Systems Consolidation (SWSC) plant and the TA-03

steam plant boilers. Effluent for infrequent cooling of the TA-03 power plant is also discharged here. Outfall 001 is the main effluent source of water to Sandia Canyon, and average discharges approach 300,000 gal./d. NPDES Outfalls 03A027 and 03A199 (Plate 1), associated with facility cooling of the Strategic Computing Complex and the Laboratory Data Communications Center, also discharge to upper Sandia Canyon. These two outfalls contribute approximately 100,000 gal./d of cooling water effluent to the canyon. Together these three outfalls (001, 03A027, and 03A199) provide sufficient water to mobilize contaminants within the watershed. Appendix F of this report shows the daily outfall volumes recorded for Outfall 001 from October 2006 to June 2012. Effluent at the outfall points is monitored in compliance with the NPDES permits. Sandia Canyon will likely experience decreased effluent volume from NPDES Permitted Outfall 001 as part of the Sanitary Effluent Reclamation Facility (SERF) expansion project. As part of the SERF expansion, a large portion of the effluent currently related to Sandia Canyon will be treated with reverse osmosis and rerouted to cooling towers at TA-03.

2.1.2 Mortandad Canyon

The Laboratory's Radioactive Liquid Waste Treatment Facility (RLWTF) located at TA-50 began operations in July 1963, and water treatment continues today. The RLWTF has discharged treated wastewater to Mortandad Canyon through Effluent Canyon through an outfall that is currently permitted as NPDES Outfall 051 [SWMU 50-006(d)]. The largest quantity of contamination and radionuclides released to the Mortandad watershed has come from this outfall, which is referred to in the remainder of this document as Outfall 051. Discharges and contaminant nature and extent related to this outfall are summarized in the Mortandad Canyon Investigation Report (LANL 2006, 094161). Releases are relevant to the Sandia Canyon Phase II investigation because perchlorate, nitrate, and tritium released from Outfall 051 are considered to be cocontaminants in perched-intermediate zones and the regional aquifer with chromium released from Outfall 001 in Sandia Canyon. This outfall has historically released much lower volumes of effluent than Outfall 001 with peak discharges occurring in 1968 (LANL 2006, 094161). Appendix F of this report shows monthly outfall volumes recorded between July 2007 and July 2010 to be less than 200,000 gal./mo. Since August 2010, only two discharges from this outfall have occurred, both in November 2010, and totaling less than 2000 gal. (Appendix F). Effluent discharges from Outfall 051 have effectively stopped, although the outfall is still permitted for release.

2.2 Previous Investigations of Contamination in Canyons Media

Contamination in sediment, surface water, and groundwater in Sandia Canyon has been evaluated in several studies before this report, dating back to 1971 (Purtymun 1971, 004795). This previous work documented the presence of elevated levels of inorganic chemicals, organic chemicals, and radionuclides in canyon media and has evaluated the potential effects of contaminants on biota. Some key studies were summarized in the Phase I IR (LANL 2009, 107453); those provide background and supplemental data for the investigations presented in this report. Summaries of additional general environmental sampling since the Phase I IR are also reported in the Laboratory's Environmental Reports (LANL 2010, 111232; LANL 2011, 207316). Relevant information from these studies is included in subsequent sections of this report. The Phase I IR results are summarized below.

2.2.1 Consent Order Investigations

Results of the Sandia Canyon Phase I Investigations through 2009 were presented in the Phase I IR (LANL 2009, 107453). The Phase I IR also incorporated results from chromium investigations to date. It included the results of sediment investigations from 12 reaches in Sandia Canyon. It summarized surface water and groundwater investigations that included the installation and monitoring of 5 alluvial monitoring wells, 5 piezometers, 6 vadose-zone characterization core holes, 2 perched-intermediate monitoring

wells, and 8 regional monitoring wells. Monitoring included surface water and groundwater sampling, water balance investigations, and water-level measurements. Source identification and geochemical investigations were also presented including quantification of the chromium source, an environmental mass balance for chromium, drying and leaching of wetland materials, a chromium isotope investigation, and experimental measurements to identify chromium speciation and chromium attenuation mechanisms. Numerical modeling was also performed to identify transport pathways through the vadose-zone and regional aquifer and to identify the location where chromium reaches the regional aquifer. Surface geophysics, biological investigations, and human health and baseline ecological risk assessments were also included in the report.

The risk assessments presented in the Phase I IR identified a potential carcinogenic risk from polycyclic aromatic hydrocarbons (PAHs) in sediment, and potential adverse ecological effects to terrestrial receptors from PCBs in sediment; both of these potential risks were identified for the upper part of Sandia Canyon. Hexavalent chromium was identified as a groundwater COPC because its concentration exceeds the New Mexico groundwater standard in perched-intermediate and regional groundwater. The work presented in this investigation report builds upon these previous studies.

2.3 Site-Stabilization Activities

Several remediation activities in the Sandia watershed that have reduced the potential for transport of contaminants from SWMUs or AOCs into the canyon bottoms are described in the Phase I IR (LANL 2009, 107453). More recent stormwater management and wetland stabilization activities are discussed below.

2.3.1 Stormwater Management

The Laboratory is authorized by the U.S. Environmental Protection Agency (EPA) to discharge stormwater associated with industrial activities from specified SWMUs and AOCs, including several in Sandia Canyon, under the Laboratory's Individual Permit (EPA 2010, 213450). Baseline controls are put in place to minimize pollutants in storm water discharges. These include best management practices (BMPs) that control erosion and sedimentation, and manage run-on and runoff. Example BMPs include berms, straw waddles, rock check dams, and gabions. Monitoring of storm water discharges at specified sampling points known as site monitoring areas against applicable target action levels is also required. Table 2.3-1 lists baseline and augmented BMPs that have been installed at SWMUs that discharge to Sandia Canyon.

2.3.2 Planned Stabilization of the Sandia Canyon Wetland

The Laboratory prepared the Work Plan and Final Design for Stabilization of the Sandia Canyon Wetland (LANL 2011, 207053) in response to requirements set forth by NMED (NMED 2011, 203806; NMED 2011, 111518). The work plan provides general project background and documents the final design of the proposed measures intended to physically stabilize the Sandia Canyon wetland. The Sandia wetland will likely experience decreased effluent volume from NPDES Permitted Outfall 001 as part of the SERF expansion project (section 2.1.1).

The project objectives are to arrest the headcut in the lower portion of the wetland and to allow reduction of effluent volume from Outfall 001. The headcut in the lower section of the wetland will be stabilized by constructing a stepped grade-control structure that will allow a grade transition from the current elevation of the wetland to the stream bank near stream gage E123 (Plate 1). This measure will stabilize the wetland sediment and associated contaminant transport into the lower sections of the canyon. These

measures should also maintain reducing conditions within the wetland sediment; reducing conditions are conducive to maintaining chromium in its more immobile trivalent state.

A series of 12 shallow (3- to 12-ft-deep drive-point) wells were installed in the wetland in July 2012 as monitoring for this stabilization effort. Data from the wells will be used to evaluate hydrologic or geochemical changes associated with the engineered controls and/or those associated with the SERF expansion and subsequent effluent reduction.

3.0 SCOPE OF ACTIVITIES

The scope of activities in this report include investigations of sediment, surface water, groundwater, and geochemistry in the Sandia Canyon watershed, as presented in the Phase II work plan (LANL 2010, 110480). Data from these studies are used to evaluate spatial and temporal trends in contamination within the Sandia Canyon watershed and across watershed boundaries, including variations in contaminant concentrations at increasing distances from the source areas and as a function of time. Groundwater investigations in the adjacent watersheds of Los Alamos and Mortandad Canyons are also included because they are important to understanding subsurface transport of contaminants originating from Sandia Canyon. These investigations are discussed below.

3.1 Sediment Investigations

The sediment investigation presented in this report focused on sampling supplemental reach S-5EC in Sandia Canyon (LANL 2010, 110480). Figure 3.1-1 and Plate 1 show the locations of the Phase I and Phase II investigation reaches within Sandia Canyon. Samples were analyzed for a full suite of inorganic and organic compounds. The new reach contains a large sediment deposition area where a single defined stream channel is replaced by a broad canyon-bottom fan. The new sediment data were collected to define the sediment thickness, volume, and contaminant inventory in an area of sediment deposition within a relatively wide section of Sandia Canyon between reaches S-5C and S-5E. Data from this reach are used in conjunction with data from the 12 reaches sampled previously in the Phase I investigation to identify spatial trends in contamination at a watershed scale, including variations in contaminant concentrations and inventories at increasing distances from source areas and temporal trends in contamination. The investigation methods are discussed in section 4.1 and Appendix B, section B-1, of this report; in the Phase I IR (LANL 2009, 107453); in approved Phase I work plan and subsequent related documents (LANL 1999, 064617; LANL 2003, 081597; LANL 2005, 091542); and in the canyons core document (LANL 1997, 055622; LANL 1998, 057666).

3.2 Surface Water and Groundwater Investigations

The water investigations presented in this report focus on watershed-scale characterization of surface-water base-flow, springs, alluvial groundwater, intermediate perched groundwater, and regional groundwater within and beneath the Sandia Canyon watershed to satisfy the requirements in several documents (LANL 2010, 109830; LANL 2010, 110480; LANL 2011, 208811; NMED 2011, 111518)). Figure 3.2-1 and Plate 1 show the locations of surface-water and groundwater sites sampled as part of this investigation and the Phase I investigation. Surface water and groundwater information from adjacent watersheds (primarily Mortandad and Los Alamos Canyons) is also considered in this report because contaminants have been transported across watershed boundaries in the subsurface. Surface-water and groundwater monitoring is discussed further in section 3.2.5. The investigation methods are discussed in Appendix B of this report.

Data from these components of the hydrogeologic system are screened to evaluate potential human health and ecological risk as well as to identify spatial trends in contamination at a watershed scale, including variations in contaminant concentrations at increasing distances from the source areas and as a function of time. This work involved sampling persistent surface water and springs, drilling and installing monitoring wells, sampling new and preexisting groundwater wells, and measuring water-level variations in all groundwater sources.

3.2.1 Perched-Intermediate Monitoring Well Installations

Perched-intermediate well SCI-3 was proposed to monitor water quality beneath Sandia Canyon and to help define the extent of chromium contamination in perched groundwater within the Cerros del Rio basalt (LANL 2010, 110480), as required by NMED's approval with modification of the Sandia Canyon Phase I IR (NMED 2010, 108683). Borehole SCI-3 was planned to penetrate through the Cerros del Rio volcanic series in the vicinity of existing perched intermediate well SCI-1 (Figure 3.2-1, Plate 1), which has a screen in the perched interval above the Cerros del Rio basalts (LANL 2011, 111728). The screen placement for SCI-3 was to be within a deeper perched interval at a horizon within the lower Cerros del Rio comparable with that at perched-intermediate well SCI-2 to the southeast. The well was to be completed with a single screen set within the zone of intermediate saturation capable of sampling for chromium and associated contaminants within Sandia Canyon. The SCI-3 borehole was drilled in 2011, but the borehole was plugged and abandoned because the limited perched zone within the Cerros del Rio lavas was insufficient for placement of a well screen.

Perched-intermediate well SCI-4 was proposed to monitor water quality beneath the ridge separating Sandia and Mortandad Canyons. The main purposes of well SCI-4 were to determine if perched groundwater systems in the two canyons are hydraulically connected and to further define the vertical and lateral extent of chromium contamination in perched groundwater, as required by NMED's Approval with Modification on the Sandia Canyon Phase I IR (NMED 2010, 108683). Well SCI-4 was to be located on the same drill pad as new regional well R-62 (Figure 3.2-1, Plate 1); completion of the well was contingent upon the presence of perched water encountered during drilling of R-62 (LANL 2010, 111127). Well SCI-4 was intended to target the deeper perched-intermediate groundwater between depths of approximately 840 ft and 860 ft within the Cerros del Rio volcanic series. The proposed borehole total depth was approximately 900 ft. A single screen set within the deeper zone of intermediate saturation was planned for the well. Perched water was detected during the drilling of R-62, but borehole videos and water level data indicated the perched zone of interest in the lower part of the Cerros del Rio basalt was not productive enough to support a perched intermediate well, and the well was not installed.

Perched-intermediate well R-10i was planned to monitor water quality in a perched interval initially encountered while drilling regional aquifer wells R-10 and R-10a (Figure 3.2-1, Plate 1) (LANL 2011, 202573). Well R-10i will supplement Laboratory boundary and off-site perched groundwater monitoring that is currently provided by wells R-9i, R-12, and R-23i. Installation of R-10i will proceed as required by NMED's approval with modification of the Sandia Canyon Phase I IR (NMED 2010, 108683). Well R-10i will be located on the same drill pad as wells R-10a and R-10 (Figure 3.2-1, Plate 1). The R-10i borehole is expected to penetrate perched saturation within riverine sand and gravel deposits (older alluvium) that occur between lavas of the Cerros del Rio volcanic field. The perched zone may be confined and water level may occur at a depth of approximately 303 ft within the upper Cerros del Rio basalts. The target borehole depth is approximately 400 ft. The well will be completed with one well screen, placed within the riverine gravels.

3.2.2 Regional Aquifer Monitoring Well Installations

Regional groundwater monitoring well R-50 was installed in 2010 to monitor groundwater quality and contaminant movement and to define the southern extent of chromium contamination in the vicinity of monitoring wells R-28 and R-42 (Figure 3.2-1 and Plate 1). The well is also used to measure water levels at two discrete depth intervals within the regional aquifer. This well was recommended in the Phase I IR (LANL 2009, 107453). R-50 is a dual-screen well installed in a small tributary of Mortandad Canyon south of R-28. The upper 10-ft-long screened interval is set with the top of the screen at 1077 ft below ground surface (bgs) within the Puye Formation, and the lower 20-ft-long screened interval is set with the top of the screen at 1185 ft bgs within Miocene pumiceous sediments. Details of the well completion and hydrogeologic conditions encountered in R-50 are provided in the Completion Report for Regional Aquifer Well R-50 (LANL 2010, 109980).

Regional groundwater monitoring well R-61 was installed in 2011 to monitor water quality in the regional aquifer and to help define the vertical and lateral extent of chromium contamination known to exist in the vicinity of wells R-28, R-42, and R-50 (Figure 3.2-1, Plate 1), as required by NMED's approval with modification of the Phase I IR (LANL 2009, 107453; NMED 2010, 108683). R-61 is a dual-screen well with screened intervals set between 1125 and 1135 ft bgs within Puye Formation sediments and between 1220 and 1241 ft bgs within Miocene pumiceous sediments. Details of the well completion and hydrogeologic conditions encountered in R-61 are provided in the Completion Report for Regional Aquifer Well R-61 (LANL 2011, 206492).

Regional groundwater monitoring well R-62 was installed in 2011 to help define the upgradient extent of chromium contamination known to exist in the vicinity of wells R-28, R-42, and R-50, as required by NMED's approval with modification of the Phase I IR (NMED 2010, 108683). R-62 is located on a narrow ridge separating Sandia and Mortandad Canyons at the east end of Sigma Mesa (Figure 3.2-1 and Plate 1). R-62 has a single screen set between 1156 and 1179 ft bgs in Miocene pumiceous sediments. Details of the well completion and hydrogeologic conditions encountered in R-62 are provided in Completion Report for Regional Aquifer Well R-62 (LANL 2012, 215008).

3.2.3 R-28 Cross-Hole Pumping Test

A cross-hole pumping test was proposed at well R-28 to better understand the spatial distribution of regional aquifer heterogeneity and anisotropy in the vicinity of the chromium plume near well R-28 and R-42 (LANL 2010, 110480). The data obtained from the test are used to constrain flow parameters over a larger scale than is obtained from standard single-hole pumping tests and to constrain groundwater modeling related to chromium transport. The pumping test of up to 10 d was planned with monitoring of pressure (water-level) responses at nearby regional wells.

3.2.4 Well Redevelopment

Recent groundwater data from the two screens of new regional well R-61 are nonrepresentative because of high iron and manganese concentrations that indicate reducing conditions. The cause of the observed conditions is uncertain. The Laboratory submitted a work plan for the redevelopment of both well screens in June 2012 (LANL 2012, 221454). Redevelopment will include (1) physical redevelopment methods using swabbing, surging, jetting, and pumping techniques, and (2) chemical treatment using a sequence of treatment products.

3.2.5 Surface Water and Groundwater Sampling

This investigation included sampling of surface water, alluvial groundwater, springs, perched-intermediate groundwater, and regional groundwater to provide snapshots of water quality throughout the hydrological system. Water-quality data from this sampling provide information about constituents that can be used to fingerprint potential sources and pathways, leading to improved CMs of processes controlling chromium mobility and transport and to the selection of appropriate remedial actions. Table 3.2-1 lists the sites sampled, and Figure 3.2-1 shows the water sampling locations for the Phase I and Phase II investigations.

This report primarily focuses on describing contaminants in the Chromium Investigation monitoring group. The Chromium Investigation monitoring group was established in 2011 as part of the facility-wide groundwater monitoring network (LANL 2011, 208811) (Figure 3.2-2). Monitoring focuses on the characterization and the fate and transport of chromium contamination in perched-intermediate groundwater and within the regional aquifer. The distribution of wells in the monitoring group addresses historical releases from Outfall 001, which discharges into Sandia Canyon, and Outfall 051, which discharges from the RLWTF into the Mortandad Canyon watershed. Other locations are monitored as part of the General Surveillance monitoring group (LANL 2011, 208811), which includes base-flow locations, alluvial monitoring wells, and springs.

Both filtered and nonfiltered water samples were collected, and the suite of analytes included general chemistry, inorganic constituents, metals (including total and hexavalent chromium), stable isotopes of hydrogen, nitrogen, and oxygen, perchlorate, volatile organic compounds (VOC), semi-volatile organic compounds (SVOC), high explosive (HE) compounds, total organic carbon (TOC), and radionuclides (including tritium). The field parameters for groundwater samples include temperature, conductivity, pH, alkalinity, dissolved oxygen, and turbidity. Analytical results for the metals and general chemistry are presented in Appendix C (on DVD).

3.2.6 Water-Level Measurements

Automated water-level data are collected with transducers at alluvial monitoring wells SCA-1, SCA-2, SCA-3, SCA-4, and SCA-5, piezometers SCP-2a,b and SCP-1a,b,c and intermediate wells SCI-1 and SCI-2. These data are used to study the spatial and temporal water level responses in the canyon.

Automated groundwater-level data are collected with transducers in regional wells throughout the Sandia, Mortandad and Los Alamos watersheds. These data are used to define the elevation of the water table beneath the site and to study groundwater level responses to water-supply pumping.

3.2.7 Surface Geophysics

A direct current (DC) electrical resistivity survey was conducted in the wetland area near the headwaters of Sandia Canyon in 2011. Long-term effluent discharges from runoff, sanitary wastewater, and cooling tower blowdown created the wetland environment. The objective of the survey was to identify low resistivity locations, which are indicative of increased moisture content, changes in rock type, perched water, or an increased concentration of electrolytes compared to background conditions. Data acquisition was made along four parallel longitudinal lines on strike with Sandia Canyon and five supplementary lines placed orthogonally to the longitudinal lines.

3.2.8 Geochemical Data Analyses

Geochemical data analyses were designed to better define infiltration and migration pathways and mixing zones in perched-intermediate and regional groundwater beneath Sandia and Mortandad Canyons. These geochemical investigations address requirements set forth in the Phase II Work Plan (LANL 2010, 110480). Analyses include using chromium isotopes to identify reduction in the subsurface, contaminant and stable isotope distributions and time series to define migration pathways, and major and minor ion chemistry (using stiff diagrams and piper plots) to differentiate groundwaters and pathways. The investigation results are discussed in detail in Appendixes D, H, and I of this report, and impacts to the CM are presented in section 7.2.

3.2.9 Simulations of Contaminant Transport

Site-scale groundwater-flow and contaminant-transport models were developed to model the fate and transport of the historical chromium source in Sandia Canyon. Analytical models and a transient 3-D numerical model of the groundwater flow and transport in the regional aquifer were developed. The 3-D model accounts for the structure of aquifer properties, the impacts of aquifer recharge caused by enhanced infiltration along Sandia and Mortandad Canyons, and the effects of water-supply pumping on water levels. It is calibrated against water-level data and concentrations of chromium in monitoring wells. The model also provides information about the potential vertical distribution of the chromium plume in the regional aquifer. These simulations address requirements set forth in the Phase II Work Plan (LANL 2010, 110480). The results are discussed in detail in Appendixes J and K of this report, and impacts to the CM are presented in section 7.2.

3.3 Deviations from Planned Activities

There were no deviations from activities planned for the Phase II investigation.

4.0 FIELD AND LABORATORY INVESTIGATIONS

Field investigations in the Sandia Canyon watershed included investigations of sediment, surface water, and groundwater. The approaches and methods of these investigations are briefly discussed in the following sections and the referenced appendixes.

4.1 Sediment

Sediment investigations in Sandia Canyon included detailed geomorphic characterization and sediment sampling for a full suite of inorganic and organic compounds in a single discrete reach, S-5EC, following the general process described in the work plan and canyons core document, as well as the Phase I IR (LANL 1997, 055622; LANL 1998, 057666; LANL 1999, 064617; LANL 2009, 107453). The geomorphic characterization included preparing a detailed geomorphic map delineating the horizontal extent of geomorphic units with varying physical characteristics, contaminant concentrations, and/or age. This map is presented in Plate 2 (sampling locations are marked with their respective "ER location ID" on the plate). The geomorphic characterization also included measuring the thicknesses of potentially contaminated post-1942 sediment deposits to estimate the volume of contaminated sediment in the reach. Several methods were used to identify the bottom of post-1942 sediment deposits, including determining the depth of burial of trees and associated buried soils, and noting the presence or absence of materials imported to the watershed after 1942 (e.g., quartzite gravel, plastic).

Field data from the Sandia Canyon Phase I investigation specific to the amount of chromium present within each type of geomorphic unit were used to help allocate samples for analysis at off-site laboratories. Section B-1 of Appendix B includes more detailed discussion of the investigation methods. All analytical results of the sediment sampling incorporated in this investigation report are presented in Attachment C-1 in Appendix C (on DVD).

Plate 2 presents the geomorphic map for reach S-5EC in Sandia Canyon, including sampling locations, stratigraphic description locations, and cross-section locations within this reach. Figure 4.1-1 shows cross-sections within reach S-5EC, and Figure 4.1-2 presents contextual cross-sections from the reaches immediately upstream (Reach S-5C) and immediately downstream (Reach S-5E) of reach S-5EC (LANL 2009, 107453). The horizontal extent of contaminated or potentially contaminated sediment deposits in each reach is delineated by the extent of the channel ("c") and floodplain ("f") units in these maps. Section B-1 of Appendix B presents field-investigation results, including sediment thickness measurements.

4.2 Surface Water and Groundwater

The surface water and groundwater investigations in the Sandia Canyon watershed were designed to define the nature and extent of contamination, to identify the physical and chemical processes controlling contaminant distributions, and to identify the transport pathways that could result in potential human health and ecological risk. This work includes sampling persistent surface water, drilling and installing monitoring wells, sampling new and preexisting groundwater wells, and measuring water level variations in all groundwater sources. The investigation methods are discussed in Appendix B of this report.

4.2.1 Perched-Intermediate Monitoring Well Installations

The SCI-3 borehole was not completed as a perched-intermediate monitoring well. The Laboratory proposed to plug and abandon (P&A) the borehole because driller's observations, video logs, and water-level observations indicated no significant water-bearing zones could be identified in the borehole to support a monitoring well (LANL 2011, 207365). The SCI-3 borehole was drilled to a TD of 711 ft and ended in lower Puye Formation. Cuttings were described to identify the hydrostratigraphic units and their contacts. NMED agreed that the borehole could be P&A'd (LANL 2011, 207365), and it was backfilled and capped (LANL 2011, 207442). No replacement is planned.

Installation of perched-intermediate well SCI-4 was contingent upon the presence of perched water observed during the drilling of regional well R-62. Two perched groundwater zones were encountered at the proposed SCI-4 site. However, data collected during drilling of R-62 indicated that installing a perched-intermediate well at that location was not practical. Borehole videos and water-level data indicated that the perched zone in the lower part of the Cerros del Rio basalt was not productive enough to support installing SCI-4 (LANL 2012, 215008). SCI-4 intermediate well was not drilled because of insufficient water flow in the perched zone. No replacement is planned.

Perched-intermediate well R-10i has not yet been installed. Currently the well is scheduled to be completed by January 20, 2014 (LANL 2011, 207519; NMED 2011, 208093).

4.2.2 Regional-Aquifer Monitoring Well Installations

Three regional wells were installed in Sandia and Mortandad Canyons as part of the Phase II investigation to fulfill the requirements of a variety of documents (LANL 2009, 107453; NMED 2010, 108683; LANL 2010, 110480). These wells are R-50, R-61, and R-62 (Figure 3.2.1 and Plate 1). Detailed well completion reports describe the investigation methods, well completion diagrams, geologic logs, and borehole geophysical logs for the wells. The well completion reports are described in section 3.2.2 of this

investigation report. In addition to these three new regional wells, nine regional wells were previously installed in Sandia and Mortandad Canyons as described in the Phase I IR (LANL 2009, 107453).

4.2.3 R-28 Cross-Hole Pumping Test

The 10-d, cross-hole pumping test at well R-28 was conducted from February 15 to February 25, 2012 (LANL 2012, 215114). R-28 was pumped at an average of 27.7 gallons per minute. Drawdown and recovery were observed at well R-28, and in seven nearby regional wells. Results of the pumping test are included in Appendix L of this report.

4.2.4 Well Redevelopment

Redevelopment of the two R-61 well screens was started in September 2012 and should be completed in October 2012, in accordance with requirements in the redevelopment work plan (LANL 2012, 221454).

4.2.5 Surface Water and Groundwater Sampling

As described in section 3.2.5, this investigation included sampling of surface water, alluvial groundwater, springs, perched-intermediate groundwater, and regional groundwater. Table 3.2-1 lists the sites sampled, and Figure 3.2-1 and Plate 1 show the sampling locations. Figure 3.2-2 shows the Chromium Investigation monitoring group. Water-quality field parameters, including pH, specific conductance, temperature, and turbidity, were measured for each surface and groundwater sample collected. Ongoing sampling of surface water under base flow conditions, springs, and regional groundwater is conducted as part of the Interim Facility-Wide Groundwater Monitoring Plan, Revision 1 (LANL 2011, 208811) and field and analytical procedures are described in that document.

4.2.6 Water-Level Measurements

Historical and new water-level data were compiled for alluvial, perched-intermediate, and regional wells in the Los Alamos, Mortandad, and Sandia watersheds. These data, which included both manual and automated measurements, allow hydraulic interconnections between wells to be assessed by comparing water-level responses with pumping records at municipal supply wells. Water-level data were also collected to determine hydraulic gradients within groundwater bodies and to assess hydraulic conductivity. Details of the field methodology and results are presented by Koch and Schmeer (2011, 201566). Further results are presented in Appendixes F and G of this report.

4.2.7 Surface Geophysics

HydroGeophysics of Tucson conducted a DC geophysical investigation of the wetland at the headwaters of Sandia Canyon between September 12 and 20, 2011. The results of the geophysical survey are included in Appendix E of this report. Data were collected along four longitudinal and five orthogonal lines, which were arranged following initial results from three longitudinal lines. Electrodes were placed at 10- and 20-ft spacing along the lines of investigation. The data were acquired in two-dimensional (2-D) profiles and inverted in both 2-D and 3-D format to reduce distortions noted in the 2-D format. The objective was to identify areas of low-resistivity that may indicate infiltration zones, perched water, and geological structures. During data processing, errors greater than 5% were removed from the data set.

The results indicate a near-surface conductive layer in the western half of the surveyed area, which extends to a depth of 40 ft. A highly resistive zone beneath the wetland was interpreted to be welded tuff that underlies the alluvial deposits. Models of electrical properties from the DC survey indicated various

subsurface geological and hydrological features of low resistivity that are correlated with perched alluvial aquifer, clay- and water-filled structural features, such as faults and fracture zones, and subvertical infiltration zones. Results also showed several high- and low-resistivity features that correspond to observed or reasonably inferred geological features such as the thick (6.1–7.6 m) conductive layer of alluvial aquifer deposited on top of welded unit Qbt 2 and structural features such as faults or zones of intense fracturing. The welded tuff beneath the wetland was identified as a widespread resistive layer. Even though low and high resistivity zones were clearly mapped, the roles of clay and water content on electrical conductivity were not well constrained, and this caused significant limitation in interpreting the resistivity data, as described in Appendix E.

5.0 REGULATORY CRITERIA

This section provides information on the regulatory context, water-quality standards, and other screening levels for the Sandia Canyon Phase II investigation.

5.1 Regulatory Context

Requirements governing canyons investigations are discussed in Section IV.B of the Consent Order. As described in Section IV.B, the canyons investigations primarily focus on fate and transport of contaminants from the point of origin to each canyon watershed drainage system and, if necessary, to the regional aquifer and/or to the Rio Grande.

The canyon bottoms addressed in this investigation report are potentially contaminated with both hazardous and radioactive constituents. NMED, pursuant to the New Mexico Hazardous Waste Act, regulates cleanup of hazardous wastes and hazardous constituents. DOE regulates cleanup of radioactive contamination, pursuant to DOE Order 5400.5, Radiation Protection of the Public and the Environment; DOE Order 435.1, Radioactive Waste Management; and DOE Order 458.1, Administrative Change 2, Radiation Protection of the Public and the Environment. Information on radioactive materials and radionuclides, including the results of sampling and analysis of radioactive constituents, is voluntarily provided to NMED in accordance with DOE policy and Section III.A of the Consent Order.

The regulatory requirements for conducting canyons investigations under the Consent Order are implemented through work plans approved by NMED. The approved work plan for Sandia Canyon is the Work Plan for Sandia Canyon and Cañada del Buey (LANL 1999, 064617; LANL 2003, 081597; NMED 2003, 076014; LANL 2005, 091542; NMED 2005, 091689; NMED 2005, 089312; LANL 2007, 095060). The Phase II investigation was conducted to fulfill the requirements set forth in the Phase II Work Plan for (LANL 2010, 110480). The Phase II Work Plan was written in response to NMED's approval with modification of the Investigation Report for Sandia Canyon (NMED 2010, 108683). NMED approved the Phase II Work Plan in 2011 with modifications (NMED 2011, 111518).

Two types of surface-water samples are evaluated for consistency with the Phase I report. Stormwater is transient and exists for some period directly in response to precipitation events. All other surface water samples are referred to as nonstorm-related surface water. Some of the locations included in the nonstorm-related surface-water data are springs. Because springs are emergent groundwater, sampling results from springs are compared with comparison values applicable to groundwater and surface water.

The assessments in this Phase II report primarily involve comparisons with the results of the Phase I IR for all media and contaminants. Surface-water and groundwater comparison values are used to support the identification of key contaminants for the assessment of nature and extent of contamination. Standards and other comparison values are discussed in section 5.2.

5.2 Water Quality Standards and Comparison Values

Concentrations in surface water are compared with applicable water-quality standards and other relevant values. The New Mexico Water Quality Control Commission (NMWQCC) establishes surface-water standards in the State of New Mexico Standards for Interstate and Intrastate Surface Waters (20.6.4 New Mexico Administrative Code [NMAC]). Certain watercourses may be “classified” and have segment-specific designated uses. A designated use may be an attainable or an existing use (e.g., livestock watering) for surface water. Nonclassified surface waters are described as ephemeral, intermittent, or perennial, each of which also has corresponding designated uses described in 20.6.4.97-99 NMAC. The designated uses for surface water are associated with use-specific water-quality criteria (WQC), including numeric criteria.

Sandia Canyon from Sigma Canyon (between reaches S-3E and S-4W; Plate 1) upstream to NPDES Outfall 001 at the Laboratory is classified as perennial (20.6.4.4.126 NMAC) and has designated uses of coldwater aquatic life habitat (acute and chronic standards 20.6.4.900[H], 20.4.6.900[I], and 20.4.6.900[J] NMAC, including all human health organism only standards); livestock watering (20.6.4.900[F] and 20.4.6.900[J] NMAC); wildlife habitat (20.4.6.900[G] and 20.4.6.900[K] NMAC); and secondary contact (20.4.6.900[E] NMAC).

The remaining segments in Sandia Canyon are ephemeral (20.6.4.128 NMAC applies to the ephemeral portion of Sandia Canyon watershed upstream of the eastern Laboratory boundary and 20.6.4.97 NMAC applies downstream of the Laboratory boundary), with designated uses of livestock watering (20.6.4.900[F] and 20.4.6.900[J] NMAC), wildlife habitat (20.4.6.900[G] and 20.4.6.900[K] NMAC), limited aquatic life (chronic standards 20.6.4.900[H], 20.4.6.900[I], and 20.4.6.900[J] NMAC, including human health organism only standards for persistent chemicals), and secondary contact (20.4.6.900[E] NMAC). As indicated by 20.6.4.128 NMAC, the acute total ammonia standard for salmonids absent (20.6.4.900[K] NMAC) applies to all ephemeral and intermittent watercourses on Laboratory property; therefore, this standard applies to all locations in Sandia Canyon west of the eastern Laboratory boundary.

The numeric water-quality criteria for livestock watering (20.6.4.900[F] and 20.4.6.900[J] NMAC); wildlife habitat (20.4.6.900[G] and 20.4.6.900[J] NMAC); acute aquatic life (20.6.4.900[H], 20.4.6.900[I], and 20.4.6.900[J] NMAC); human health organism only (persistent chemicals only) (20.6.4.11[G] and 20.4.6.900[J] NMAC); and secondary contact (20.6.4.900[E] NMAC) apply to surface water for all of the watercourse classifications.

Concentrations of radionuclides in surface water were compared with the lowest of the following values:

- 20.4.6.900[J] NMAC livestock watering standards
- New Mexico Environment Improvement Board Standards for Protection Against Radiation (20.3.4.461 [D] NMAC, Table II Column 2)
- DOE Biota Concentration Guides (BCGs) for protection of ecological receptors (DOE 2002, 085637)

For groundwater, comparisons to the lowest of the following standards were performed:

- human health (20.6.2.3103[A] NMAC: Human health standards)
- other standards for domestic water (20.6.2.3103[B] NMAC: Other standards for domestic water supply)
- EPA maximum contaminant levels (MCLs)

If none of the above standards exist for an analyte, the following values were compared with concentrations in groundwater:

- DOE DCGs based on 4 mrem/yr
- NMED tap water SLs
- EPA regional tap water SLs

Comparisons of surface water and groundwater concentrations to Phase I IR results and comparison values are summarized in section 6.

6.0 CANYONS CONTAMINATION

This section describes the methodology and results of screening assessments conducted to identify COPCs in sediment, surface water, and groundwater samples collected in Sandia Canyon. Identifying COPCs forms the basis for evaluating contamination in canyons media. A subset of these COPCs is discussed as part of the CM development in section 7. Section 6.1 briefly describes how the data were prepared for the screening processes. Section 6.2 presents the screen for sediment, section 6.3 presents the screens for nonstorm-related surface water and groundwater, and section 6.4 presents the stormwater evaluation. The term “sediment” includes all post-1942 sediment deposits in the canyon bottoms, including deposits in abandoned channels and floodplains as well as in active stream channels; therefore, sediment includes alluvial soil as defined in some other studies.

6.1 Data Preparation

Data packages for the analytical data for all media are presented in attachments in Appendix C. The data used in the assessments were obtained from the Laboratory’s environmental database and are presented in attachment in Appendix C. Samples collected, analytical methods, and data-quality issues are summarized in Appendix C, and data qualifiers are defined in Appendix A. Sampling locations may be referred to by more than one name, and a crosswalk showing synonyms for location names is presented in Table 6.1-1.

Certain analytical results were not evaluated in the Phase II COPC screens for the following reasons:

- Results from water samples collected before 2003—Results from samples collected from 2003 to July 2009 and later were used in the Phase I COPC screens and samples collected from August 2009 to June 2012 are used in the Phase II COPC screens because these data are most representative of current site conditions.
- Water data from locations not included in Table 6.1-1—These data are discussed in section 7 as part of the CM only. Locations included in the water screens are noted in Table 6.1-1.

Water samples collected during well development were excluded.

6.2 Sediment COPCs

This section presents the process for screening analytical results obtained from sediment samples collected in Sandia Canyon. Phase II samples collected and analyses performed by the analytical laboratories are presented in Table 6.2-1. Sample locations are presented in Figure 3.1-1 and Plates 1 and 2. Analytical results were screened to develop a list of COPCs, as presented in section 6.2.1. Phase II consisted of a single reach, S-5EC, located downstream of S-5C and upstream of S-5E.

6.2.1 Identification of Sediment COPCs

Inorganic COPCs in sediment are identified by a screening process that includes comparing the maximum concentrations by reach with Laboratory-specific sediment background values (BVs) (LANL 1998, 059730). Analytes are retained as COPCs using rules specific to the class of analyte. This process is discussed below.

For inorganic chemicals, an analyte is retained as a COPC in a reach if

- the analyte has a BV and a detected or nondetected result in the reach exceeds the BV or
- the analyte does not have a BV but has at least one detected result in the reach.

No BVs are available for organic chemicals, and retaining an organic chemical as a COPC is based on detection status. For organic chemicals, an analyte is retained as a COPC in a reach if there is at least one detected result in the reach.

A total of 10 inorganic chemicals and 24 organic chemicals were retained as COPCs during Phase II in comparison with a total of 31 inorganic chemicals, 50 organic chemicals, and 11 radionuclides retained as Phase I sediment COPCs in Sandia Canyon. Table 6.2-2 presents Phase II sampling results greater than BVs for inorganic chemicals, and Table 6.2-3 presents Phase II sampling results for all detected organic chemicals. The maximum detected sampling results for reach S-5EC are shown at the end of Tables 6.2-2 and 6.2-3, along with the maximum concentrations from Phase I for inorganic chemicals and organic chemicals, respectively.

6.2.2 Comparison of Phase II Sediment COPC Concentrations to Phase I Concentrations

Maximum concentrations of Phase II sediment COPCs were compared with the maximum concentrations measured in Phase I. One inorganic COPC (antimony) was identified as a Phase II COPC but was not a Phase I sediment COPC. Antimony was a Phase II COPC based on detection limits greater than the BV; antimony was not detected in any of the Phase II sediment samples. Five organic COPCs (4,4'-dichlorodiphenyldichloroethylene [4,4'-DDE]; dichlorophenyltrichloroethylene [4,4'-DDT]; diphenylamine; methylene chloride; and tetrachloroethene) were identified as Phase II COPCs but were not Phase I sediment COPCs. The maximum detected Phase I concentrations are presented for the other nine inorganic COPCs in Table 6.2-2 and the other 19 organic COPCs in Table 6.2-3. The Phase II concentrations represent a small fraction of the Phase I concentrations, with the Phase II values being from less than 1% to 22% of the Phase I values (Tables 6.2-2 and 6.2-3). Additional information on the nature, sources, and spatial trends of Phase II sediment COPCs is provided in section 7.1.

6.3 Surface Water COPCs

This section presents the process for screening Phase II stormwater and nonstorm-related surface-water sampling results from Sandia Canyon. Stormwater and nonstorm-related surface-water samples collected and analyses performed by the analytical laboratories are presented in Table 6.3-1. Sampling locations are presented in Table 3.2-1, in Figure 3.2-1, and on Plate 1. Analytical results from nonstorm-related surface-water samples were screened to develop a list of COPCs, as presented in section 6.3.2. Spring samples were screened both as nonstorm-related surface-water and as groundwater (section 6.4).

6.3.1 Stormwater Screen against Comparison Values

The stormwater screen evaluates detected analyte concentrations in filtered and nonfiltered stormwater samples using the lowest comparison value applicable for that field preparation from the State of

New Mexico Standards for Interstate and Intrastate Surface Waters (§20.6.4 NMAC), as described in section 5.2.

One inorganic chemical (copper) in filtered samples was greater than its stormwater comparison value. One group of organic chemicals (total PCBs) in nonfiltered samples was greater than its stormwater comparison value. Stormwater gross-alpha radiation in nonfiltered samples was greater than its comparison value. Table 6.3-2 summarizes the stormwater results by analyte, location, field preparation that exceed the lowest comparison value.

6.3.2 Identification of Nonstorm-Related Surface-Water COPCs

There are no BVs for surface water, and retaining an analyte as a COPC is based on detection status. This process is performed for groups of data defined by field preparation (filtered or nonfiltered samples) and analyte type (inorganic chemicals, organic chemicals, and radionuclides). An analyte is retained as a COPC for a surface-water location if at least one result was detected at that location.

A total of 48 inorganic chemicals in filtered and/or nonfiltered samples, 156 organic chemicals in nonfiltered samples, and 12 radionuclides in filtered and/or nonfiltered samples were retained as Phase II nonstorm-related surface-water COPCs in water in Sandia Canyon. The organic chemicals include 137 PCB congeners and 10 PCB homolog sums. These PCB congener and homolog sample results are represented by the total PCB concentration in these water samples. Maximum sampling results for nonstorm-related surface water COPCs are presented in Tables 6.3-3 to 6.3-6.

Maximum detected concentrations of water COPCs in filtered and nonfiltered samples were compared with a comparison value, as discussed in section 5.2, to identify which COPCs are most important from a regulatory perspective.

Four inorganic COPCs (arsenic, copper, selenium, and thallium) and one group of organic COPCs (total PCBs) have maximum concentrations above a comparison value. These COPCs are highlighted in gray, as applicable, in Tables 6.3-3 to 6.3-6. Radionuclide COPCs do not have maximum concentrations above a comparison value.

6.4 Groundwater COPCs

This section presents the process for screening Phase II groundwater sampling results from Sandia Canyon. Groundwater samples collected and analyses performed by the analytical laboratories are presented in Table 6.4-1. Sampling locations are presented in Table 3.2-1, Figure 3.2-1, and Plate 1. Analytical results from groundwater samples were screened to develop a list of COPCs, as presented in section 6.4.1. Spring samples were screened both as surface-water (section 6.3) and as groundwater.

6.4.1 Identification of Groundwater COPCs

Groundwater COPCs are identified by a screening process that includes comparing the maximum detected concentrations with Laboratory groundwater BVs (LANL 2007, 095817) for filtered and nonfiltered samples.

For inorganic chemicals and radionuclides, an analyte is retained as a COPC for a location if

- the analyte has a BV and a detected result at that location exceeds the BV, or
- the analyte does not have a BV but has at least one detected result at that location.

No groundwater BVs are available for organic chemicals, and retaining an organic chemical as a COPC is based on detection status. For organic chemicals, an analyte is retained as a COPC for a location if at least one result was detected at that location.

For the Phase II groundwater samples, 49 inorganic chemicals in filtered and nonfiltered samples, 30 organic chemicals in nonfiltered samples, and 12 radionuclides in filtered and nonfiltered samples were retained as COPCs. In contrast, Phase I had a total of 43 inorganic chemicals in filtered and nonfiltered samples, 49 organic chemicals in nonfiltered samples, and 16 radionuclides in filtered and nonfiltered samples that were retained as COPCs. Maximum sampling results for groundwater are presented in Tables 6.4-2 to 6.4-19.

6.4.2 Comparison of Water COPC Concentrations to Comparison Values

Maximum detected concentrations of water COPCs in filtered and nonfiltered samples were compared with comparison values, as discussed in section 5, to identify which COPCs are most important from a regulatory perspective. Matching SLs and analytes is straightforward for most analytes by the name, Chemical Abstract Service (CAS) identification, or by use of appropriate surrogates. However, the measured forms of chromium and mercury require additional explanation. For total chromium in filtered water, the NMED tap water screening level for chromium(VI) is used as one of the comparison values because it is assumed that most chromium in filtered water is the chromium(VI) form. Total chromium in nonfiltered water is a combination of both chromium(III) and chromium(VI) and thus has no directly comparable NMED tap water screening level. Chromium(VI) was also measured in water, and the hexavalent chromium tap water screening value from NMED is used. The NMED tap water screening level for mercury (elemental) is included in the tables for comparison to mercury because there is no tap water value for total mercury.

For the Phase II groundwater samples, eight inorganic COPCs, five organic COPCs, and one radionuclide COPC have maximum concentrations above a water-quality standard in contrast to Phase I, which had 12 inorganic COPCs and five organic COPCs with maximum concentrations above a comparison value. These COPCs are highlighted in gray, as applicable, in Tables 6.4-2 to 6.4-19.

6.5 Summary

Table 6.5-1 presents a summary of the COPCs in sediment, nonstorm-related surface water, groundwater, and detected analytes in stormwater in Sandia Canyon. Table 6.5-1 indicates which sediment COPCs had maximum results in Phase II or water COPCs that exceeded comparison values. Table 6.5-2 provides the count of results greater than comparison values and the total count for each COPC. Arsenic, copper, selenium, thallium, total PCBs, and gross alpha have concentrations greater than comparison values for stormwater or nonstorm-related surface water and the nature and sources of these COPCs are discussed in relation to sediments in section 7.1. For groundwater, chromium, 1,4-dioxane, and perchlorate have notable numbers of Phase II results greater than comparison values. These groundwater COPCs will be the key contaminants discussed in section 7.2. The other groundwater COPCs exceed a comparison value in less than 5% of the samples; some have only a single result greater than the comparison value.

7.0 PHYSICAL SYSTEM CONCEPTUAL MODEL

This section discusses aspects of the physical system CM that are relevant for understanding the nature, sources, extent, fate, and transport of contaminants in the Sandia Canyon watershed and in the Chromium Investigation monitoring group. The discussion of contaminants focuses on COPCs that are

shown to be most important for evaluating potential present-day human health risk based on the comparisons with screening action levels (SALs), soil screening levels (SSLs) and standards presented in sections 6 and 8.2 that represent known contaminant releases into the watershed and that are most relevant for evaluation of hydrogeologic CMs (key constituents). Some additional COPCs relevant for understanding contaminant transport are also discussed. As used in this section, “contaminants” refers to COPCs known to represent releases from Laboratory SWMUs or AOCs or other anthropogenic sources, whereas “COPC” is a more general term that also includes analytes identified in section 6 that may or may not represent such releases. For example, some COPCs identified by comparison with BVs or detection limits may represent naturally elevated concentrations.

Section 7.1 discusses COPCs in sediment and the fluvial processes controlling their distributions. Section 7.2 describes the hydrology and contaminant transport of the watershed, including descriptions of surface water, alluvial groundwater, the vadose zone, intermediate-perched groundwater, and regional groundwater, and summarizes spatial and temporal trends for contaminants in these media. The sections summarize the physical system CM based on the combined contaminant and pathways data. Key aspects of the physical system CM are shown in Figure 7.0-1. Supporting information about trends in hydrologic conditions, contaminant distributions in both sediment and water samples, and geochemistry that support the CM is presented in Appendixes D through M.

7.1 Contaminants in Sediment

A more detailed discussion of sediment and contaminant transport and distribution is presented in the Phase I IR (LANL 2009, 107453). For the Phase II investigation, a single sediment reach, S-5EC, was sampled and characterized. The Phase II sediments CM is consistent with the model described in the Phase I IR (LANL 2009, 107543). With the exception of zinc, the average concentrations of COPCs in sediments in reach S-5EC are between those in reaches S-5C and S-5E (COPC concentrations in S-5EC are overall lower than upstream reach S-5C and higher than found in downstream reach S-5E). The average zinc concentration in S-5EC is slightly higher than in S-5C, possibly from runoff from the adjacent highway (Councell et al. 2004, 227712).

This section discusses general aspects of contaminants associated with sediment in Sandia Canyon reach S-5EC, including how the distribution and concentration of contaminants are affected by fluvial processes acting over decadal time periods. Subsequent sections discuss details of the distribution and concentration of specific COPCs in sediment deposits in S-5EC relative to the bounding reaches S-5C and S-5E that are important for evaluating potential human health, ecological risk, or the downcanyon transport of contaminants in floods.

Most contaminants in sediment in Sandia Canyon derived from Laboratory sources were originally released in cooling water from outfalls or as sanitary wastewater releases and surface spills near the head of the canyon in TA-03, as discussed in the Phase I IR (LANL 2009, 107453). Reach S-5EC is located approximately midway between the head of Sandia Canyon and the Rio Grande (Figure 3.1-1), and east of relatively steep reaches (S-3W and S-3E) incised into the Bandelier Tuff where the stream channel locally directly overlies bedrock. Below the narrow bedrock-controlled reaches the canyon broadens, the stream channel gradient decreases, and the width of post-1942 geomorphic units increases in the area encompassing S-4W, S-4E, and S-5C (Figure 3.1-1). This is an area of post-1942 sediment aggradation that contains a relatively large volume of post-1942 sediment deposits (LANL 2009, 107453). Reach S-5EC is located 0.1 km downstream of S-5C and 1.7 km upstream of S-5E. Post-1942 geomorphic units average about 42 m wide in S-5EC, as compared to 60 m wide in S-5C and decrease to a width of 10–25 m in S-5E (Figure 4.1-2).

Reach S-5EC is characterized by a wide active channel flanked by broad floodplains in its upper (western) end and a large intra-canyon fan with broad post-1942 channel deposits covering approximately the eastern two-thirds of the reach (Plate 2). Figure 4.1-1 presents two cross-sections in S-5EC, which demonstrate the variable elevation and width of geomorphic units and the thickness of post-1942 deposits in the eastern two-thirds of the reach, where the majority of post-1942 deposits are located. The width of post-1942 geomorphic units varies from about 25 m (80 ft) at the west end of S-5EC, reaches a maximum of about 65 m (200 ft) about 120 m downcanyon, and decreases to approximately 25 m (80 ft) at the east end of S-5EC. The area of post-1942 fan deposition within the canyon begins at a distance of approximately 100 m east of the start of the reach and extends for a distance of approximately 200 m (Plate 2). The channel is braided and intermittent over this distance. The reach from 0 to 300 m is an actively aggrading area. An incised channel is reestablished from approximately 300 m to the end of the reach at 325 m. The width of the post-1942 geomorphic units narrows in this same area as flood waters are conveyed toward the incised channel. Tree-ring dating (dendrochronology) indicates that the majority of post-1942 sediment was deposited after 1975 in some locations in the reach (Figure 4.1-1).

Downcanyon from reach S-5EC, the width of post-1942 geomorphic units and the volume of post-1942 sediment decreases significantly. A cross-section through reach S-5E is shown in Figure 4.1-2, illustrating the relatively narrow, thin post-1942 geomorphic units. These changes are associated with the progressive downcanyon infiltration of stormwater runoff and reduced flood frequency and magnitude.

Multiple floods occurring over decadal time periods result in sediment deposits in each reach with a range in age and particle size distribution and hence in contaminant concentration. Schematic cross-sections illustrating the distribution of coarse and fine sediment in S-5C, S-5EC and S-5E are shown in Figures 4.1-1 and 4.1-2. The term “coarse facies” refers to sediment with median particle size in the less than 2 mm (0.08 in.) fraction of medium to very coarse sand, and these deposits commonly have a high gravel content. The term “fine facies” refers to sediment with median particle size of silt to medium sand. The active channel (c1 geomorphic unit) is typically dominated by relatively young coarse facies sediment deposits. Abandoned channels (c2, and c3, units), which are areas occupied by the channel sometime after 1942 but subsequently abandoned following channel migration and/or channel incision, typically include fine facies sediment overlying older coarse facies sediment. A young channel/fan lobe (c2f) that is inset into c2 is a predominantly coarse-grained facies gravelly deposit. Abandoned channels can also include coarse deposits as the uppermost, youngest layer. Post-1942 floodplains (f1 unit) typically include thinner layers (<40 cm) of post-1942 fine facies sediment which bury pre-1943 sediments or soils. Possible post-1942 floodplains (f2 units) typically are characterized by very thin (<15 cm) layers of probable post-1942 fine facies sediment, which bury pre-1943 sediments or soils. Section B-1 of Appendix B presents additional discussion of sediment facies and geomorphic units.

As shown in Figures 4.1-1 and 4.1-2, the layers with the highest contaminant concentrations in reaches S-5C, S-5EC, and S-5E are surface layers. This is in contrast to upstream reaches where layers with the highest contaminant concentrations are often at depth, buried by younger sediment layers with lower concentrations (LANL 2009, 107453). These figures also show how the relation of sediment layers to trees provides one means of estimating the thickness and age of different sediment layers (tree age determined from tree-ring dating [dendrochronology]; see Appendix B-1 for more discussion of field-investigation methods).

Most of the contaminants in S-5EC sediments occur in areas of post-1942 sediment deposition outside the active stream channels, as also seen in other reaches in Sandia Canyon and in other canyons at the Laboratory (LANL 2003, 077965; LANL 2004, 087390; Reneau et al. 2004, 093174; Reid et al. 2005, 091247; LANL 2006, 094161; LANL 2009, 106939). At present, post-1942 deposits outside the active

channel probably constitute the primary source for contaminants carried by floods, with active channels and erosion from hillslopes constituting lesser sources. The concentration and inventory (amount) of contaminants in deposits outside the active channel vary longitudinally within the canyons. Concentrations are typically highest in fine sediment deposits near the sources that date to the period of contaminant releases and decrease in younger deposits, in coarser deposits, and downcanyon. Contaminant inventories display more irregular patterns than contaminant concentrations and are related to longitudinal variations in the volume, grain size, and age of sediment deposits within a canyon. Findings from the supplemental S-5EC investigation are consistent with this pattern. Subsequent sections provide examples of the variations in contaminant concentration and inventory in sediment deposits within Sandia Canyon, focusing on a comparison of S-5EC contaminant concentrations with the reaches immediately upstream (S-5C) and downstream (S-5E).

7.1.1 Inorganic Chemicals in Sediment

As discussed in section 6.2, concentrations of COPCs in supplemental reach S-5EC are generally much less than the maximum concentrations measured in Phase I (LANL 2009, 107453). To illustrate spatial trends for inorganic chemicals, the watershed scale results from Phase I and II are presented for the following representative COPCs: arsenic, chromium, lead, and zinc. Spatial-trend plots for all Phase II inorganic COPCs are provided in Appendix D. An explanation of variations in background concentrations of COPCs is presented in Section 7 of the Phase I IR (LANL 2009, 107453).

This section focuses on spatial variations in arsenic, chromium, lead, and zinc in Sandia Canyon, with an emphasis on comparing data from S-5EC with S-5C and S-5E. Supporting information is included in Appendix D. Table D-2.2-1 presents average concentrations in reaches S-5C, S-5EC, and S-5E for inorganic chemicals discussed in this section, substituting one-half of the detection limit for nondetected sampling results. Table D-2.2-1 presents the upper and lower bounds on these averages using either the detection limit (upper bound) or zero (lower bound) for nondetects, which indicate uncertainties in the average values. This table shows that average concentrations of these inorganic chemicals are generally lower in coarse facies sediment than in fine facies sediment, as found in other canyons (LANL 2004, 087390; LANL 2006, 094161; LANL 2009, 106771; LANL 2009, 106790). Figure 7.1-1 and the following discussions focus on data from fine facies sediment. Figure 7.1-1 and Table D-2.2-1 also show the uncertainty in the average concentration of some inorganic chemicals in some reaches because of elevated detection limits and/or detected concentrations close to detection limits.

The plots in Figure 7.1-1 include both the sediment BV for each inorganic chemical, which is an estimate of the upper level of background concentrations, and the average value from the background sediment data set, where available (averages from McDonald et al. 2003, 076084, Table 10, pp. 49-50). The background averages are included to be consistent with the presentation of averages from potentially contaminated samples, although averages for fine facies sediment are expected to be higher than the entire background data set, which also includes coarse facies samples. For reaches where an inorganic chemical is not a COPC, the average background concentration is plotted in Figure 7.1-1.

Arsenic is an important inorganic chemical for evaluating potential human health risk in Sandia Canyon, with maximum concentrations being greater than the sediment BV of 3.98 mg/kg in four investigation reaches (S-1N, S-1S, S-2, and S-3W). The highest concentrations are from the current and former cattail wetland in Reach S-2 (LANL 2009, 107453), suggesting releases of arsenic from TA-03 into upper Sandia Canyon (Figure 7.1-1 and Table D-2.2-1). Maximum arsenic concentrations are below the sediment BV in all reaches below S-3W, including reach S-5EC.

As discussed in the Phase I IR (LANL 2009, 107453), chromium is an important inorganic chemical for evaluating potential human health risk and ecological risk in Sandia Canyon and is of concern for impacts to groundwater (e.g., LANL 2006, 094431; LANL 2007, 098938; section 7.2). Maximum chromium concentrations are greater than the sediment BV of 10.5 mg/kg in 9 of the 11 Phase I reaches, with the exception of reaches S-6W and S-6E located downcanyon from the eastern Laboratory boundary. Maximum chromium concentrations are also above the sediment BV in reach S-5EC. Chromium sources for the Sandia Canyon watershed are discussed in the Phase I IR (LANL 2009, 107453). Chromium concentrations decrease significantly between reach S-2 and the downcanyon reaches (Figure 7.1-1). The average chromium concentration of 21 mg/kg in reach S-5EC is intermediate between reaches S-5C and S-5E (Figure 7.1-1 and Table D-2.2-1). Concentrations are slightly above background levels in reach S-5E, immediately above NM 4, and below the BV in reaches closer to the Rio Grande. These relations indicate minimal transport of chromium released from TA-03 into the Rio Grande.

The highest chromium concentration in reach S-5EC, 40.4 mg/kg, was measured in post-1975 fine-grained c2 sediments near the midpoint of the reach (Figure 4.1-1; sampling location SA-614455; Plate 2). This value is intermediate between the maximum chromium concentrations in reaches S-5C (73.9 mg/kg) and S-5E (22.5 mg/kg). The majority of the anthropogenic chromium inventory, 72%, is in the fine facies of unit c2 (Table D-2.3-1). The second largest portion (16%) of this inventory is in unit f1 fine facies, followed by c2f and c1 fine facies sediments (Table D-2.3-1). All coarse facies chromium concentrations were less than the BV; therefore, the anthropogenic chromium inventory for S-5EC coarse facies sediment is insignificant. Total estimated anthropogenic chromium inventory for reach S-5EC is 49.8 kg or 151 kg/km (Table D-2.3-1).

Lead is an important COPEC for evaluating potential human risk in Sandia Canyon (LANL 2009, 107453) and was also identified as an important COPC for evaluating potential ecological risk (LANL 2007 099152; section 8.1). Lead had maximum concentrations above the sediment BV of 19.7 mg/kg in 9 of the 11 Phase I reaches, with the only exceptions being reaches S-6W and S-6E, located downcanyon from the eastern Laboratory boundary (LANL 2009, 1075453). Maximum lead concentrations also exceed the sediment BV in S-5EC. The highest concentration (690 mg/kg) in the Sandia watershed was measured in the western part of reach S-2 (LANL 2009, 107453). The highest average concentrations of lead in fine facies sediment are from reaches S-1S and S-1N, indicating multiple sources in the upper part of the Sandia Canyon watershed. Lead is a common contaminant found below roads and other developed areas, and one source is the past use of leaded gasoline (Walker et al. 1999, 082308, p. 364; Breault and Granato 2000, 082310, p. 48; Callender and Rice 2000, 082307, p. 232). Releases from Laboratory SWMUs or AOCs may constitute other sources. For example, although concentrations generally decrease downcanyon from reaches S-1S and S-1N, lead concentrations increase in reach S-5C, indicating releases from either TA-53 or the Protective Force firing range in TA-72 (Figure 7.1-1). Lead concentrations decrease markedly between S-5C and S-5EC over the short distance between these two reaches, and continue to decline between S-5EC and S-5E (Figure 7.1-1 and Table D-2.2-1). The highest lead concentration in S-5EC, 28.9 mg/kg, was collocated with the maximum chromium concentration measured in post-1975 fine-grained c2 sediments at sampling location SA-614455 (Figure 4.1-1 and Plate 2). This value is intermediate between the maximum lead concentrations in S-5C (63.2 mg/kg) and S-5E (25.1 mg/kg). Average lead concentrations in reaches S-5C, S-5EC, and S-5E are all less than the sediment BV (Table D-2.2-1).

Zinc was identified as an important COPEC for evaluating potential ecological risk in Sandia Canyon (LANL 2007, 099152; section 8.1). It has maximum detected concentrations above the sediment BV of 60.2 mg/kg in 8 of the 11 Phase 1 investigation reaches and has its maximum concentration in the active cattail wetland in reach S-2 (1140 mg/kg; Phase I IR). Its spatial distribution indicates releases into both the north and south forks of Sandia Canyon and downcanyon transport at least as far as reach S-5EC

(Figure 7.1-1; Table D-2.2-1). The average zinc concentration of 54.0 mg/kg in reach S-5EC is slightly higher than the average concentration in reach S-5C and declines to below the sediment BV by S-5E (Figure 7.1-1; Table D-2.2-1). The highest lead concentration in reach S-5EC, 87.2 mg/kg, was collocated with the maximum chromium and zinc concentration measured in post-1975 fine-grained c2 sediments at sampling location SA-614455 (Figure 4.1-1 and Plate 2). This value is intermediate between the maximum zinc concentrations in S-5C (89.9 mg/kg) and S-5E (less than BV of 60.2 mg/kg). Average zinc concentrations in reaches S-5C, S-5EC, and S-5E are all less than the sediment BV (Table D-2.2-1).

7.1.2 Organic Chemicals in Sediment

As discussed in section 6.2, concentrations of COPCs in the supplemental sediment investigation reach S-5EC are generally much less than the maximum concentrations measured during the Phase I investigation. To illustrate spatial trends for organic chemicals, the watershed scale results from Phase I and II are presented for the following representative COPCs: Aroclor-1254, Aroclor-1260, benzo(a)pyrene, and total petroleum hydrocarbon (TPH) diesel range organics (DRO). Spatial trend plots for all Phase II organic COPCs are provided in Appendix D.

7.1.2.1 PCBs

PCBs were detected in every Phase I investigation reach except the two easternmost reaches, S-6W and S-6E (LANL 2009, 107453). PCBs have low solubilities and a strong affinity for organic material and sediment particles (Chou and Griffin 1986, 083419). PCBs were widely used in electric transformers and other industrial applications (e.g., Walker et al. 1999, 082308, pp. 364-365), and their widespread use is consistent with their spatial distribution in sediments in Sandia Canyon. The highest concentrations were measured in sediment below a former transformer storage area at TA-03, SWMU 03-056(c), although the sediment data indicate that PCBs were also derived from other sources in the watershed, as discussed in the Phase I IR (LANL 2009, 107453). Two PCBs were detected in S-5EC using the Aroclor method: Aroclor-1254 and Aroclor-1260. Other PCBs detected in the Sandia Canyon watershed sediment samples (Aroclor-1016, Aroclor-1242, and Aroclor-1248) were not detected in S-5EC.

Aroclor-1254 was detected in all of the Phase I reaches except S-6W and S-6E, east of NM 4 and the eastern Laboratory boundary. The highest concentration (2.53 mg/kg) was from a sample in the middle of reach S-2 (LANL 2009, 107453). The spatial distribution of Aroclor-1254 indicates releases from TA-03 into both the north and south forks of Sandia Canyon, and average concentrations are similar in both reaches (Figure 7.1-2). Concentrations generally decrease downcanyon from S-2 (LANL 2009, 107453). Aroclor-1254 concentrations decrease downcanyon below S-4E in reaches S-5C, S-5EC, and S-5E and Aroclor-1254 was not detected in the lower-most reaches S-6W and S-6E. The average (midpoint range) Aroclor-1254 concentration of 0.024 mg/kg in S-5EC is intermediate between S-5C and S-5E concentrations (Figure 7.1-2; Table D-2.2-2). The highest Aroclor-1254 concentration in S-5EC fine facies, 0.0592 mg/kg, was collocated with the maximum inorganic COPC concentrations measured in post-1975 fine-grained c2 sediments at sampling location SA-614455 (Figure 4.1-1; Plate 2). However, unlike other COPCs evaluated in the Phase II investigation, the highest Aroclor-1254 value of 0.0748 was in coarse facies deposits in unit c1 at location SA-614443 near the upper end of the reach (Plate 2). This value is intermediate between the maximum Aroclor-1254 concentrations in S-5C (0.098 mg/kg) and S-5E (0.026 mg/kg).

Aroclor-1260 shows a spatial distribution similar to Aroclor-1254, with multiple sources in upper Sandia Canyon and a general downcanyon decrease below the sources (Figure 7.1-2). Samples collected from S-5EC as part of the supplemental reach investigation fit this pattern of decreasing

Aroclor-1260 concentration downcanyon of the source areas (Figure 7.1-2.). The average (midpoint range) Aroclor-1260 concentration of 0.035 mg/kg in S-5EC is intermediate between S-5C and S-5E concentrations (Figure 7.1-2 and Table D-2.2-2). The highest Aroclor-1260 concentration in S-5EC, 0.0813 mg/kg, was collocated with the maximum inorganic COPC concentrations measured in post-1975 fine-grained c2 sediments at sampling location SA-614455 (Figure 4.1-1 and Plate 2). This value is intermediate between the maximum Aroclor-1260 concentrations in S-5C (0.157 mg/kg) and S-5E (0.0527 mg/kg).

7.1.2.2 PAHs

Four PAHs were identified in the Phase I investigation as being most important for evaluating potential human health risk: benzo(a)anthracene; benzo(a)pyrene; benzo(b)fluoranthene; and indeno(1,2,3-cd)pyrene. These PAHs have similar spatial distributions, with the highest average concentrations in S-1N, generally lower but elevated concentrations in S-1S and S-2, and much lower concentrations downcanyon (LANL 2009, 107453). Detected results for benzo(a)anthracene and benzo(a)pyrene in reach S-5C may indicate an additional source in the eastern part of TA-53 and/or the Protective Force firing range at TA-72, although there was large uncertainty in the average concentrations in S-5C because of elevated detection limits for analyses obtained in 2000 by the SVOC method (SW-846:8270; most results in this data set were obtained with the PAH method, SW-846:8310). The average (midpoint range) benzo(a)pyrene concentration of 0.0017 mg/kg in S-5EC is much lower than the average (midpoint range) benzo(a)pyrene concentration of 0.329 mg/kg in S-5C (Figure 7.1-3; Table D-2.2-3). The low concentration measured in S-5EC relative to S-5C suggests that the average value shown for S-5C is artificially high because of the uncertainty in the detection limit discussed above. The benzo(a)pyrene concentration declines to below detection limit in S-5E. The highest benzo(a)pyrene concentration in S-5EC, 0.0457 mg/kg, was collocated with the maximum inorganic COPC and PCB concentrations measured in post-1975 fine-grained c2 sediments at sampling location SA-614455 (Figure 4.1-1; Plate 2). This value is similar to the maximum benzo(a)pyrene concentration in S-5C (0.044 mg/kg), and is higher than the maximum in S-5E (below detection limit).

A former asphalt batch plant next to the north fork of Sandia Canyon is a possible source for the elevated PAH concentrations in S-1N, but this area also receives runoff from large areas of pavement and other development, which are additional sources of PAHs unrelated to releases from SWMUs and AOCs. Similar elevated concentrations of PAHs have been found in sediment downcanyon from urbanized areas in the Los Alamos townsite (LANL 2004, 087390) and in other regions (Edwards 1983, 082302; Lopes and Dionne 1998, 082309; Walker et al. 1999, 082308; Van Metre et al. 2000, 082262).

7.1.2.3 TPH-DRO

TPH-DRO was detected in every Phase I investigation reach in Sandia Canyon. Detected TPH-DRO concentrations are above the NMED screening guideline of 520 mg/kg in 10 samples from 2 reaches (S-1N and S-1S). In S-1N, average concentrations in both fine and coarse facies sediment are above the screening guideline, and in S-1S the average concentration in fine facies sediment is above the guideline (Figure 7.1-4). Concentrations are much lower in downcanyon reaches, including supplemental reach S-5EC. The sample with the maximum concentration of 2700 mg/kg was collected from the active stream channel (c1 unit) in S-1N, indicating recent releases into the channel (LANL 2009, 107453).

Relatively low concentrations of TPH-DRO were detected in the reaches downcanyon from S-2, with slight increases seen in reaches S-5C and S-5E (Figure 7.1-4). The average TPH-DRO concentration in reach S-5EC is lower than S-5C and S-5E (Table D-2.2-4) but is higher than the reaches immediately upstream and downstream of these reaches (Figure 7.1-4). This increase in TPH-DRO concentrations in

S-5C, S-5-EC, and S-5-E suggests some releases from the eastern part of TA-53 and/or the Protective Force firing range in TA-72. The highest TPH-DRO concentration in S-5EC, 99.2 mg/kg, was detected in fine-grained f2 sediments at sampling location SA-614450 (Figure 4.1-1; Plate 2). This value is intermediate between the maximum TPH-DRO concentrations in S-5C (120 mg/kg) and S-5E (69.6 mg/kg). TPH-DRO detected in reaches S-6W and S-6E indicates possible transport from Laboratory sites to the Rio Grande, but this diesel could also be associated with runoff from major roads (East Jemez Road and NM 4), and other Laboratory-derived contaminants have not been identified that far downcanyon.

7.1.3 Summary of Sources and Distribution of Key Sediment COPCs

Based on data presented in the 2009 Sandia IR, the sediment COPCs in Sandia Canyon have a variety of sources, including Laboratory TAs and associated SWMUs or AOCs and natural background. Table 7.1-1 of the Phase I IR (LANL 2009, 107453) summarized the inferred primary sources of the sediment COPCs discussed above and also the inferred downcanyon extent of COPCs that are or may be derived from Laboratory sources. Two COPCs discussed in this Phase II report, zinc and benzo(a)pyrene, had a downcanyon extent reaching to somewhere between S-5C and S-5E. Both of these constituents were identified in S-5EC at either above BV or above the detection limit; therefore, their downcanyon extent may be revised to between S-5EC and S-5E. Sources and downcanyon extent for these COPCs are discussed further below.

7.1.3.1 TA-03

TA-03 is the primary source for most COPCs in Sandia Canyon sediment. Sediment data, combined with historical records, indicate releases of inorganic and organic chemicals from multiple sites into both the north fork and south fork of Sandia Canyon. Identified sources include discharges of cooling water from the TA-03 power plant at NPDES Outfall 001 and PCB spills from SWMU 03-056(c), a former transformer storage area. COPCs released from TA-03, as shown by sediment data, include the inorganic chemicals arsenic, barium, cadmium, chromium, copper, cyanide, lead, mercury, molybdenum, nickel, silver, and zinc, various PAHs, PCBs, pesticides, and TPH-DRO. Although some of these chemicals may be from sources unrelated to SMWUs and AOCs, they are identified as COPCs and are present for varying distances downcanyon, with several extending as far east in the watershed as reach S-5EC and to NM 4 (e.g., chromium, lead, molybdenum, Aroclor-1254, and Aroclor-1260).

7.1.3.2 TA-53 and/or TA-72

The sediment data from Phase II reach S-5EC indicate several COPCs, including lead, Aroclor-1242, and possibly some PAHs and TPH-DRO, were, or may have been, released from either the eastern part of TA-53 or the Protective Force firing range in TA-72. These COPCs are mixed with contaminants derived from TA-03 and can be traced relatively short distances downcanyon.

7.1.3.3 Natural Background Variability

Sediment data from different canyons indicate that natural background concentrations for many inorganic chemicals and radionuclides are more variable than found in the original sediment background data set used to develop BVs for the Laboratory (LANL 1998, 059730; McDonald et al. 2003, 076084). As a result, sediment concentrations can be elevated above BVs even where no Laboratory releases occurred (e.g., LANL 2009, 106506). In the Sandia Canyon sediment data set, the spatial distribution of some inorganic COPCs (Figure 7.1-7) indicates they are predominantly or entirely derived from naturally occurring materials, representing locally elevated background levels. These include aluminum, cobalt,

iron, and thallium. Isolated occurrences of nickel above the BV close to the Rio Grande also indicate natural background variability. One inorganic COPC with no BV, perchlorate, also has a spatial distribution that suggests it largely or entirely represents naturally occurring material and not releases from Laboratory sites.

7.1.4 Contaminant Inventory

Data collected in this supplemental investigation allow for a refinement in the determination of geographic variations in the amount, or inventory, of contaminants in sediment deposits in different parts of Sandia Canyon that was presented during the Phase I IR (LANL 2009, 107453). Inventories have been estimated for select COPCs in Sandia Canyon derived from Laboratory sites. Supporting data for these inventory estimates are presented in section D-2.3 of Appendix D.

Figure 7.1-5 summarizes the geographic distribution of chromium in sediment deposits in Sandia Canyon, which updates estimates presented in the Phase I IR (LANL 2009, 107453) and a previous report (LANL 2007, 098127). No inventories are estimated for reaches where chromium is not a COPC (S-6W and S-6E), which would largely or entirely represent inventories associated with background concentrations. The estimated total inventory of anthropogenic chromium in post-1942 sediment deposits in Sandia Canyon remains essentially unchanged from the previous Phase I IR (LANL 2009, 107453) estimate of approximately 18,000 kg (40,000 lb) (Table D-2.4-2). The inventory of anthropogenic chromium calculated, based on inclusion of the Phase II data from reach S-5EC, is 17,814 kg. This amount compares with an estimate of 17,974 kg calculated in the Phase I IR and represents a reduction in the estimated anthropogenic chromium inventory of approximately 1%. The reason for this reduction in anthropogenic chromium inventory is that interpolating between S-5C and S-5E overestimated the inventory in S-5EC. Approximately 68% of the total is contained within fine facies sediment. In Figure 7.1-5, the chromium inventory is plotted both as a normalized inventory in each reach per kilometer of channel ([a] units of kg/km) and as cumulative amounts from the TA-03 Outfall 001 to the Rio Grande ([b] units of kg). The cumulative plot extrapolates between sampled reaches. An estimated 85% of the total is contained within reach S-2, where concentrations are highest and where a large volume of post-1942 sediment exists. Approximately 5% of the chromium is contained along the next 4 km of channel, between S-2 and the east end of S-4W, where storm runoff is confined to a relatively narrow band along the channel. Approximately 10% occurs in the next 5 km, on Laboratory land east of NM 4, and less than 0.5% occurs farther downcanyon.

Estimated inventories of PCBs in Sandia Canyon sediment deposits range from approximately 3 kg (7 lb) for Aroclor-1248 to 35 kg (78 lb) for Aroclor-1254 (Table D-2.3-2). As with chromium, most of the mass is contained within reach S-2, ranging from an estimated 81% for Aroclor-1260 to 99.6% for Aroclor-1248. Most of the PCBs are also associated with fine facies sediment, ranging from an estimated 67% for Aroclor-1242 to 74% for Aroclor-1260. Inclusion of data from the reach S-5EC results in a decrease in the estimated contaminant inventory of Aroclor-1242 in Sandia Canyon sediment of approximately 3%, does not affect the estimated inventory of Aroclor-1248, results in a decrease in estimated contaminant inventory for Aroclor-1254 of approximately 1%, and results in a decrease in estimated contaminant inventory for Aroclor-1260 of approximately 2% (Table D-2.3-2 of this report compared with Table D-2.3-2 in the Phase I IR [LANL 2009, 107453]). Figures 7.1-6 and 7.1-7 summarize the geographic distribution of Aroclor-1254 and Aroclor-1260 in sediment deposits in Sandia Canyon and show the distribution of PCBs that are detected in S-5EC. In the case of Aroclor-1254, approximately 0.1% is contained west of the landfill bridge, mostly in reach S-1S below SWMU 03-056(c), the former transformer storage area. An estimated 88% is contained within S-2, 2% between S-2 and S-4W, 9% between S-4W and the eastern Laboratory boundary, and 1% farther downcanyon. In the case of Aroclor-1260, approximately 1% is contained west of the landfill bridge, mostly in reach S-1S below SWMU 03-056(c), the former transformer

storage area. An estimated 81% is contained within S-2, 2% between S-2 and S-4W, 15% between S-4W and the eastern Laboratory boundary, and 1% farther downcanyon. Other COPCs are expected to have similar spatial variations in inventory as chromium and PCBs, with most of their mass occurring in S-2 associated with the large sediment volume and proximity to sources.

7.1.5 Relations between Particle Size and Contaminant Concentration

As discussed in the Phase I IR (LANL 2009, 107453), the preferential tendency for contaminants to adsorb onto small particles results in generally higher concentrations of COPCs in fine facies compared with coarse facies sediments, although these relationships may be obscured because of temporal variations in release history and other factors (Reneau et al. 1998, 065407; LANL 2004, 087390; Reneau et al. 2004, 093174; LANL 2006, 094161). This trend of higher COPC concentrations in fine facies sediments was observed in the results of the Phase II investigation in reach S-5EC. An in-depth discussion of this relationship is presented in the Phase I IR (LANL 2009, 107453).

7.1.6 Flood Attenuation and Downcanyon Extent of Contamination

Gaging station records of stream discharge (e.g., LANL 2007, 098938; Ortiz et al. 2008, 105250) indicate that floods generated from upper Sandia Canyon significantly attenuate as they move downcanyon, recording transmission losses into the alluvium. For example, during the period October 1, 2004, to July 31, 2009, 22 recorded storm runoff events exceeded 1 cubic foot per second (cfs) at stream gage E124 located between reaches S-3E and S-4W, but only 5 of these events were recorded at gage E125 3.8 km (2.4 mi) downcanyon, near reach S-5E and the eastern Laboratory boundary. The infiltration and loss of surface water upcanyon from E124 is also well documented (LANL 2007, 098938). These observations are consistent with the large volume of post-1942 sediment that has been deposited in the vicinity of reaches S-4E, S-5C, and S-5EC (Phase I IR [LANL 2009, 107453]; Figures 4.1-1, 4.1-2 and Table B-1.0-1).

Analytical data discussed in previous sections demonstrate most of the contaminants associated with sediment released from TA-03 were deposited in reach S-2, close to their sources. A secondary focus of sediment and contaminant deposition is the area from reach S-4E to S-5EC. Only small amounts of Laboratory-derived contaminants are found downcanyon in reach S-5E immediately above the eastern Laboratory boundary and NM 4. For example, the maximum chromium concentration decreases downcanyon from 3740 mg/kg in S-2 to 22.5 mg/kg in S-5E, approximately twice the BV of 10.5 mg/kg, and all samples farther downcanyon have chromium below the BV. The PCBs Aroclor-1254 and Aroclor-1260 show the same spatial distribution, having highest concentrations near sources in TA-03, being detected at low concentrations in S-5E, and not being detected farther downcanyon. The downcanyon extent of recognizable contamination in Sandia Canyon derived from Laboratory sites is therefore between S-5E and S-6W, or between 3.4 and 6.5 km above the Rio Grande.

Detects of one COPC derived from Laboratory sites, TPH-DRO, at low concentrations downcanyon from NM 4 suggest possible transport from Laboratory sites to the Rio Grande. However, this TPH-DRO may also have been derived from runoff from major roads (East Jemez Road and NM 4), and the TPH-DRO data are inconclusive in terms of indicating the downcanyon extent of Laboratory-derived contaminants.

Several inorganic chemicals, including chromium, nickel, and uranium, have been detected above sediment BVs at the Laboratory's Environmental Surveillance Program sampling station in lower Sandia Canyon above the Rio Grande. Although these data suggest possible downcanyon transport from Laboratory SWMUs or AOCs, this interpretation is not supported by data from reaches S-6W and S-6E, where these analytes are not COPCs. An alternative explanation for the results above BVs at the

surveillance station is that the sampled sediment represented Rio Grande sediment that had been deposited during high water conditions in the lower part of Sandia Canyon and not sediment transported down Sandia Canyon. This hypothesis is supported by field observations of Rio Grande floodwaters inundating the lower part of Sandia Canyon and other canyons draining the Pajarito Plateau during spring snowmelt conditions, in some cases extending as backwater for tens of feet west from the river bank, and by analytical data collected from Rio Grande sediment deposits. For example, an evaluation of concentrations of chromium and other inorganic chemicals in Rio Grande sediment samples collected in 2009 from upriver and downriver of Laboratory sources demonstrated that concentrations are often higher than sediment BVs in Rio Grande sediment associated with particle size effects (finer-grained sediment deposited along the river) and also partly because the upriver bedrock geology is different from that occurring on the Pajarito Plateau (LANL 2010, 111232, pp. 243–247). Because of uncertainties in the source of sediment sampled at the surveillance station in lower Sandia Canyon, sediment samples collected upstream of possible backwater effects in reaches S-6W and S-6E provide more reliable data on possible contaminants transported downcanyon from Laboratory sources, and these data indicate no identifiable Laboratory-derived contaminants.

7.1.7 Temporal Trends in Sediment Contamination

Data on sediment contamination in other canyons at the Laboratory indicate that concentrations were highest at the time of peak releases and subsequently decreased over time from mixing of contaminated and noncontaminated sediment (e.g., Malmon 2002, 076038; LANL 2004, 087390; Reneau et al. 2004, 093174; LANL 2006, 094161). Although little direct data pertain to changes in concentrations of contaminants in Sandia Canyon sediment over time, available data indicate contaminant concentrations here follow the same trends found elsewhere and have decreased over time since peak releases. For example, in reaches where the stream channel has been incising and stranding older post-1942 sediment deposits above the channel, the highest concentrations of chromium have been measured in these older, higher deposits (LANL 2009, 107453). Similarly, where progressive aggradation has been occurring, the highest concentrations of chromium have been found buried at depth (reach S-4E; Phase I IR).

In contrast to this trend, reaches S-5C, S-5EC, and S-5E exhibit the highest contaminant concentrations in surface sediment layers (Figures 4.1-1 and 4.1-2). Dendrochronology data show that in S-5EC the highest concentrations of all COPCs from samples collected in this reach are post-1975, with the possible exception of TPH-DRO. This may reflect a lag time in downstream transport of COPCs or may be a result of a single flood event that transported and deposited sediments with a relatively higher concentration of COPCs than found elsewhere in the reach.

The historical stream incision that has been occurring in the part of Sandia Canyon that includes S-3E and S-4W has supplied large volumes of noncontaminated pre-1943 sediment to the channel, which mixes with contaminated sediment derived from upcanyon and accelerates the natural downcanyon decreases in concentration. These processes are expected to continue, resulting in similar or lower concentrations of contaminants in the future.

7.2 Conceptual Model for Hydrology and Contaminant Transport in Groundwater

The CM for hydrology and contaminant transport in surface water and groundwater in and beneath Sandia Canyon is based on multiple lines of field observations, laboratory data, and simulation results. The CM was developed and is presented in detail in the Phase I IR (LANL 2009, 107453). It is updated here to focus primarily on groundwater flow and contaminant transport pathways through the vadose zone, perched-intermediate groundwater, and the regional aquifer beneath Sandia and Mortandad Canyons. The nature and extent of chromium contamination is a primary focus of the CM update.

Information from Phase II investigation boreholes and studies, described in sections 3 and 4, is incorporated. Hydrologic conditions, contaminant distributions, and sources from Mortandad Canyon factor into this update because the chromium investigation monitoring extends south beneath Mortandad Canyon and because of the presence of contaminants originating from Mortandad Canyon that are collocated with contaminants sourced from Sandia Canyon (Figure 3.2-2).

Figure 7.0-1 illustrates the flow and transport pathways, which begin as surface water discharged at the head of the canyon and end with arrival and transport in the regional aquifer. Most surface water in Sandia Canyon enters the vadose zone through infiltration from the alluvial system that is located in the middle and lower canyon sections (Figure 7.0-1). From there, water percolates downward through the vadose zone where some encounters perching horizons on and within the Cerros del Rio basalts. The general dip of these perching horizons causes lateral flow to occur in a southerly or southwesterly direction. Leakage from the perched zones allows groundwater and associated contaminants to migrate downward toward the regional aquifer. Chromium and associated constituents released into Sandia Canyon in the 1950s through early 1970s have migrated along these pathways and are observed in the regional aquifer beneath Sandia and Mortandad Canyons. Concentrations of chromium in the regional aquifer exceed the New Mexico groundwater standard of 50 µg/L (Figure 7.2-1). Perchlorate released at Outfall 051 into a tributary of Mortandad Canyon is observed in the regional aquifer beneath Mortandad Canyon at concentrations above the Consent Order screening level of 4 µg/L (Figure 7.2-1). Mixing of the plumes from Mortandad and Sandia Canyon sources occurs in the perched-intermediate zones beneath Mortandad Canyon and within the regional aquifer beneath and to the south of Mortandad Canyon. Hydrologic conditions and chemical signatures are used in the analysis below to discriminate between pathways. Key constituents released into Sandia Canyon include chromium, nitrate (from treated sewage effluent), molybdenum, phosphate, zinc, and some tritium (section 2.1.1). Perchlorate, nitrate (primarily from a nitric acid source), tritium, and 1,4-dioxane indicate a Mortandad Canyon source. The individual components of this hydrologic CM are discussed further with supporting evidence in the sections below.

Reduction of chromium(VI) to chromium(III) in the environment is an important process affecting chromium transport. The process effectively decreases the overall mobility of the chromium inventory. Table 7.2-1 summarizes the reductive capacity of the wetland sediments and the various rock units present along the flow path along which chromium travels between the surface and into the regional aquifer. This table is based on studies that are largely presented in the Phase I IR but have been further evaluated during the Phase II investigation. A chromium mass balance presented in the Phase I IR indicated that the majority of the mass released from the original source is contained as chromium(III) in the reach S-2 sediments and as adsorbed and reduced phases that are predominantly immobile in the vadose zone. That estimate indicates a small fraction of the original chromium(VI) released into upper Sandia Canyon remains mobile and is responsible for the chromium plume present in the regional aquifer.

7.2.1 Surface Water

Sources of surface water in the Sandia watershed are currently dominated by effluent releases. Effluent water releases to Sandia Canyon have occurred since the early 1950s and continue today, with the primary sources being treated sanitary wastewater and cooling tower blowdown, as described in section 2.1.1, with effluent volumes in 2011 averaging greater than 300,000 gal./d (Appendix F). Data indicate the NPDES outfalls contribute approximately 75% of the total surface water flow in the canyon, with stormwater runoff and snowmelt contributing the remainder (LANL 2008, 102996). The long-term discharges and runoff support a wetland near the head of Sandia Canyon (Reach S-2) and have supplied a sufficient water volume to facilitate vadose zone contaminant transport further downcanyon. Persistent

surface flow occurs through the wetland and into the narrow bedrock portion of the upper canyon, ending in the lower canyon where surface expression is lost to infiltration in canyon-bottom alluvium (Plate 1).

A water-balance analysis conducted during 2007 and 2008 is summarized in the Phase I IR (LANL 2009, 107453). That study showed (1) little surface water loss (approximately 2% of both effluent and runoff) occurs through the wetland area [in Figure 7.0-1 surface water segment 1 (SW1)]; (2) virtually no deep infiltration occurs east of the wetland between gage E123 and temporary gage D123.6 (Figure 7.0-1, SW2); (3) approximately 23% of surface water infiltrated bedrock units between temporary gages D123.6 and D123.8 (SW3 in Figure 7.0-1); (4) the greatest portion of surface water (>60% of the total) infiltrates the alluvium west of gage E124 in an area where the canyon floor broadens and the alluvium thickens (western portion of SW4 in Figure 7.0-1); and, finally, (5) surface water flows past gage E124 (eastern portion of SW4 in Figure 7.0-1) only during times of high alluvial groundwater levels a few times per year.

The Phase II investigation (LANL 2010, 110480) further studied the potential effects of surface water loss from the wetland area (SW1 in Figure 7.0-1) with a geophysical survey of the wetland. A DC electrical resistivity-based geophysical survey was conducted as part of the Phase II investigation to provide a model of electrical properties of subsurface materials of the region beneath and adjacent to the wetland in upper Sandia Canyon (Appendix E). The DC resistivity survey found that large continuous areas of the wetland are underlain by highly resistive welded tuffs (upper Tshirege Member) that probably represent a significant barrier to the infiltration of surface and alluvial water into the subsurface. A very conductive layer extending from the surface to 20 ft to 25 ft (6.1 m to 7.6 m) below ground level correlates well with an alluvial aquifer perched on a welded unit (Qbt 2) of the Bandelier Tuff. In several areas, the survey also identified subvertical conductive zones that penetrate the upper bedrock tuffs and seem to correlate with mapped fault and/or fracture zones. These subvertical conductive zones are noted because they may represent infiltration pathways. However, the DC resistivity data do not differentiate between conductive zones that contain higher water content (possibly representing active infiltration) and clay-rich altered tuff and fault gouge (possibly representing former infiltration zones that are now groundwater barriers). Thus, the geophysics results alone are ambiguous with respect to identifying infiltration pathways. Subvertical conductivity anomalies are identified, but it cannot be determined whether these were active infiltration pathways during the period of chromium release or what infiltration volumes and rates such pathways may have transmitted. Modeling analysis conducted for this report is used to invoke additional lines of evidence to evaluate the potential role of the conductivity anomalies on migration of contamination to the regional aquifer.

The Phase II investigation analyzed the potential for deep chromium migration from the wetland by considering how chromium migration from that area would impact the distribution of chromium in the regional aquifer. The model was updated to reflect concentrations of chromium in the regional aquifer for newly drilled wells (i.e., R-50, R-61, and R-62) (Appendix J). In addition, 3-D calculations calibrated to water levels are included (Appendix K). These modeling studies indicate the observed distribution of chromium in the regional aquifer cannot be caused by a significant chromium pathway transmitting chromium from the wetland area to the regional aquifer. The lower chromium concentrations in the regional aquifer south of R-42/R-28 are not consistent with a large chromium flux arriving beneath the wetland. However, a small chromium flux that generates near-background concentrations downgradient is feasible (Appendix J).

7.2.2 Alluvial Groundwater

Alluvial groundwater in Sandia Canyon is recharged daily by surface-water flow, largely supplied by effluent from Outfall 001 and periodically by stormwater. This groundwater generally accumulates in the lower part of the alluvial deposits that fill the canyon bottom, most often perching on or within shallow bedrock units. The alluvial groundwater body extends farther downcanyon (roughly more than 1 km

[0.6 mi] farther east) than do the daily stream-flow events. Because alluvial groundwater acts as a primary source of infiltrating water into the deeper tuff units, the extent of this groundwater defines deeper infiltration zones beneath the canyon. Information presented in the Phase I IR indicates alluvial groundwater occurs approximately between stream gage D123.8 and alluvial well SCA-5, with the majority located between alluvial wells SCA-2 and SCA-4. Alluvial groundwater is lost to bedrock units beneath the canyon floor in this area (Figure 7.0-1) (LANL 2009, 107453). Recharge of the alluvial groundwater and subsequent flow into the suballuvium bedrock are both spatially and temporally heterogeneous, with percolation rates into the bedrock potentially as high as a few meters per year (LANL 2008, 102996, Appendix C). Deeper percolation of alluvial groundwater provides a driving force for subsurface transport of mobile constituents, such as chromium(VI), nitrate, sulfate, molybdenum, tritium, and chloride along the length of the canyon and into the deeper subsurface. The combination of surface water and alluvial groundwater losses in the areas defined by SW3 and SW4 leads to the deep infiltration zones depicted in Figure 7.0-1. Incision of the older alluvial facies within the canyon bottom between gages D123.6 and E124 provides evidence that the morphology of the alluvium in the canyon has evolved, potentially in response to effluent releases in the canyon (NMED 2010, 108683). Thicker alluvium may have extended further upcanyon than is currently observed; this in turn could have provided alluvial storage that allowed for increased infiltration further up canyon than is currently observed. The CM includes the potential for significant infiltration in the area defined by SW3 (Figure 7.0-1) to account for this potential change in infiltration area with time.

7.2.3 Vadose-Zone Hydrology

Percolation of alluvial groundwater results in deeper, unsaturated flow into suballuvium bedrock units. Movement of moisture in the vadose zone is heterogeneous and probably dominated by vertical gravity-driven flow through highly porous Banderier Tuff and upper Puye Formation sediments, but moisture-gradient-driven flow and hydraulic-head-driven spreading along stratigraphic contacts are expected to be important as well. Infiltration through the Cerros del Rio basalt is expected to be dominated by flow through fractured basalt matrix and interflow breccias. Infiltration in the lower vadose zone is probably dominated by gravity-driven flow through porous sediments of the lower Puye Formation and underlying Miocene pumiceous deposits. Saturated hydraulic-head-driven flow occurs in zones of perched-intermediate groundwater like those found at wells SCI-1 and SCI-2, as described in the following section.

The analysis of available hydrogeological data indicates the primary zone of infiltration along Sandia Canyon occurs in the middle portion of the canyon, approximately between alluvial wells SCA-2 and SCA-4 where perched alluvial groundwater is present (Figure 7.0-1) (LANL 2006, 094431; LANL 2009, 107453). The size of the primary infiltration zone may vary based on fluctuations in the average effluent discharge rate and transient stormwater and snowmelt events. During periods of higher than average surface-water flow, the infiltration zone may expand along the axis of the canyon to the east, and infiltration rates along the margins of the infiltration zone increase temporarily (LANL 2009, 107453, Appendix F). Calibration to moisture data indicates percolation rates are on the order of 1 to 6 m/yr in the primary infiltration zone depicted in Figure 7.0-1 (LANL 2008, 102996), resulting in travel times to the regional aquifer of approximately 20 to 50 yr. Percolation rates are likely lower beneath the wetland, and farther upcanyon and downcanyon where alluvial groundwater is either not present or not persistent. Corresponding travel times to the regional aquifer in those areas are longer because of less infiltration of surface water.

7.2.4 Perched-Intermediate Groundwater

Perched-intermediate groundwater is present at multiple depths beneath both Sandia and Mortandad Canyons but primarily related to the Cerros del Rio basalt. Hydrologic and geochemical evidence

indicates these zones are connected and lateral flow toward the south/southwest occurs. Figure 7.2-2 presents a cross-section to illustrate a CM for potential mixing of perched-intermediate groundwater beneath Los Alamos, Sandia, and Mortandad Canyons; the figure shows mean values of major ion groundwater chemistry and rock type. This CM is supported by other geochemical indicators as well (Appendixes D, H, and I). Figure 7.2-3 shows the same information in map view. Stiff diagrams illustrate the relative concentrations of major cations (sodium, calcium, magnesium, and potassium) to major anions (chloride, bicarbonate, and sulfate) at each location (see legend in Figure 7.2-1). Both these figures also show the most current chromium concentrations at the wells. The CM figure depicts potential mixing of perched-intermediate groundwater caused by lateral flow along perching layers at the top and base of the Cerros del Rio basalt that dip generally westward and southward, respectively. Likewise, there is evidence of contaminant transport from the perched-intermediate zones downward to the regional aquifer. This section and the regional aquifer section below provide evidence for both these flow paths and discuss the impact on contaminant concentrations in perched-intermediate groundwater and the regional aquifer, particularly for the distributions of chromium and perchlorate in these deeper groundwater zones.

The perched-intermediate zones are recharged by percolation of alluvial groundwater through the underlying bedrock units. There is no direct correlation of water levels with runoff events or alluvial groundwater fluctuations in Sandia or Mortandad Canyons (Appendix F), implying recharge of the perched-intermediate zones occurs over much longer time scales than the frequency of runoff events. Perched-intermediate groundwater occurs within the Puye Formation on top of the Cerros del Rio basalt at wells SCI-1 and MCOI-4 (Figures 7.0-1 and 7.2-2). This contact may have favorable characteristics for perching groundwater over a wide area. A second (deeper) perched-intermediate zone is penetrated by wells SCI-2, MCOI-5, and MCOI-6 within fractured lavas and interflow breccias in the lower part of the Cerros del Rio basalt (Figures 7.0-1 and 7.2-2; Appendix M). Structure contour maps depict dips of these perching horizons to the south/southwest (LANL 2007, 098938; Appendix M).

The perched-intermediate zone monitored by well SCI-1 is the shallowest of the perched-intermediate wells and seems to be most responsive to variations observed in surface water/alluvial groundwater. The temperature of the water is similar to the temperature of alluvial groundwater in Sandia Canyon, indicating it may be actively recharged from alluvial groundwater (Appendix F). Geochemical indicators also suggest similarity with alluvial waters. The major ion chemistry (Figure 7.2-2) shows the water at well SCI-1 has high major ion concentrations (i.e., high ionic strength) similar to alluvial groundwater (also see Appendix D). It is geochemically distinct from groundwater in the other perched-intermediate wells within either Sandia Canyon (SCI-2) or Mortandad Canyon (MCOI-4, MCOI-5, and MCOI-6) being characterized by (1) higher bromide, chloride, molybdenum, and phosphate (Figure D-3.0-4, D-3.0-5) than the other perched-intermediate groundwater wells and any of the regional groundwater wells in the Chromium Investigation monitoring group; and (2) lower chromium, nitrate, and tritium than the more highly chromium-contaminated wells (SCI-2, R-28, and R-42). These characteristics, particularly the high molybdenum, are consistent with derivation from more recent (post-1990) discharge waters within Sandia Canyon than the deeper contaminated wells. High phosphate is also indicative of cooling tower additives used in Sandia Canyon. The high chloride and bromide may be from increased road salt components in more recent years. Nitrogen isotopes are similar to those of alluvial water at SCA-2 and indicate a sewage effluent source, consistent with Sandia Canyon effluent (Appendix I). The groundwater at SCI-1 has predominantly infiltrated the subsurface in the last 20 yr and after the release of chromium-contaminated water ceased. Although well MCOI-4 is located along the same perching horizon beneath Mortandad Canyon, its geochemical signature is unlike that of well SCI-1 or of alluvial water. Direct connection with the waters at well SCI-1 is not evident, although chromium is elevated above background. Groundwater at well MCOI-4 is more similar to that from other Mortandad Canyon

intermediate wells as discussed below. If a hydraulic connection exists, the water levels of wells SCI-1 and MCOI-4 suggest flow to the south.

The water temperature at wells SCI-2, MCOI-4, MCOI-5, and MCOI-6 is warmer than alluvial groundwater and at SCI-1 (Appendix F). Their temperatures indicate groundwater at these wells is in thermal equilibrium with the surrounding rock and is not rapidly recharged by alluvial water. Similarity in geochemical indicators shows a relationship between groundwater at wells SCI-2 and MCOI-6 and distinct differences from waters at wells MCOI-4 and MCOI-5. Major cation and chromium concentrations in wells SCI-2 and MCOI-6 are elevated well above background levels, supporting the interpretation that these wells are impacted by a high ionic-strength Sandia Canyon source that represents older groundwater that may have infiltrated the subsurface during or soon after the period of chromium release in the canyon (1956 to 1972).

The Mortandad Canyon perched-intermediate wells (MCOI-4, MCOI-5, and MCOI-6) are contaminated with constituents historically released at Outfall 051 (i.e., perchlorate, 1,4-dioxane, nitrate, and tritium; see Appendix D). Concentrations of perchlorate, nitrate, and tritium have declined since 2005, particularly at wells MCOI-4 and MCOI-6, presumably in response to improvements in water quality at Outfall 051 since about 2000. Well MCOI-6 appears to be located at a mixing zone that is recharged by both Sandia and Mortandad Canyon sources. At well MCOI-6, while water levels (Appendix F) and perchlorate, nitrate, and tritium concentrations have declined recently, chromium concentrations have increased (Appendix D). This observation strongly supports the idea of lateral flow from Sandia Canyon extending to beneath Mortandad Canyon. Water at this well is likely responding to lower effluent volumes and increased water quality from Outfall 051. The decrease in Mortandad Canyon water volumes increases the fraction of Sandia Canyon water arriving at well MCOI-6. This reduces chromium dilution by Mortandad Canyon water and, in turn, is manifested as increasing chromium concentrations.

Lack of perched water in the Cerros del Rio basalt at wells R-28 and R-42 in Mortandad Canyon indicates perched groundwater may drain from the basalts and infiltrate the underlying Puye Formation, eventually reaching the regional aquifer in the area between wells SCI-2 and R-28/R-42, as illustrated in Figure 7.2-2. The effect on chromium and perchlorate concentrations in the regional aquifer from perched-zone leakage is discussed below.

7.2.5 Regional Aquifer

7.2.5.1 Hydrology

The regional aquifer beneath Sandia Canyon and canyons to the north and south can be represented as a complex heterogeneous system that includes confined and unconfined zones. The degree of hydraulic communication between these zones is thought to be spatially variable. The shallow portion of the regional aquifer (near the water table) is predominantly under phreatic (unconfined) conditions and the unconfined conditions are observed at a limited depth below the regional water table; the thickness of the phreatic zone is approximately 30 to 50 m [98 to 164 ft]).

The infiltration recharge of the regional aquifer originating along Sandia Canyon is expected to be substantial considering the large volumes of effluent discharged. Infiltration is expected to be relatively focused in the middle portion of the canyon, as presented in Figure 7.0-1, but may also occur south of the canyon axis because of the lateral flow in perched-intermediate zones. The potential impact of this infiltration recharge on the regional aquifer water levels was analyzed in Appendix I of the chromium fate and transport update report (LANL 2008, 102996), and further analysis of mounding near well R-36 was included in the Phase I IR (LANL 2009, 107453). It was concluded that recharge might cause a mound of the regional water table beneath the canyon of variable width and depth (less than 3 m high) depending

on various hydrogeological parameters, such as hydraulic conductivity. The spatial analysis of the regional water-table elevations (Appendix G, section G-1) indicates a small mound (less than 0.1 m) occurs at well R-42 that could result in localized flow from well R-42 toward well R-43.

The deep portion of the regional aquifer is predominantly under confined conditions, and it is stressed by Pajarito Plateau water-supply pumping. Based on analyses provided in Appendix G (section G-2) of this report and Appendix G of the Phase I IR (LANL 2009, 107453), the pumping wells appear to have little impact on the regional water table near Sandia Canyon. The analyses of water-level transients from water-supply pumping (Appendix G) and drawdowns during pumping tests (Appendix L) indicate three-dimensionality in the aquifer heterogeneity and in groundwater flow in the study area. The 3-D modeling results presented in Appendix K indicate that full to partial confinement of the deep portion of the aquifer is required to calibrate to hydraulic heads observed in the shallow monitoring-well screens. Water-supply pumping of the deep aquifer is expected to have a small impact on the groundwater flow and transport in the shallow phreatic zone of the regional aquifer. Therefore, it can be expected contaminant transport follows the shallow water-table gradients rather than diverting deeper toward the pumping water-supply wells. However, the poor hydraulic communication does not preclude the possibility that some contaminant migration could occur between the shallow and deep aquifer zones. Between the two zones, the hydraulic gradient has a strong downward vertical component because of water-supply pumping (e.g., water-level difference between wells R 35a and R-35b is about 4 to 5 m), creating the possibility that downward contaminant flow may occur along “hydraulic windows,” although these have not been directly observed.

The development of regional- and site-scale water-table maps is discussed in Appendix G (Figure G-1.1-1). The water-table maps include new data collected at recently installed regional wells in the vicinity of Mortandad and Sandia Canyons. The ambient regional groundwater flow gradients are relatively high to the west (close to the Pajarito fault zone) and to the east (close to the Rio Grande), varying between 0.0005 and 0.05 m/m. Gradients are relatively low in the area of the chromium contamination; on the order of 0.001 with an uncertainty range from 0.0005 to 0.002. The gradients are computed based on the water-level contours presented in Figure G-1.1-1. The analyses of the regional water-table gradients and flow directions in the study area are complicated because of the sharp contrast of zones with steep and flat hydraulic gradients. The regional water table near wells R-42 and R-28 has a relatively low hydraulic gradient compared with the rest of the regional aquifer, potentially because of the high effective aquifer permeability in this portion of the aquifer. The observed data suggest mounding of the regional water table near wells R-8, R-36, and R-42. The potential mound near R-42 appears to have relatively small height (~0.1 ft) compared with pronounced mounding near R-8 (~20 ft) and R-36 (~5 ft). However, given the potential mounding near R-42, it is possible that in addition to the predominant east-southeastern groundwater flow direction, a portion of the chromium plume may have migrated to the north and to the south of contaminant arrival locations at the top of the regional aquifer, which may have enhanced the contaminant mixing in the regional aquifer.

Groundwater flow and contaminant transport directions in the phreatic zone are generally determined by the gradient of the regional water table. However, the resultant advective flow paths of contaminant migration may not be strictly perpendicular to the equipotential water-table lines (i.e., parallel to the direction of the hydraulic gradients). Deviations from the flownet conformity rule may occur because of anisotropy and heterogeneity of aquifer materials. Flow and head gradient vectors do not coincide in an anisotropic medium when the flow gradient is not coincident with the principal directions of the permeability tensor (Freeze and Cherry 1979, 088742, Chapter 5). As a result, the south-southwest dips of aquifer rock units in this area may influence the flow vectors. The advective flow paths of contaminant migration in the regional aquifer will also be impacted by aquifer heterogeneity. Mounding of the regional water table because of infiltration recharge along and south of Sandia Canyon can also affect

contaminant flow directions locally (Appendix G). All these effects are taken into account in the 3-D flow simulations presented in Appendix K.

7.2.5.2 Contaminant Distributions

Contaminant distributions in the regional aquifer are discussed in this section in terms of their spatial relationships to the centroids of the chromium and perchlorate plumes that exceed their respective SLs in the regional aquifer, shown in Figure 7.2-1.

Chromium Plume Centroid. Regional wells R-28, R-42, R-50, and R-62 are located in the centroid of the chromium plume as defined by the 50 µg/L–contour interval (Figure 7.2-1), with the highest concentrations detected at wells R-42 and R-28. Groundwater in regional wells R-28 and R-42 are geochemically distinct among regional groundwater wells within the Chromium Investigation monitoring group. These two wells share many geochemical characteristics with groundwater in perched-intermediate aquifer well SCI-2. These characteristics include elevated chromium concentrations, high ionic strengths with elevated sulfate and calcium (Figures 7.2-2, 7.2-3, and D-3.0-2), and moderately elevated bromide, chloride, nitrate, and tritium concentrations (Figures D-3.0-4 and D-3.0-5). Groundwaters at wells R-28 and R-42 also have nitrate and sulfate stable isotope ratios similar to those observed in well SCI-2, and different from most other values measured in the regional aquifer (Appendix I). Finally, chromium isotopes measured in wells SCI-2, R-28, and R-42 indicate little evidence of reduction of chromium(VI) based on chromium isotope data. This result is interpreted as representing a flow path where long-term high chromium(VI) concentrations have presumably overwhelmed or bypassed the reductive capacity of the basalts in the vadose zone (Appendix H). All these geochemical indicators point to a predominant flow path that strongly links lateral flow from perched-intermediate water at well SCI-2 (and for some lines of evidence, MCOI-6) with groundwater at wells R-28 and R-42 while, for the most part, excluding other regional wells from this pathway. Together, these geochemical indicators are consistent with the centroid of the chromium plume at wells R-28 and R-42 reflecting moderately old (1950s–1980s) discharge water from the Sandia Canyon outfall (NPDES Outfall 001). The water age suggests the currently observed plume results from contaminant transport through the vadose zone that has occurred over the past 30 to 50 yr; groundwater infiltration is expected to be faster because the contaminants are slowed down by geochemical reactions with host rocks.

Regional well R-50 is located along the southern boundary of the chromium plume (Figure 7.2-1). The chromium concentration in the upper screen has increased from initial observed concentrations following construction and is currently approximately 100 µg/L. The concentration in the lower screen is at background. In the upper screen, most lines of evidence indicate that water appears to represent a mixing trend between lightly and highly (i.e., an R-28/R-42 end-member) contaminated groundwaters when considering plots of chromium versus chloride, tritium, nitrate, and sulfate (Appendix D). Nitrate, sulfate, and chromium isotopes measured in well R-50 are consistent with mixing of groundwater from the R-28/R-42 area with groundwater at background concentrations (Appendixes I and H). For the most part, these geochemical indicators indicate that R-28/R-42 and R-50 are along a common flow path, with well R-50 being farther downgradient from the arrival location of chromium(VI) at the regional aquifer. This interpretation is also consistent with modeling results presented in Appendixes J and K.

Regional well R-62 is located along the western portion of the chromium plume (Figure 7.2-1) and helps to delineate the upgradient extent. Too little data are available from this new well to estimate mixing relations.

Key implications for the geochemical CM related to the centroid of the chromium plume include the following:

- A high likelihood the principal arrival zone at the regional aquifer for the chromium plume centroid is located near the R-28/R-42 area and lateral flow along perched-intermediate zones from initial infiltration locations starting in Sandia Canyon may be the mechanism for the arrival location south of Sandia Canyon.
- Constituents largely discharged to Sandia Canyon in the early 1990s or later (molybdenum and chlorate most notably) are not observed in the regional aquifer at highly elevated levels, suggesting a contaminant travel time from the surface to the regional aquifer of greater than 20 yr.

Perchlorate Plume Centroid. Regional wells R-15 and R-61 both have distinctly elevated perchlorate (>4 $\mu\text{g/L}$) at relatively low chromium concentrations (Figure 7.2-1), high perchlorate/chloride ratios, and moderately elevated tritium concentrations (Appendix D). Nitrate is variable with moderately elevated levels in well R-15 and low/variable levels in well R-61. Together, these data indicate that much or all of the contamination at these wells is derived from a Mortandad Canyon source. The constituent 1,4-dioxane is not detected in the regional aquifer, although it is identified as geochemically diagnostic of a Mortandad Canyon source and is present at concentrations of <50 $\mu\text{g/L}$ in the MCOI-group perched-intermediate groundwater wells. The absence of 1,4-dioxane in wells R-15 and R-61 may mean its concentration is below the detection limit ($\sim 2\text{--}3$ $\mu\text{g/L}$), or this constituent was released later than others that have arrived at the regional aquifer.

Chromium Plume Margins. Regional groundwater wells R-11, R-43, R-44, R-45, and R-61 all contain chromium at levels greater than regional background values (approximately 6 $\mu\text{g/L}$ –10 $\mu\text{g/L}$) and are therefore within the chromium plume but have concentrations below the 50 $\mu\text{g/L}$ New Mexico groundwater standard. In cases where a well has multiple screens, only the uppermost screen typically contains chromium above background concentrations (Figure 7.2-1). Groundwater from all of these wells has relatively low ionic strengths and major element compositions similar to background regional groundwater wells (Figures 7.2-2 and 7.2-3). Temporal trends and element/element relations for conservative constituent concentrations are somewhat equivocal for identifying mixing trends (Appendix D): (1) well R-43 has distinctly different mixing curve slopes on plots of chromium versus chloride and sulfate and contains essentially no tritium, suggesting a different mode of mixing and perhaps a different arrival location at the regional aquifer than the chromium plume centroid wells; (2) wells R-11, R-44, and R-45 have low concentrations of most key constituents; the chromium versus sulfate and chromium versus nitrate plots for the latter suggest mixing with a plume centroid source; and (3) well R-61 has too little data to establish robust temporal mixing trends, although it is likely to be similar to the other contaminated margin wells.

Key implications for the geochemical CM of these data include the following:

- Two geochemically distinct regional groundwater plumes are present within the chromium monitoring group wells, one clearly derived from a Sandia Canyon source (with elevated chromium concentrations as a key indicator) and one derived from a Mortandad Canyon source (with elevated perchlorate concentrations as a key indicator) (Figure 7.2-1).
- More than one contaminant arrival area may exist at the top of the regional aquifer for contaminants arriving from Sandia Canyon. The arrival area(s) for contaminants from Mortandad Canyon may be more limited.
- Regional aquifer contamination is limited to the upper portions of the regional aquifer.

- Wells R-50 and R-43 have distinct mixing modes, with the former exhibiting more geochemical similarities to the plume centroid wells than the latter.
- Well R-61 shows both elevated chromium and elevated perchlorate, suggesting mixing between the two plumes, although the data set for this well is limited.

8.0 RISK ASSESSMENTS

This section presents a synopsis of the Phase I risk assessments and additional information based on the results of the Phase II investigations.

8.1 Baseline Ecological Risk Assessment

Biological, sediment, and water data were collected in Sandia Canyon reaches to evaluate the potential for adverse ecological effects from contaminants in sediment and persistent surface water in the Phase I IR (LANL 2009, 107453). A biota investigation work plan was developed based on the application of the eight-step EPA Ecological Risk Assessment Guidance for Superfund (EPA 1997, 059370) to chemicals of potential ecological concern (COPECs) in sediment and persistent surface water (LANL 2007, 099152). No new canyon-specific ecological investigations were completed as part of the Phase II investigation. A summary of the baseline ecological risk assessment from the Phase I IR is provided below. Study design COPECs for Sandia Canyon were metals, PCBs, and pesticides.

In summary, COPECs were identified as study design COPECs in the ecological screening of soil, sediment, and surface water in Sandia Canyon. Assessment endpoints (AEs) consist of an entity (a receptor species) and an attribute (survival, growth, or reproduction) of the entity being assessed. Seven AEs for Sandia Canyon are identified based on the study design COPECs and the conceptual site exposure model:

- survival and reproduction of the Mexican spotted owl
- health and reproductive success of avian ground invertivore feeding guild species (e.g., American robin, bluebird)
- survival of mammalian invertivore and omnivore feeding guild species (e.g., shrews and deer mice)
- survival and growth of detritivore species (earthworms)
- survival and growth of native plant species
- survival and reproduction of the southwestern willow flycatcher
- abundance and survival of the aquatic community in the reaches of Sandia Canyon that retain surface water long enough to support aquatic communities

A weight of evidence approach (WOE) utilizing various lines of evidence for the seven AEs indicated potential adverse effects of COPECs on terrestrial and aquatic receptors exist in Sandia Canyon (LANL 2009, 107453). For the terrestrial environment, the main COPECs of concern are PCBs, and the potential for adverse effects existed through the food web. There are uncertainties with regard to PCB congener concentrations. For the aquatic environment, both field macroinvertebrate surveys and chironomid bioassay results pointed toward differences that may be related to contaminants from Laboratory operations or other sources. The main uncertainty associated with this conclusion was that non-COPEC confounding factors described in the Phase I IR are also correlated to bioassay measures (LANL 2009, 107453). The ecological studies pointed toward exposures in the wetlands and the potential for adverse

effects from these exposures. Other reaches in Sandia Canyon had much lower exposures and no potential for ecological risk based on the WOE.

8.2 Human Health Risk Assessment Synopsis

The human health risk assessment in the Phase I IR evaluated the potential for adverse effect on human health in the Sandia Canyon from COPCs in sediment and surface water (LANL 2009, 107453). The risk assessment approach used followed guidance from NMED (2009, 106420). The approach used media- and scenario-specific SLs to evaluate the potential for human health risks from sediment, surface water and, cumulative (sediment risks plus surface water risks) in Sandia Canyon. The risk assessment used information pertaining to current and reasonably foreseeable future land use in Sandia Canyon to assess potential impacts under reasonable maximum exposure (RME) conditions. The canyon bottoms in Sandia Canyon include a mixture of land ownership potentially supporting a variety of land-uses. More details on the risk assessment approach are presented in the Phase I IR (LANL 2009, 107453).

In summary, the potential health effects associated with COPCs in Sandia Canyon were assessed relative to a dose criterion of 15 mrem/yr for sediment, a cancer risk criterion of 1×10^{-5} , and a hazard criterion of 1. The risk-assessment results for carcinogenic risk in sediment in reach S-1N were above these thresholds for the recreational scenario (2×10^{-5}); all other reaches were below the carcinogenic threshold. Chemical hazards and radiologic dose in sediment are all below these thresholds. For the surface waters evaluated in Sandia Canyon, none of the risks, doses, or hazards exceeded these criteria for any of the reaches. The exceedance of the carcinogenic risk threshold in reach S-1N was driven by elevated concentrations of benzo(a)pyrene and other carcinogenic PAHs in sediment. A supplemental evaluation of PCB congener sampling results from four locations, including the highest measured concentrations of Aroclors in reach S-2, showed that the risk from PCBs is greater than 1×10^{-5} using one of these samples. This evaluation approach was conducted as a point of reference but is not considered representative of risks in the reach because the samples submitted for PCB congener analysis included the geomorphic units and locations with the highest concentrations of PCBs. Lower risk for PCB congeners were anticipated using area- and depth-integrated representative samples in reach S-2.

8.3 Phase II Investigations

Supplemental data collection relevant to the risk assessments included one additional sediment investigation reach (S-5EC) and 3 yr of surface water sampling. These additional data have been evaluated both qualitatively and quantitatively. The approach for evaluating the human-health and ecological risks for Phase II COPCs is consistent with that used to evaluate risks associated with the Phase I COPCs (LANL 2009, 107453).

The additional sediment investigation reach was evaluated in section 6.2, and as stated, a total of 10 inorganic chemicals and 24 organic chemicals were retained as COPCs in Phase II compared with a total of 31 inorganic chemicals, 50 organic chemicals, and 11 radionuclides retained as Phase I sediment COPCs in Sandia Canyon. Therefore, the Phase II investigation retains fewer COPCs compared with the Phase I investigation and as shown in section 7.1, the concentrations of COPCs and in particular of COPCs with sources in the upper watershed are significantly lower in Phase II. Antimony was a Phase II COPC based on detection limits greater than the BV; antimony was not detected in any of the Phase II sediment samples. Therefore, further evaluation of antimony is not warranted. However, five organic COPCs (4,4'-DDE; 4,4'-DDT; diphenylamine; methylene chloride; and tetrachloroethene) were identified as Phase II COPCs but were not Phase I sediment COPCs. Table 8.4-1 provides the maximum concentrations of these organic chemicals in comparison to currently applicable soil screening values. As the maximum detected concentrations of these additional Phase II sediment COPCs are significantly

lower than the human health or ecological risk soil screening values (Table 8.4-1) no further risk calculations are needed based on the presence of these COPCs.

The additional surface water investigations were roughly 3 yr of stormwater and nonstorm-related surface-water samples from the same locations as were sampled in Phase I. In either form of surface water, six analytes were above current-day comparison values for the Phase II surface water data and 20 analytes were above the comparison values used for the Phase I surface water data. Thallium was the only analyte above the current-day comparison values but less than the comparison values used for the Phase I IR. Thus, fewer Phase II analytes are above surface water comparison values. Although the thallium standard was lowered since the Phase I IR, this analyte plus the other Phase I nonstorm-related surface-water COPCs were evaluated in the risk assessments. Surface water contributed relatively little to the calculated risks to recreational users, and the Phase II surface water results do not indicate any substantial changes to these conclusions.

Therefore, the conclusions of the Phase I risk assessments are not significantly changed by the Phase II investigation results, and updates or recalculation of risks are not warranted for this Phase II IR.

9.0 CONCLUSIONS AND RECOMMENDATIONS

The Phase II investigation builds upon the 2009 Phase I investigation in Sandia Canyon. Both investigations indicate inorganic, organic, and radionuclide COPCs are present in sediment, surface water, and groundwater in the Sandia Canyon watershed at concentrations above SLs and federal and/or New Mexico groundwater standards. These COPCs are derived from several sources, including Laboratory SWMUs and AOCs, runoff from developed areas, and natural sources such as noncontaminated soils, sediments, and bedrock. The nature and extent of these COPCs are defined in sediment, surface water, the vadose zone, and regional groundwater, as described below.

The spatial distribution of contaminants in the Sandia Canyon watershed, supported by data from previous investigations, indicates that SWMUs and AOCs within TA-03 are the most important sources of contamination with respect to potential human health risks, ecological risks, and groundwater impacts. Important source areas for Laboratory-derived COPCs in TA-03 include the former outfall for the power plant cooling towers in upper Sandia Canyon [SWMU 03-012(b)], a former PCB transformer storage area [SWMU 03-056(c)] along the south fork of Sandia Canyon, and the former asphalt batch plant [Consolidated Unit 03-009(a)-00] along the north fork of Sandia Canyon. Additional Laboratory sources (e.g., TA-53 and the Protective Force firing range at TA-72) are indicated by the characterization data, although the concentrations, extent, and inventory of COPCs from these sources are minor compared with the TA-03 sources. In groundwater, contamination is present in wells beneath both Sandia and Mortandad Canyons. These wells constitute the Chromium Investigation monitoring group defined in the 2011 Interim Facility-wide Groundwater Monitoring Plan, Revision 1 (LANL 2012, 208811) and include perched-intermediate and regional wells (Figure 3.2-2). Groundwater samples from these wells indicate the former outfall for the TA-03 power plant cooling towers in upper Sandia Canyon [SWMU 03-012(b)] and NPDES Outfall 051, which has historically released effluent from the TA-50 RLWTF into the Mortandad Canyon watershed, are the key sources of groundwater contamination.

Contaminants in sediment originally released from TA-03 extend for approximately 10 to 12 km (6 to 7 mi) downcanyon from the sources. Stormwater runoff and surface-water flow from daily effluent releases generally infiltrate alluvium in the upper and middle portion of Sandia Canyon, resulting in historical deposition of contaminated sediment in that area. This finding is consistent with the lack of evidence of past transport of Laboratory-derived contaminants from Sandia Canyon into the Rio Grande. The most important historical sediment deposition area is in the upper canyon where a broad wetland exists

(reach S-2). A single sediment reach S-5EC was sampled for the Phase II investigation (Figure 3.1-1). The distribution and concentrations of COPCs were compared with those in bounding reaches S-5C and S-5E for evaluating potential human health and ecological risks.

Supplemental data collection relevant to risk assessments included sediment investigation reach S-5EC and 3 yr of surface water sampling. The conclusions of the ecological and human health risk assessments are not changed based from those presented in the Phase I report based on the additional Phase II sediment and surface water sampling results.

With the exception of zinc, the average concentrations of COPCs in sediments in reach S-5EC are bounded by those in reaches S-5C and S-5E (overall, COPC concentrations in S-5EC are lower than upstream reach S-5C and higher than those found in downstream reach S-5E). The average zinc concentration in S-5EC is slightly higher than in S-5C, possibly from runoff from the adjacent roadway. Concentrations in this supplemental reach are generally much less than the maximum concentrations measured during Phase I. The inventory estimates for chromium and PCBs in Sandia Canyon sediments were updated based on data from reach S-5EC; these slightly revised Phase I results. Approximately 85% of the inventory of chromium is located in wetland reach S-2; an estimated 81% to 99.6% of PCBs are located in reach S-2, depending on the PCB congener.

Investigations of surface water and groundwater have better constrained the nature and extent of contaminants released into Sandia Canyon. The COPCs in surface water and alluvial groundwater relate closely to those identified for sediment but generally extend for a shorter distance downcanyon from the source than do the sediment COPCs. Other more mobile constituents are found in the underlying vadose zone, perched-intermediate groundwater, and regional groundwater. A CM informed by multiple lines of evidence indicates these mobile constituents are present along a migration pathway dominated by initiation of infiltration into the vadose zone over a short segment in the middle portion of Sandia Canyon. Dissolved-phase chromium [chromium(VI)] is present within the regional aquifer at concentrations exceeding the 50 µg/L New Mexico groundwater standard. Perchlorate is also present in the regional aquifer beneath Mortandad Canyon at concentrations exceeding the Consent Order screening level of 4 µg/L. The analyte 1,4-dioxane is present in perched-intermediate groundwater beneath Mortandad Canyon at concentrations exceeding its groundwater standard.

The spatial distribution of these more mobile constituents is significantly affected by complex vadose-zone stratigraphy, porous-media hydrologic properties, and perched-intermediate and regional groundwater flow directions. Contaminants that infiltrate Sandia Canyon may be partly transported laterally via mixing with perched-intermediate groundwater that flows generally southward on top of and within the Cerros del Rio basalts before breaking through to the regional aquifer. These waters mix with perched-intermediate groundwater that infiltrates generally more vertically beneath Mortandad Canyon. The footprint of the breakthrough locations from the vadose zone into the regional groundwater is estimated based on groundwater data and calibrated groundwater models used to support the CM. The potential spatial distribution and magnitude of flux in the estimated breakthrough locations are interpreted from a series of model analyses.

Groundwater modeling indicates contaminant transport in the regional aquifer is expected to occur predominantly east-southeast from the primary infiltration window near R-42 and R-28 (toward R-44 and R-45), which is consistent with the observed hydraulic gradients along the regional water table. However, anisotropy related to complex stratigraphy and structural dips of strata may result in some more southerly component of flow. Temporal fluctuations of the chromium concentrations in wells within the network may relate to local heterogeneities and transients in the local hydrogeochemical conditions, particularly close to the primary location of contaminant arrival at the regional water table near R-42. Model estimates indicate that approximately 20 kg/yr, with a range of approximately 8 kg/yr and 100 kg/yr, continue to

enter the regional aquifer. Mass-balance calculations suggest a small mass (approximately 1100 kg) of hexavalent chromium constitutes the mass and distribution of mobile chromium observed in regional aquifer monitoring wells. Puye Formation sediments in the regional aquifer contain iron(II)-bearing minerals that could lead to additional reduction and may account for chromium(III) present to some degree on regional aquifer materials accounting for an additional chromium mass that is immobile and therefore not measured in groundwater samples (Appendix H).

Data from groundwater monitoring wells and the groundwater model provide information on the extent of chromium contamination in the regional aquifer. The installation of new regional wells R-50, R-61, and R-62 have further refined information on the extent of the chromium plume along the southern (R-50 and R-61) and western (R-62) boundaries. Perchlorate is also present in the aquifer from a Mortandad Canyon source, and its distribution is defined by observations in R-15, R-61, and R-50 and wells to the north.

Groundwater will continue to be monitored for potential changes in concentrations or distribution of contaminants within wells in the Chromium Investigation monitoring group. The monitoring plan will be included in the Laboratory's annual Interim Facility-Wide Groundwater Monitoring Plan. The information on the nature and extent of contamination originating from Sandia (and Mortandad) Canyons supports proceeding to the corrective measures evaluation phase to evaluate and recommend a final remedy for groundwater contamination.

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Copies of the master reference set are maintained at the NMED Hazardous Waste Bureau and the Directorate. The set was developed to ensure that the administrative authority has all material needed to review this document, and it is updated with every document submitted to the administrative authority. Documents previously submitted to the administrative authority are not included.

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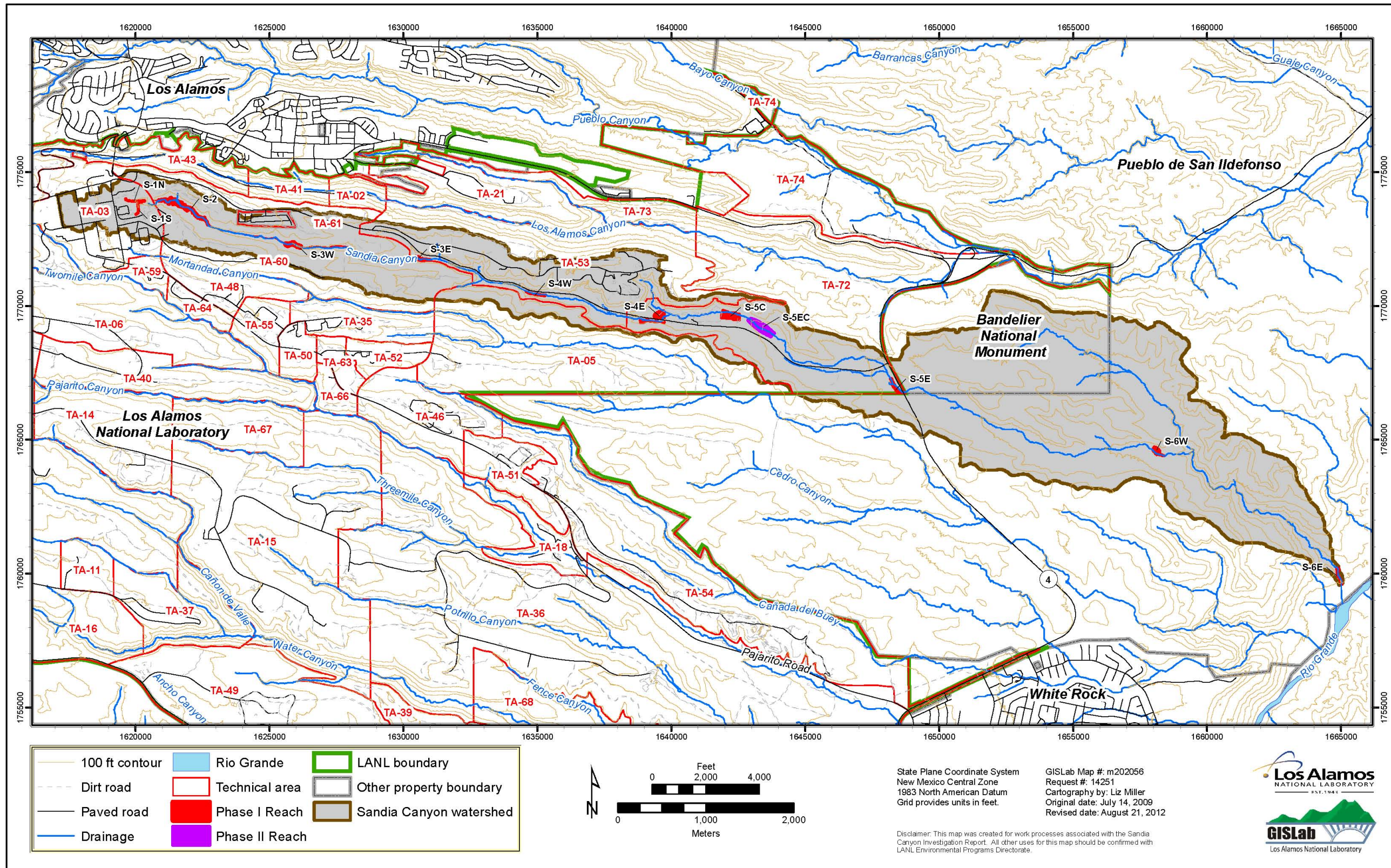


Figure 3.1-1 Sandia Canyon watershed showing reach boundaries

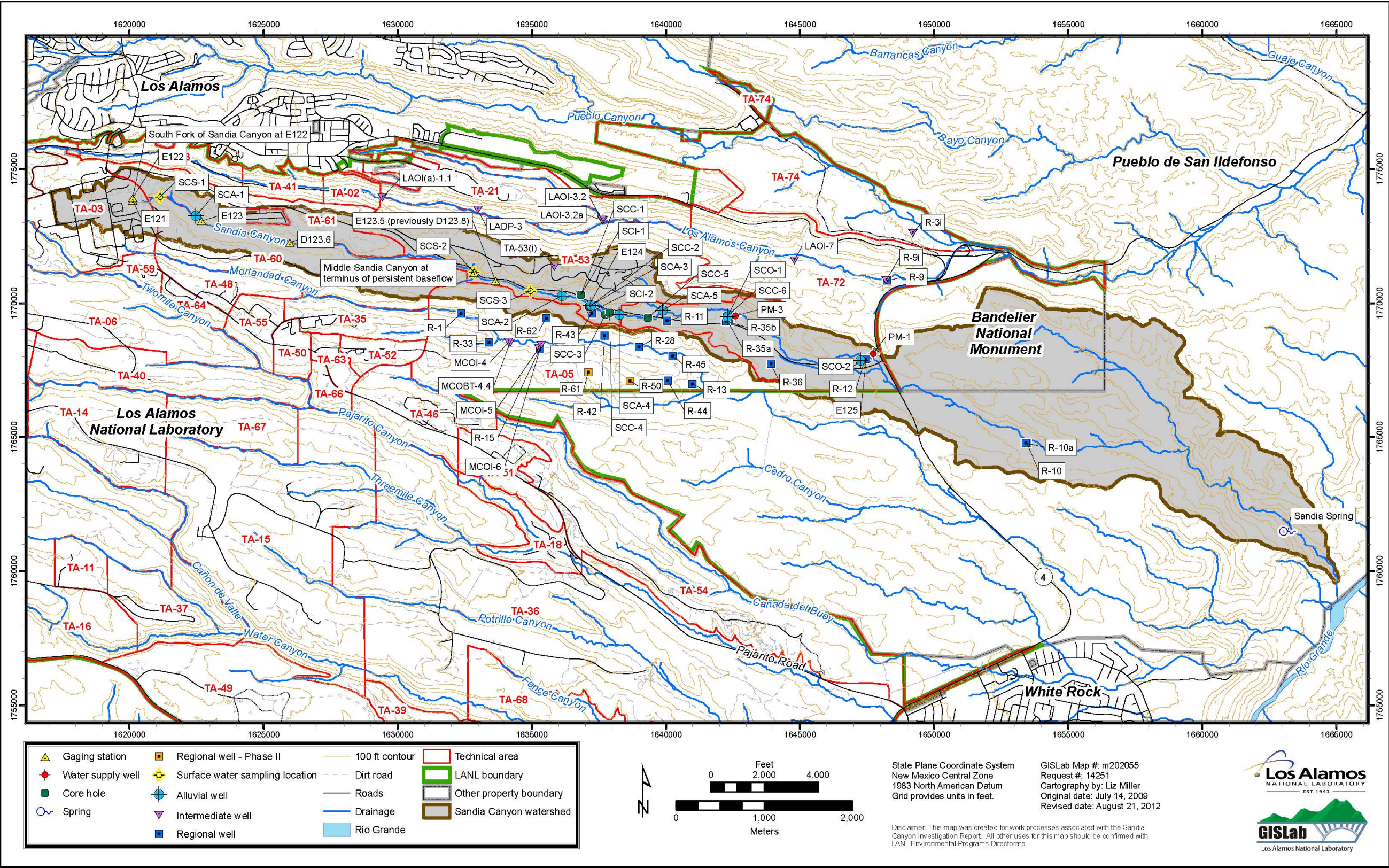


Figure 3.2-1 Sandia Canyon watershed showing water sampling locations

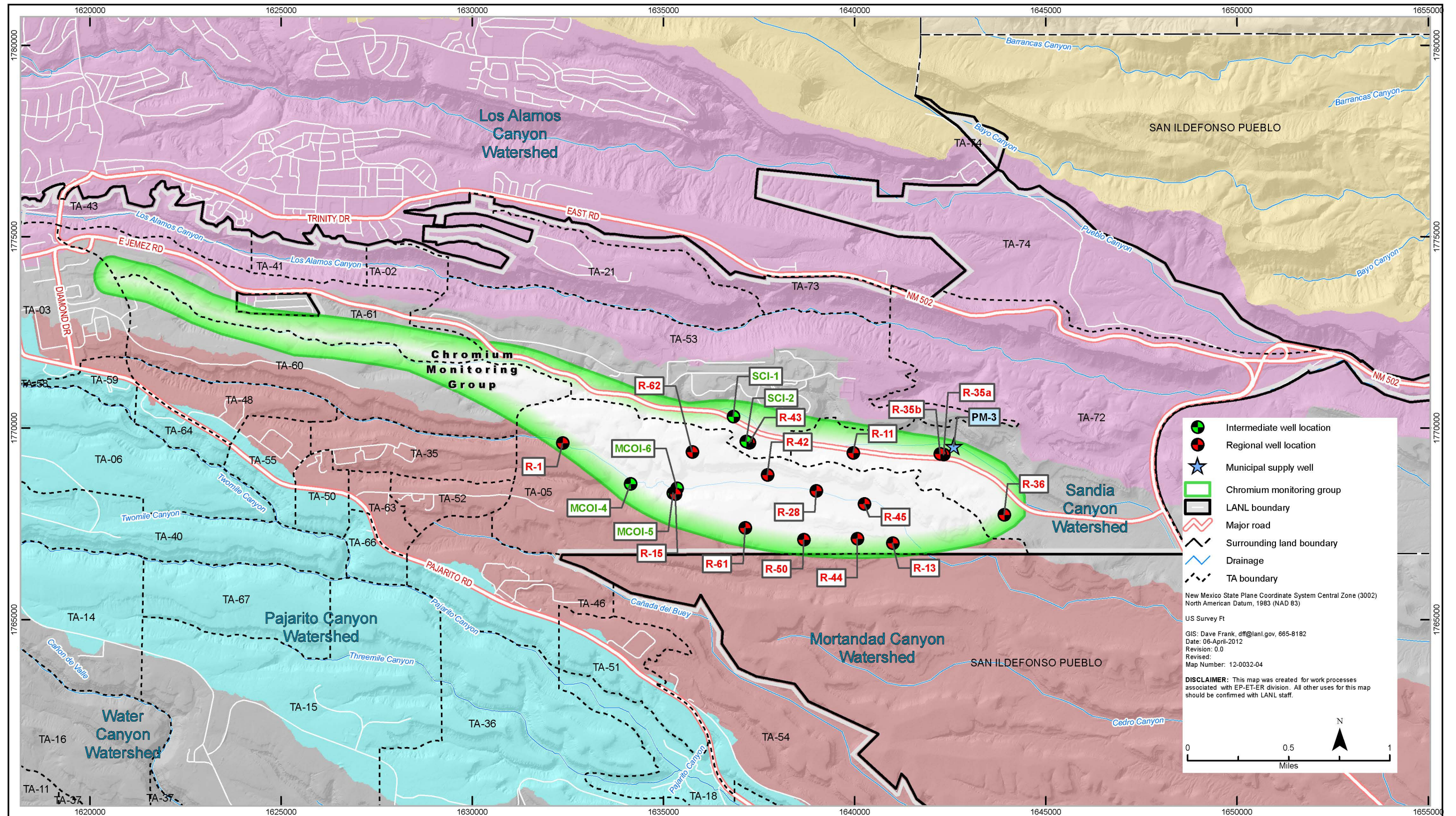


Figure 3.2-2 Chromium Investigation monitoring group

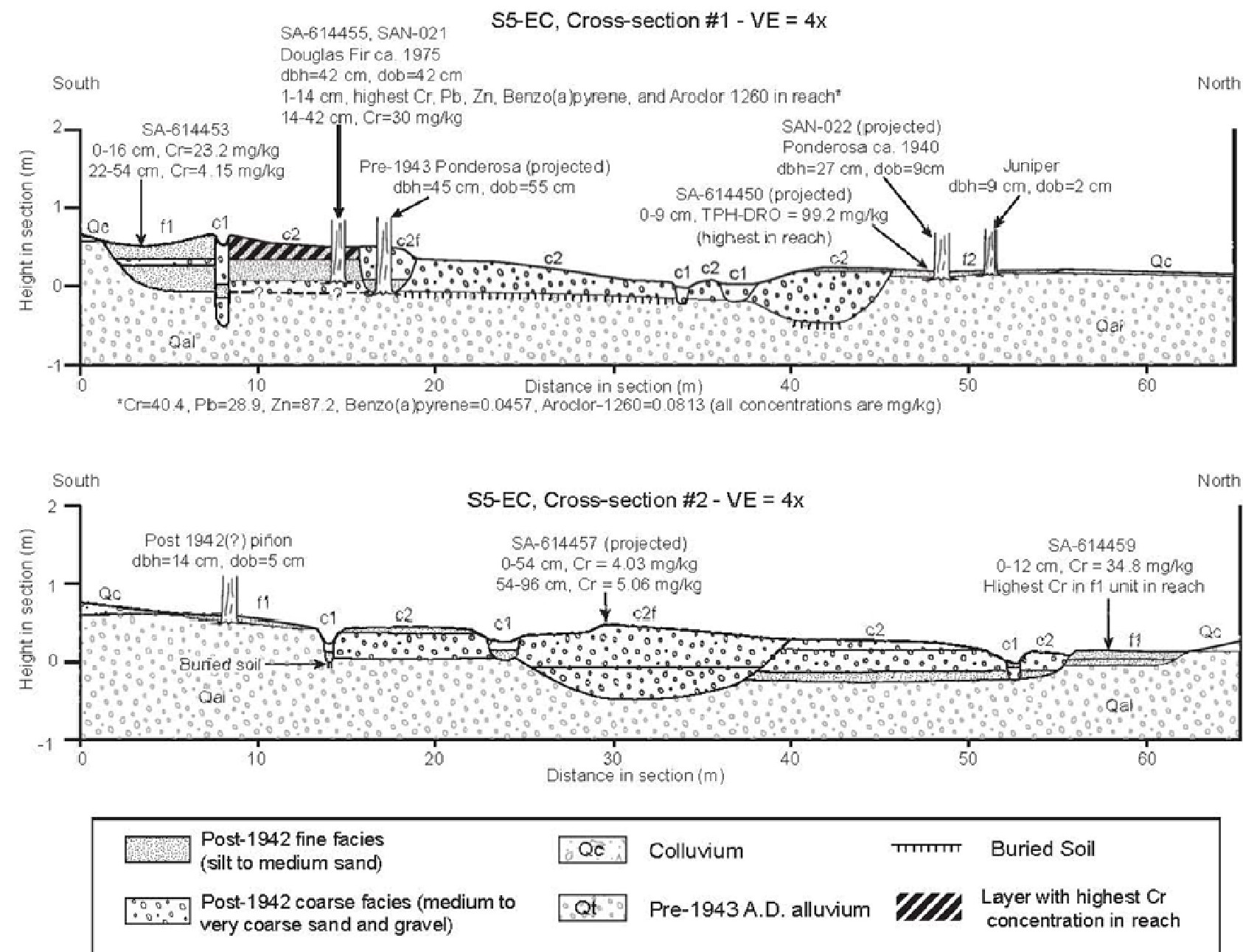


Figure 4.1-1 Schematic cross-sections showing post-1942 coarse-facies and fine-facies sediment deposits in reach S-5EC. See Plate 2 for cross-section locations

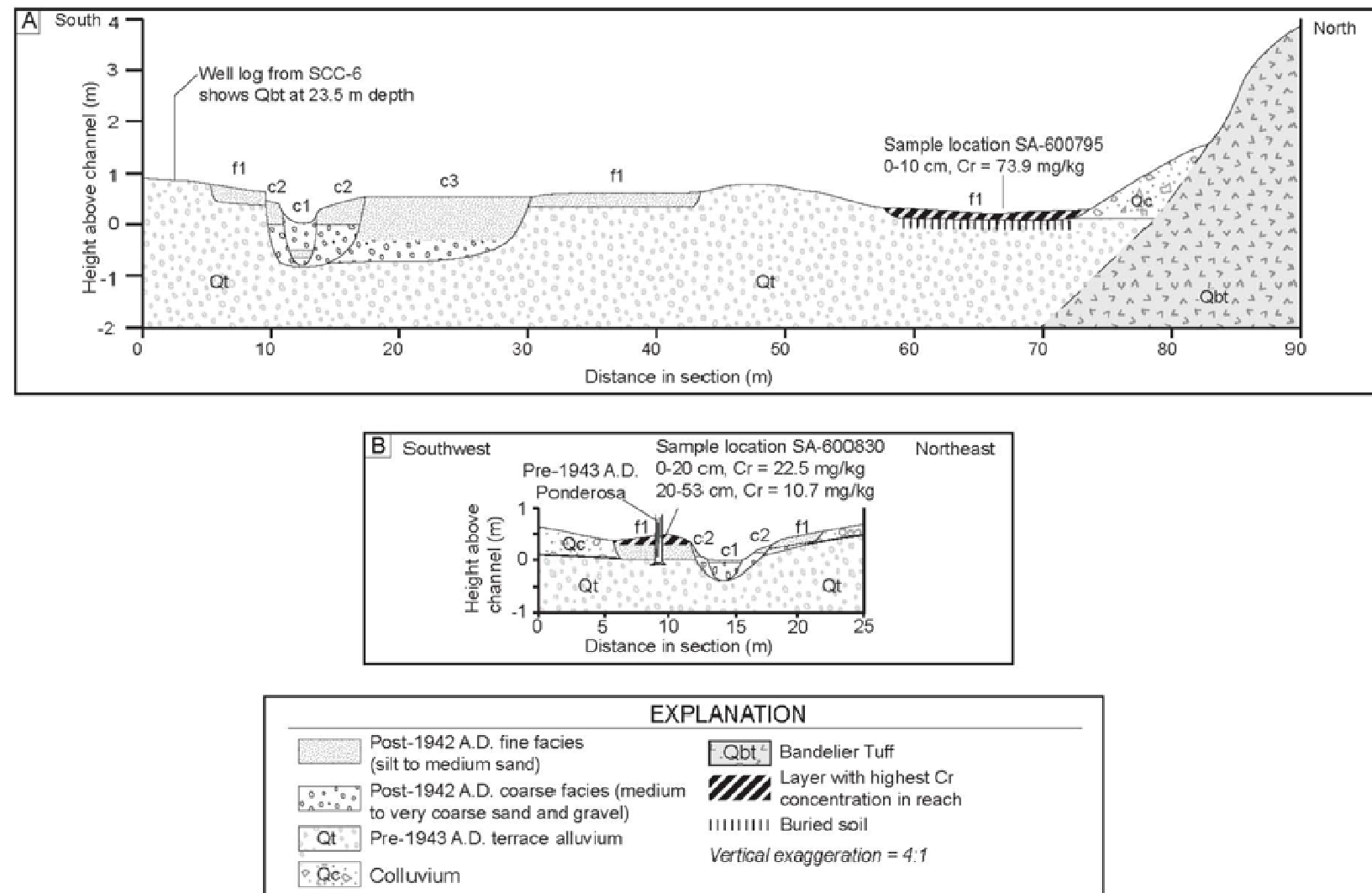


Figure 4.1-2 Schematic cross-sections showing post-1942 coarse-facies and fine-facies sediment deposits in reaches (a) S-5C, and (b) S-5E.

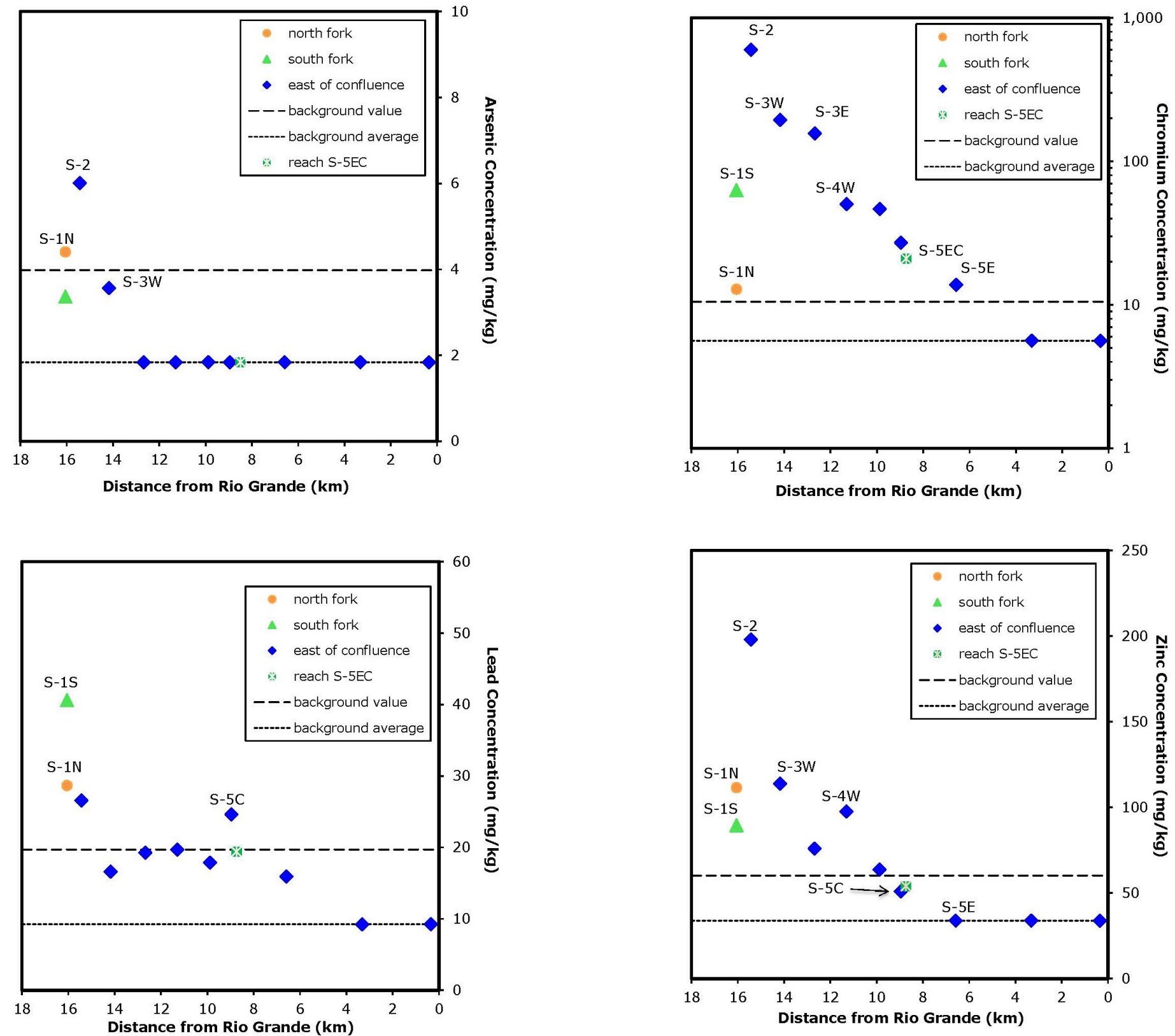


Figure 7.1-1 Estimated average concentrations of select inorganic chemicals in fine facies sediment in Reach S-5EC and other Sandia Canyon reaches

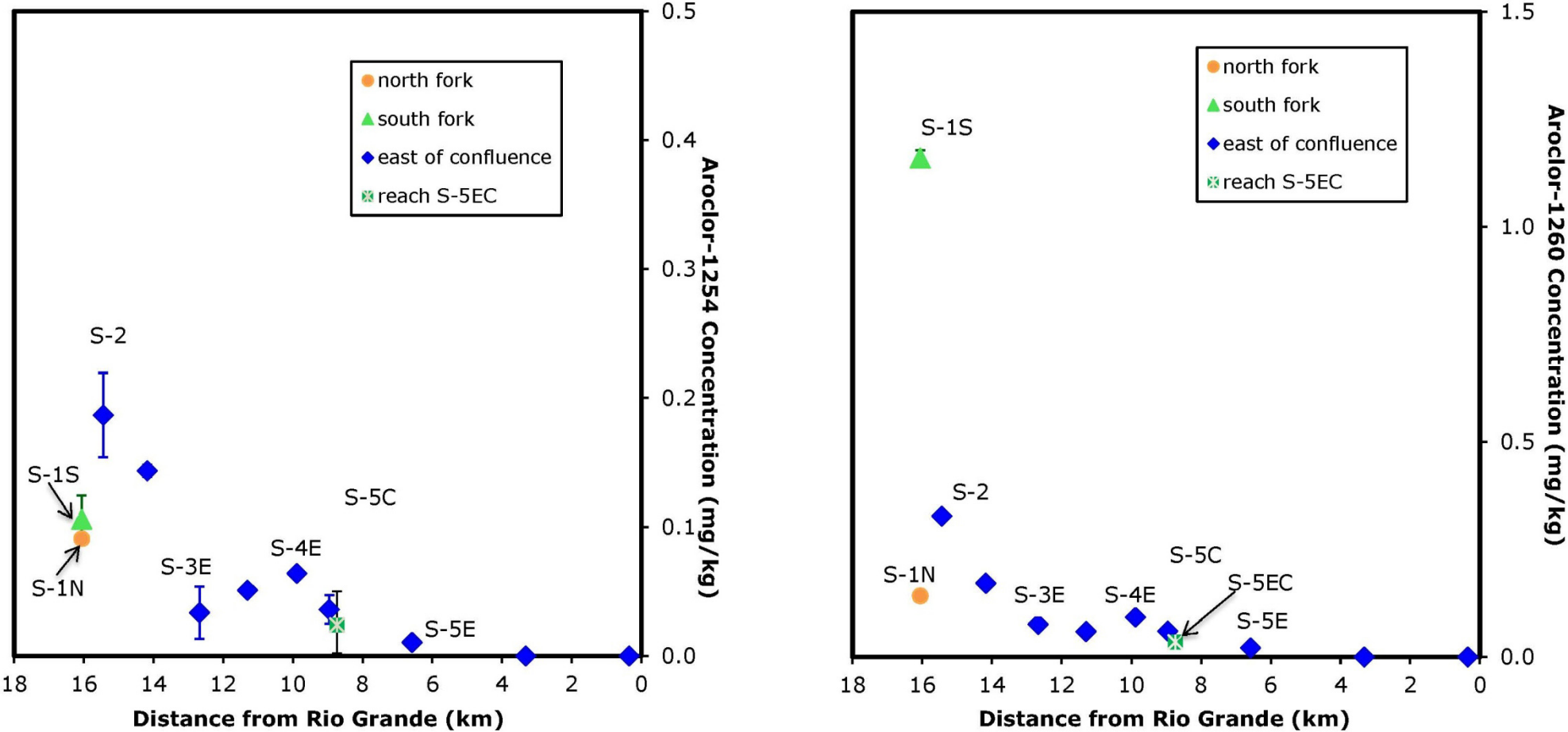


Figure 7.1-2 Estimated average concentrations of select PCBs in fine facies sediment in Reach S-5EC and other Sandia Canyon reaches

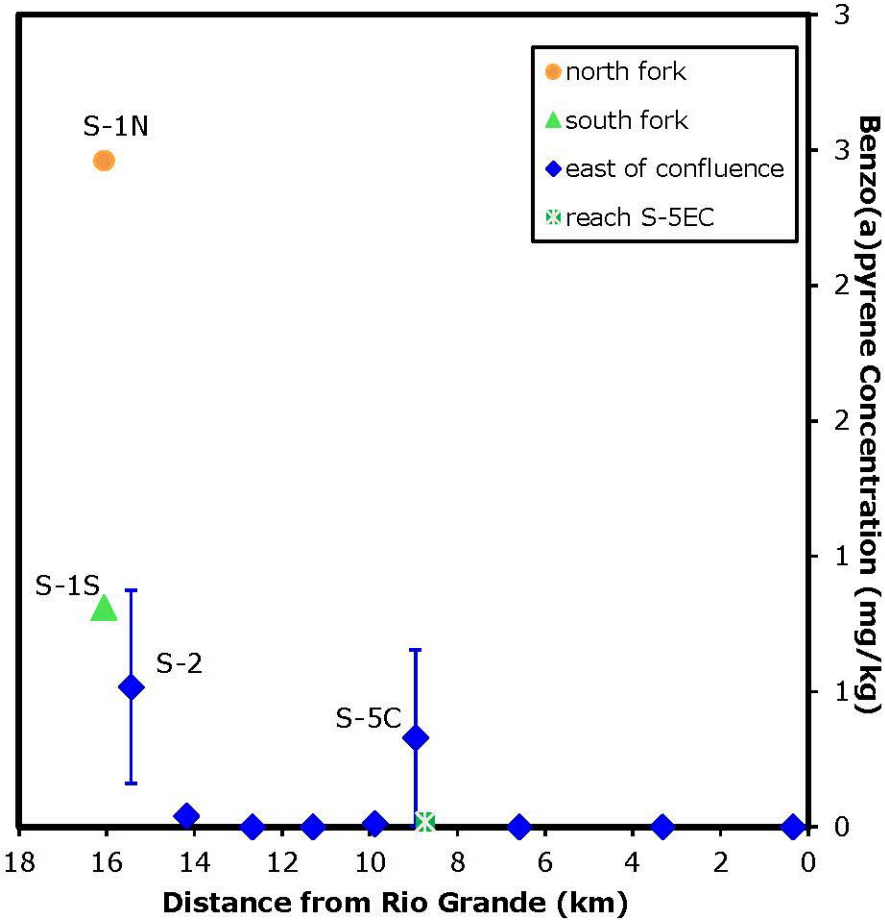


Figure 7.1-3 Estimated average concentrations of benzo(a)pyrene in fine facies sediment in Reach S-5EC and other Sandia Canyon reaches

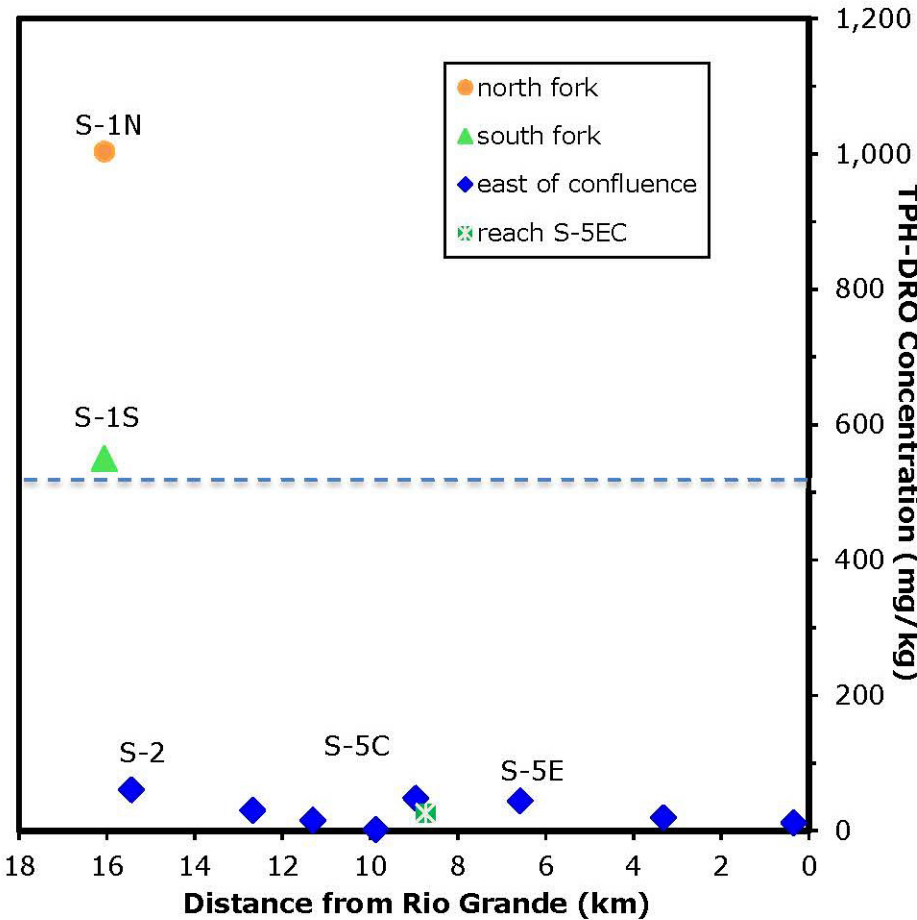


Figure 7.1-4 Estimated average concentrations of TPH-DRO in fine facies sediment in Reach S-5EC and other Sandia Canyon reaches

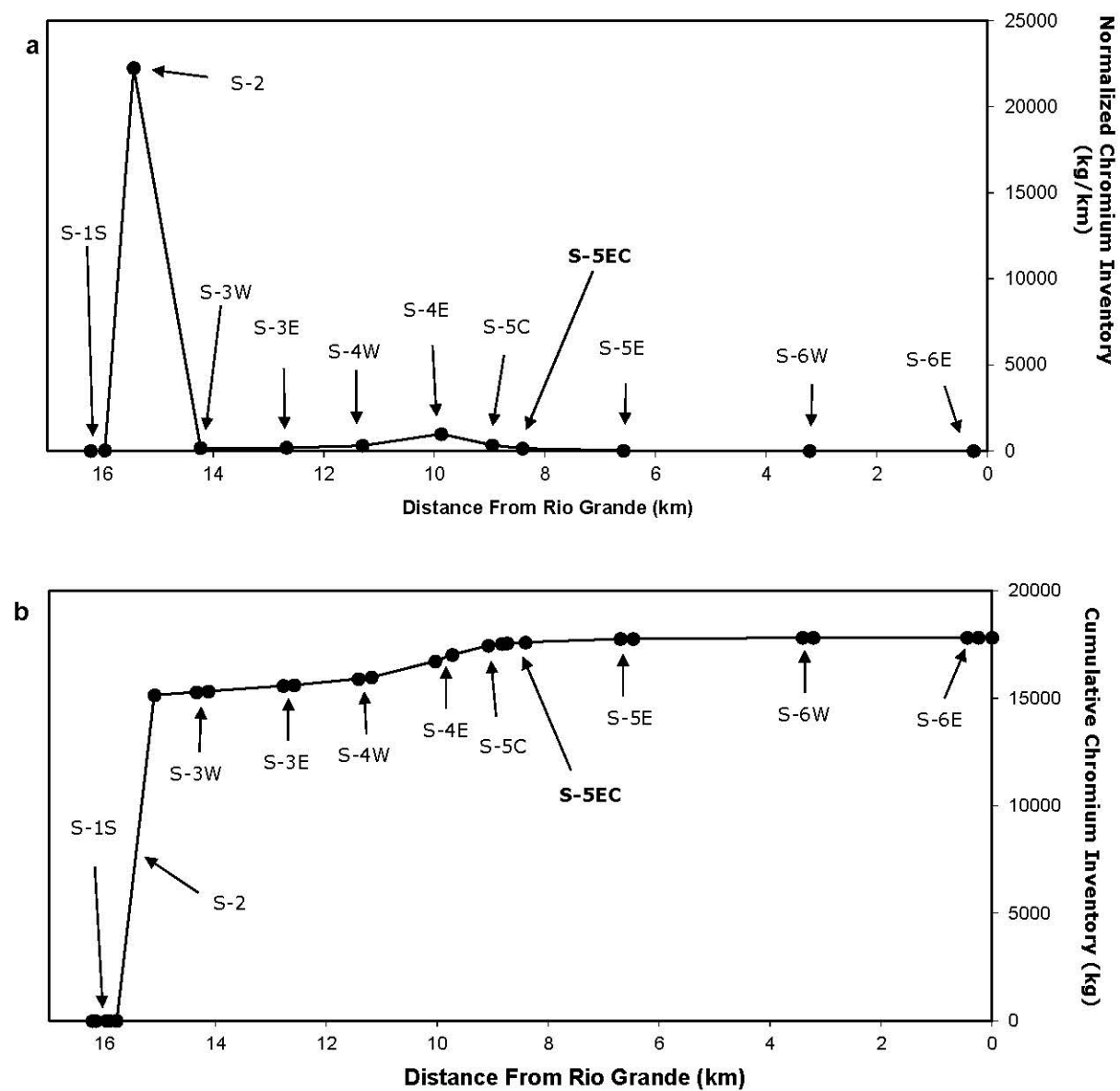


Figure 7.1-5 Estimated anthropogenic chromium inventory in Sandia Canyon; (a) normalized inventory (kg/km); (b) cumulative inventory (kg)

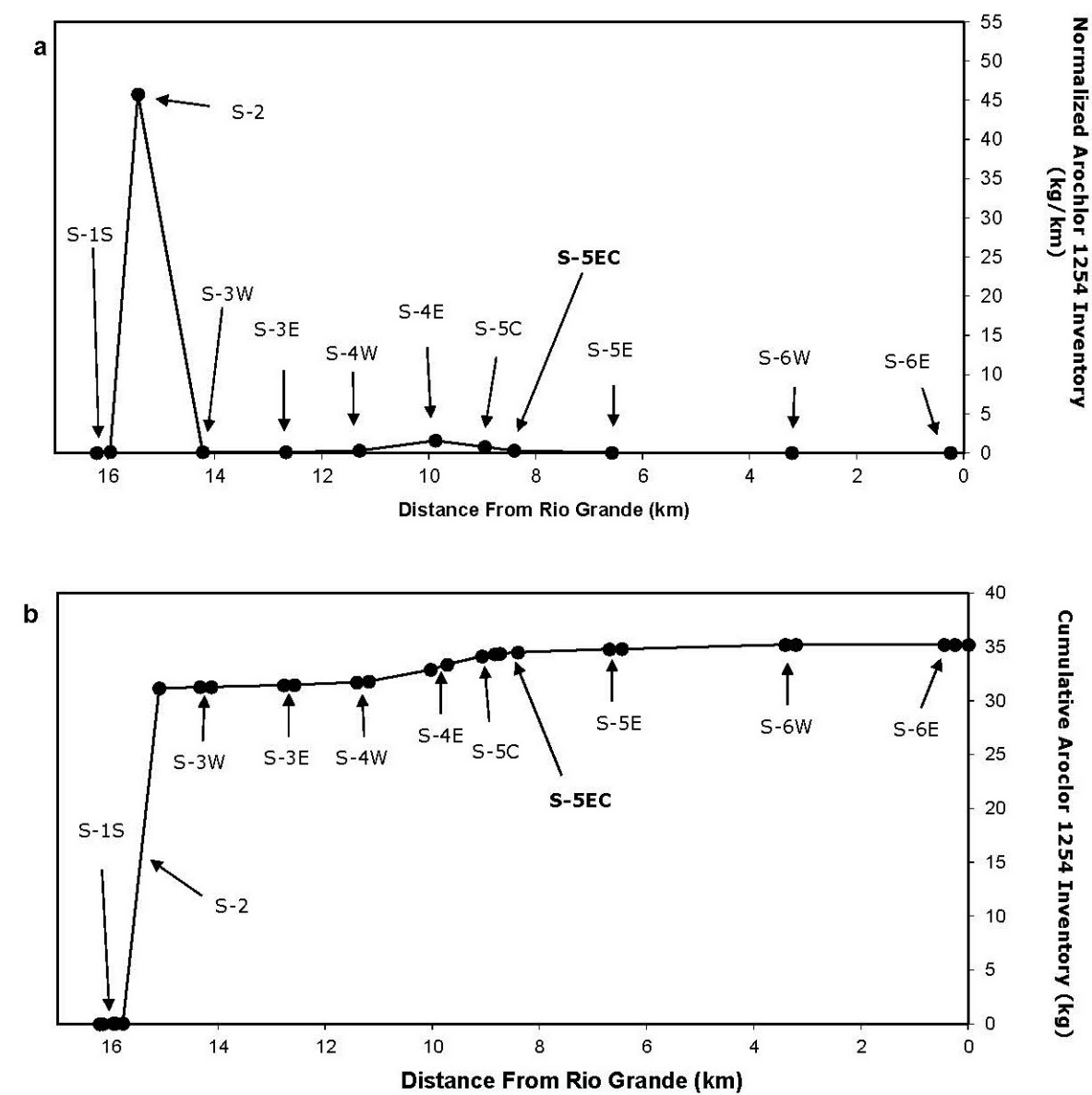


Figure 7.1-6 Estimated Aroclor-1254 inventory in Sandia Canyon; (a) normalized inventory (kg/km); (b) cumulative inventory (kg)

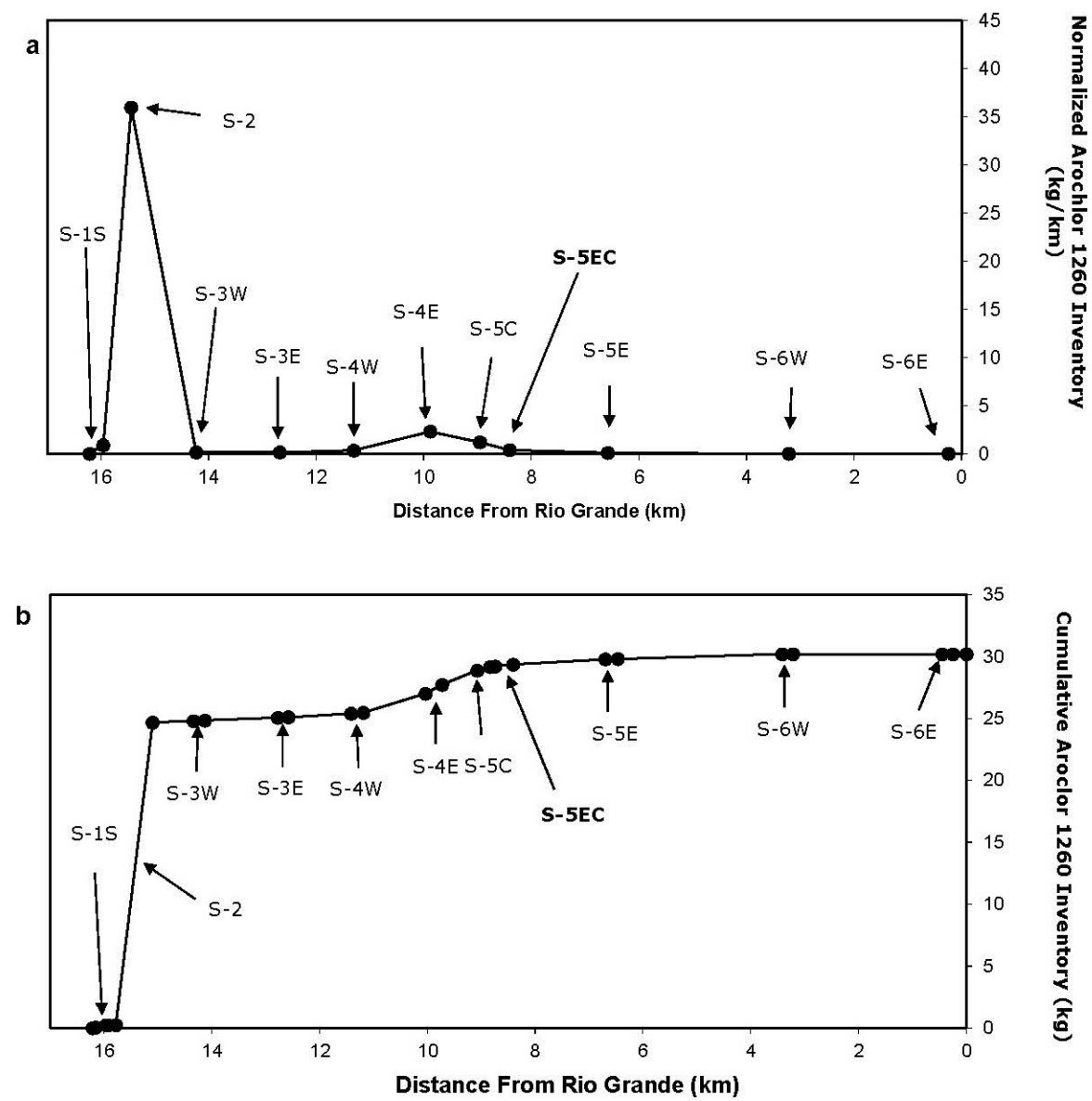


Figure 7.1-7 Estimated Aroclor-1260 inventory in Sandia Canyon; (a) normalized inventory (kg/km); (b) cumulative inventory (kg)



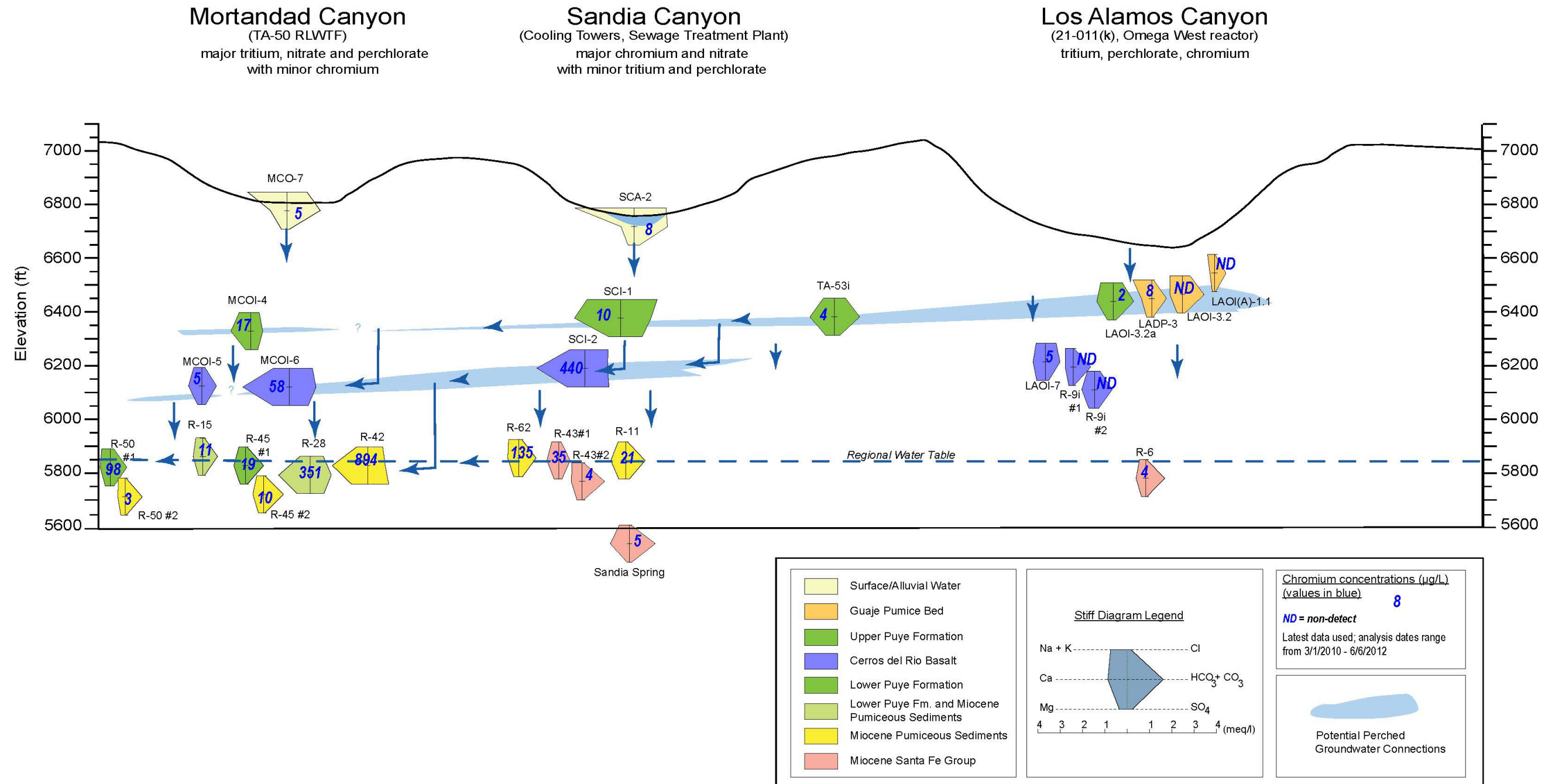


Figure 7.2-2 Conceptual model for mixing of groundwater types beneath various canyons, including major ion chemistry and chromium concentrations

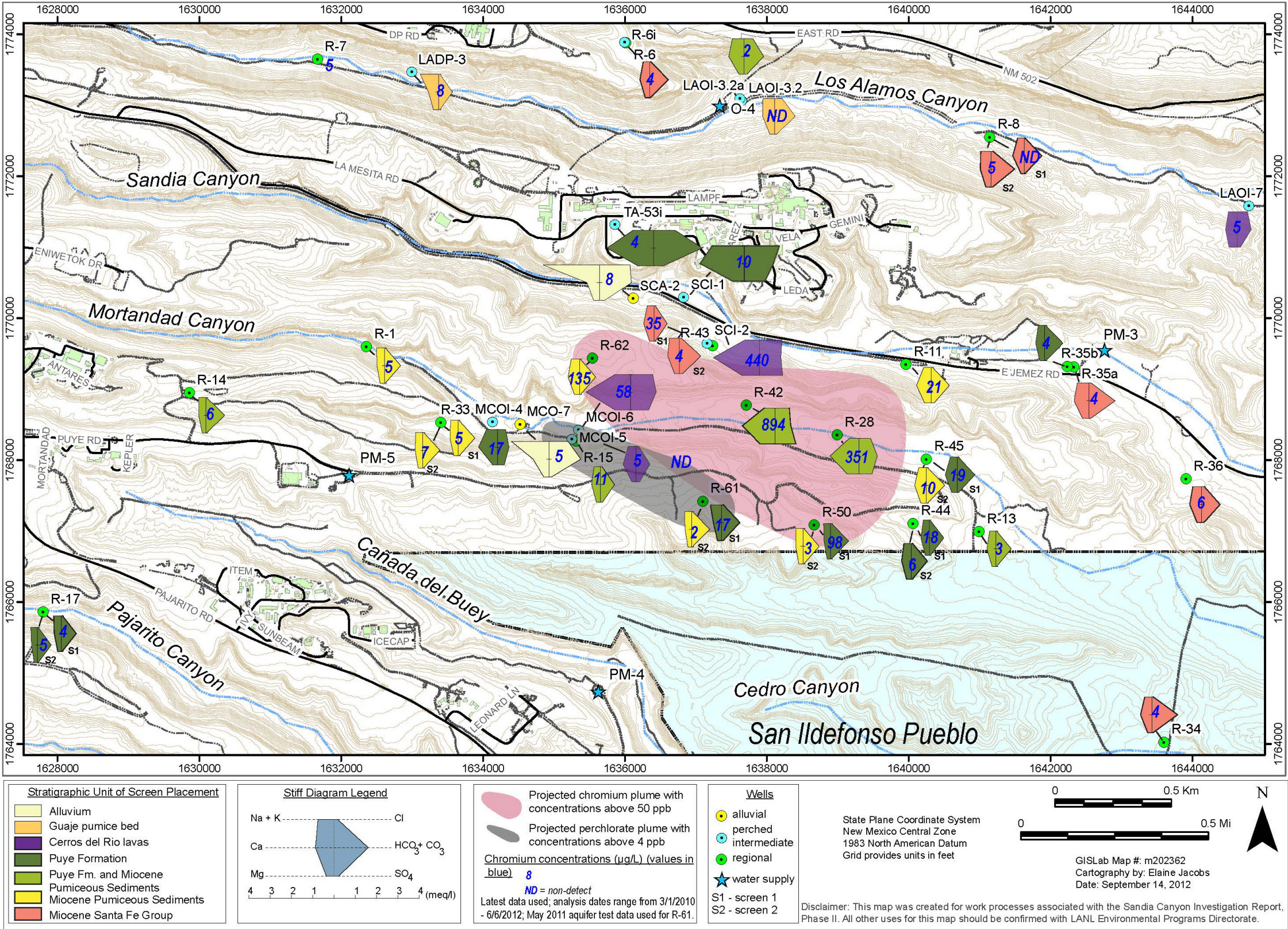


Figure 7.2-3 Major ion chemistry and chromium concentrations of perched-intermediate and regional groundwaters in the Chromium Investigation monitoring group wells

Table 2.3-1
Baseline and Augmented BMPs to Control Runoff and
Erosion in Sandia Canyon under the Laboratory's Individual Permit

SMA	SWMU	Baseline	Augmented
S-SMA-0.25	03-013(a)	x	
	03-052(f)		
S-SMA-1.1	03-029	x	
S-SMA-2	03-012(b)	x	
	03-045(b)		
	03-045(c)		
	03-056(c)		
S-SMA-2.01	03-052(b)	x	
S-SMA-2.8	03-014(c2)	x	
S-SMA-3.51	03-009(i)	x	
S-SMA-3.52	03-021	x	x
S-SMA-3.53	03-014(b2)	x	
S-SMA-3.6	60-007(b)	x	
S-SMA-3.7	53-012(e)	x	
S-SMA-3.71	53-001(a)	x	x
S-SMA-3.72	53-001(b)	x	x
S-SMA-3.95	20-002(a)	x	
S-SMA-4.1	53-014	x	
S-SMA-4.5	20-002(d)	x	
S-SMA-5	20-002(c)	x	
S-SMA-5.2	20-003(c)	x	
S-SMA-5.5	20-005	x	
S-SMA-6	72-001	x	

Note: Blank cells indicate that BMP is not augmented.

Table 3.2-1
Phase II Investigation Surface and Groundwater Sampling Locations and Rationale

Location Name	Location and Rationale
Base Flow (West to East)	
Surface Water Gaging Station E121	South Fork of Sandia Canyon, near power plant. Located west of wetland. Provides information about potential contaminant releases from TA-03 facilities to the west and baseline data about surface water entering the wetland.
Surface Water Gaging Station E122	North Fork of Sandia Canyon, near power plant. Located west of wetland. Downgradient of main contaminant release sites in Sandia Canyon. Provides baseline data about surface water entering the wetland.
Surface Water Gaging Station E123	Sandia Canyon just east of wetland. Location selected to monitor persistent surface water exiting the wetland.
Surface Water Sampling Station SCS-2	Middle Sandia Canyon. Location selected to monitor surface water near the eastern terminus of persistent base flow.
Surface Water Gaging Station E124	Surface water base flow collected at gage station E124. Location selected to monitor surface water in area where Sandia Canyon widens and surface water flow is ephemeral.
Springs	
Sandia Spring	Lower Sandia Canyon about 1 km west of the Rio Grande. Provides water-quality information near the Rio Grande.
Alluvial Groundwater Wells	
SCA-1	Upper Sandia Canyon in the wetland, straddling the TA-60 and TA-61 boundary. Provides alluvial groundwater monitoring location within the wetland.
SCA-2	Sandia Canyon at TA-53. Provide samples of alluvial groundwater where Sandia Canyon begins to widen and alluvium begins to thicken eastward. Part of main infiltration area for Sandia Canyon.
SCA-4	Sandia Canyon at TA-53. Provide samples of alluvial groundwater in area where persistent alluvial saturation occurs in thick canyon-floor alluvium. Part of main infiltration area for Sandia Canyon.
SCA-5	Sandia Canyon at TA-72. Provide samples of alluvial groundwater near the eastern limit of persistent alluvial saturation. Near eastern limit of main infiltration area for Sandia Canyon.
Perched-Intermediate Groundwater (West to East by Canyon)	
SCI-1	Sandia Canyon at TA-53. Provide samples of perched-intermediate groundwater in main infiltration area for Sandia Canyon.
SCI-2	Sandia Canyon at TA-53. Provide samples of perched-intermediate groundwater in main infiltration area for Sandia Canyon.
TA-53i	Mesita de los Alamos, north of Sandia Canyon at TA-53. Provide samples of perched-intermediate groundwater originating in Los Alamos Canyon that may affect groundwater beneath Sandia Canyon.
R-12, Screens 1 and 2	Sandia Canyon at TA-72 near eastern Laboratory boundary. Provide samples of perched-intermediate groundwater east of main infiltration area in Sandia Canyon.
MCOI-4	Mortandad Canyon at TA-05 near confluence with Ten Site Canyon. Existing monitoring well included in this investigation to provide information about the potential effects of perched-intermediate groundwater on water quality of the regional monitoring wells that are affected by chromium contamination.

Table 3.2-1 (continued)

Location Name	Location and Rationale
MCOI-5	Mortandad Canyon at TA-05 near regional well R-15. Existing monitoring well included in this investigation to provide information about the potential effects of perched-intermediate groundwater on water quality of the regional monitoring wells that are affected by chromium contamination.
MCOI-6	Mortandad Canyon at TA-05 near regional well R-15. Existing monitoring well included in this investigation to provide information about the potential effects of perched-intermediate groundwater on water quality of the regional monitoring wells that are affected by chromium contamination.
Regional Groundwater	
R-43	Sandia Canyon at TA-53. Provide samples of regional groundwater in main infiltration area for Sandia Canyon.
R-11	Sandia Canyon at TA-72. Provide samples of regional groundwater downgradient of main infiltration area for Sandia Canyon.
R-35a	Sandia Canyon at TA-72. Provide samples of regional groundwater upgradient of municipal supply well PM-3. The R-35a well screen is set at same depth as the top of PM-3 well screen.
R-35b	Sandia Canyon at TA-72. Provide samples of regional groundwater near the water table upgradient of municipal supply well PM-3.
R-36	Sandia Canyon at TA-72. Provide samples of regional groundwater for defining the nature and extent of chromium contamination in the regional aquifer. Provide samples of regional groundwater upgradient of municipal supply well PM-1.
R-1	Mortandad Canyon at TA-05 west of confluence with Ten Site Canyon. Existing monitoring well included in this investigation to provide water-quality information about the nature and extent of chromium contamination in the regional aquifer.
R-10	Sandia Canyon on San Ildefonso Pueblo land. Well screen deep within the aquifer provides samples of regional groundwater to monitor water quality along deep flow paths.
R-10a	Sandia Canyon on San Ildefonso Pueblo land. Well screen set in upper part of the aquifer provides samples of regional groundwater to monitor water quality along flow paths near the water table.
R-33	Ten Site Canyon at TA-05 near confluence with Mortandad Canyon. Existing monitoring well included in this investigation to provide water-quality information about the nature and extent of chromium contamination in the regional aquifer.
R-15	Mortandad Canyon at TA-05 east of confluence with Ten Site Canyon. Existing monitoring well included in this investigation to provide water-quality information about the nature and extent of chromium contamination in the regional aquifer.
R-62	On mesa top between Sandia Canyon and Mortandad Canyon at TA-60. New monitoring well installed as part of the Phase II investigation to provide samples of regional groundwater for defining the nature and extent of chromium contamination at western boundary of plume.
R-61	Mesa top south of Mortandad Canyon at TA-05. New monitoring well installed as part of the Phase II investigation to provide samples of regional groundwater for defining the nature and extent of chromium contamination at southern boundary of plume. Monitors water quality near the Laboratory's boundary with San Ildefonso Pueblo.
R-42	Mortandad Canyon at TA-05. Monitoring well installed as part of Phase I investigation to provide samples of regional groundwater for defining the nature and extent of chromium contamination. Located downgradient of main infiltration area for Sandia Canyon.

Table 3.2-1 (continued)

Location Name	Location and Rationale
R-50	Mesa top south of Mortandad Canyon at TA-05. New monitoring well installed as part of the Phase II investigation to provide samples of regional groundwater for defining the nature and extent of chromium contamination at southern boundary of plume. Monitors water quality near the Laboratory's boundary with San Ildefonso Pueblo.
R-28	Mortandad Canyon at TA-05. Existing monitoring well included in this investigation to provide water-quality information about the nature and extent of chromium contamination in the regional aquifer. Located downgradient of main infiltration area for Sandia Canyon.
R-45	Mortandad Canyon at TA-05. Monitoring well installed as part of Phase I investigation to provide samples of regional groundwater for defining the nature and extent of chromium contamination. Located downgradient of main infiltration area for Sandia Canyon. Contains two well screens: upper screen monitors groundwater near water table and lower screen monitors deeper flow paths.
R-44	Mortandad Canyon at TA-05. Monitoring well installed as part of Phase I investigation to provide samples of regional groundwater for defining the nature and extent of chromium contamination. Located downgradient of main infiltration area for Sandia Canyon. Contains two well screens: upper screen monitors groundwater near water table and lower screen monitors deeper flow paths.
R-13	Mortandad Canyon at TA-05. Existing monitoring well included in this investigation to provide water-quality information about the nature and extent of chromium contamination in the regional aquifer. Located downgradient of main infiltration area for Sandia Canyon. Monitors water quality near the Laboratory's boundary with San Ildefonso Pueblo.

Table 6.1-1
Phase II Water Screening Location, Synonym, and Reach

Location Name	Location Synonym	Reach ^a
Surface Water		
Sandia left fork at Asphalt Plant	E122	S-1N
Sandia right fork at Power Plant	E121	S-1S
Sandia below Wetlands	E123	S-2
Middle Sandia Canyon at terminus of persistent base flow	— ^b	S-3E and S-4W
Sandia above Firing Range	E124	S-4W and S-4E
Sandia Spring ^c	—	S-6E
Alluvial Groundwater		
SCA-1	—	—
SCA-1-DP ^d	—	—
SCA-2	—	—
SCA-4	—	—
SCA-5	—	—
Perched-Intermediate Groundwater		
SCI-1	—	—
SCI-2	—	—
R-12	—	—

Table 6.1-1 (continued)

Location Name	Location Synonym	Reach ^a
LADP-3	—	—
LAOI(a)-1.1	—	—
LAOI-3.2	—	—
LAOI-3.2a	—	—
LAOI-7	—	—
MCOI-4	—	—
MCOI-5	—	—
MCOI-6	—	—
R-3i	—	—
R-9i	—	—
TA-53i	—	—
Regional Aquifer (Sandia Monitoring Locations)		
R-43	—	—
R-11	—	—
R-35b	—	—
R-35a	—	—
R-36	—	—
R-10a	—	—
R-10	—	—
Sandia Spring ^b	—	—
Regional Aquifer (Mortandad Monitoring Locations)		
R-1	—	—
R-33	—	—
R-15	—	—
R-42	—	—
R-28	—	—
R-44	—	—
R-45	—	—
R-13	—	—
R-50	—	—
R-61	—	—
R-62	—	—
Regional Aquifer (Los Alamos Monitoring Locations)		
R-9	—	—
Regional Aquifer (Water-Supply Wells)		
O-4	G4OW	—
PM-1	G1MP	—
PM-3	G3MP	—
PM-5	G5MP	—

^a The listed location is either within the reach or else the nearest reach is listed; for locations midway between reaches, both reaches are listed.

^b — = Not applicable.

^c Sandia Spring is screened as part of the surface water dataset as well as part of the regional aquifer dataset.

^d Well SCA-1 has silted in and sampling is now done at SCA-1-DP (drive point).

**Table 6.2-1
Phase II Samples Collected and Analyses Performed for Sediment from Sandia Canyon**

Reach	Location ID	Top Depth (cm)	Bottom Depth (cm)	Sample ID	Field QC Type	Collection Date	Metals	Perchlorate	Pesticides	PCBs	PAHs	SVOCs	VOCs	TPH-DRO
S-5EC	SA-614443	0	70	CASA-11-22339	n/a ^a	7/13/2011	X ^b	X	X	X	X	X	X	X
S-5EC	SA-614444	0	58	CASA-11-22340	n/a	7/13/2011	X	X	X	X	X	X	X	X
S-5EC	SA-614445	40	80	CASA-11-22341	n/a	7/13/2011	X	X	X	X	X	X	X	X
S-5EC	SA-614446	0	13	CASA-11-22342	n/a	7/13/2011	X	X	X	X	X	X	X	X
S-5EC	SA-614447	0	30	CASA-11-22343	n/a	7/13/2011	X	X	X	X	X	X	X	X
S-5EC	SA-614448	12	35	CASA-11-22344	n/a	7/13/2011	X	X	X	X	X	X	X	X
S-5EC	SA-614448	35	62	CASA-11-22345	n/a	7/13/2011	X	X	X	X	X	X	X	X
S-5EC	SA-614450	0	9	CASA-11-22346	n/a	7/13/2011	X	X	X	X	X	X	X	X
S-5EC	SA-614451	0	15	CASA-11-22347	n/a	7/13/2011	X	X	X	X	X	X	X	X
S-5EC	SA-614451	15	34	CASA-11-22348	n/a	7/13/2011	X	X	X	X	X	X	X	X
S-5EC	SA-614453	0	16	CASA-11-22349	n/a	7/13/2011	X	X	X	X	X	X	X	X
S-5EC	SA-614453	22	54	CASA-11-22350	n/a	7/13/2011	X	X	X	X	X	X	X	X
S-5EC	SA-614455	1	14	CASA-11-22351	n/a	7/13/2011	X	X	X	X	X	X	X	X
S-5EC	SA-614455	14	42	CASA-11-22352	n/a	7/13/2011	X	X	X	X	X	X	X	X
S-5EC	SA-614457	0	54	CASA-11-22353	n/a	7/13/2011	X	X	X	X	X	X	X	X
S-5EC	SA-614457	54	96	CASA-11-22354	n/a	7/13/2011	X	X	X	X	X	X	X	X
S-5EC	SA-614459	0	12	CASA-11-22355	n/a	7/13/2011	X	X	X	X	X	X	X	X
S-5EC	SA-614460	0	50	CASA-11-22356	n/a	7/13/2011	X	X	X	X	X	X	X	X
S-5EC	SA-614461	23	51	CASA-11-22357	n/a	7/13/2011	X	X	X	X	X	X	X	X
S-5EC	SA-614462	28	50	CASA-11-22358	n/a	7/13/2011	X	X	X	X	X	X	X	X
S-5EC	SA-614443	0	70	CASA-11-22359	Field duplicate	7/13/2011	X	X	X	X	X	X	X	X
S-5EC	SA-614453	0	16	CASA-11-22360	Field duplicate	7/13/2011	X	X	X	X	X	X	X	X

^a n/a = Not applicable.

^b X = Analysis was performed.

Table 6.2-2
Inorganic COPCs in Sandia Canyon Phase II Sediment Samples

Location ID	Sample ID	Antimony	Cadmium	Chromium	Copper	Lead	Molybdenum	Perchlorate	Selenium	Silver	Zinc
SA-614443	CASA-11-22339	0.991 (U)	— ^a	—	12.7	—	—	—	0.93 (U)	—	—
SA-614444	CASA-11-22340	0.986 (U)	—	35.4	—	28.1	0.498 (J)	0.000892 (J)	0.989 (U)	—	—
SA-614445	CASA-11-22341	0.94 (U)	—	—	—	—	—	0.000565 (J)	0.965 (U)	—	—
SA-614446	CASA-11-22342	0.969 (U)	—	14.3	—	—	0.406 (J)	—	0.98 (U)	—	—
SA-614447	CASA-11-22343	0.989 (U)	—	—	—	—	—	—	0.889 (U)	—	—
SA-614448	CASA-11-22344	0.999 (U)	—	—	—	—	—	—	0.995 (U)	—	—
SA-614448	CASA-11-22345	1 (U)	—	—	—	—	—	—	0.978 (U)	—	—
SA-614450	CASA-11-22346	0.926 (U)	—	—	—	—	0.408 (J)	0.000661 (J)	0.967 (U)	—	—
SA-614451	CASA-11-22347	0.932 (U)	—	23.2	15.8	23	0.432 (J)	—	1 (U)	—	—
SA-614451	CASA-11-22348	0.944 (U)	—	—	—	23	—	—	0.913 (U)	—	—
SA-614453	CASA-11-22349	0.988 (U)	—	23.2	31.3	24.8	0.511 (J)	—	0.947 (U)	—	67.1 (J-)
SA-614453	CASA-11-22350	0.972 (U)	—	—	—	—	—	—	0.978 (U)	—	—
SA-614455	CASA-11-22351	0.951 (U)	0.488	40.4	14.4	28.9	0.645 (J)	—	0.932 (U)	1.3	87.2 (J-)
SA-614455	CASA-11-22352	0.979 (U)	—	30	—	20.8	0.534 (J)	—	0.957 (U)	—	63.1 (J-)
SA-614457	CASA-11-22353	0.95 (U)	—	—	—	—	—	—	0.934 (U)	—	—
SA-614457	CASA-11-22354	1 (U)	—	—	—	—	—	—	0.925 (U)	—	—
SA-614459	CASA-11-22355	0.988 (U)	—	34.8	—	20.5	0.564 (J)	0.000635 (J)	0.967 (U)	—	67.4 (J-)
SA-614460	CASA-11-22356	0.961 (U)	—	—	—	—	—	—	0.925 (U)	—	—
SA-614461	CASA-11-22357	0.916 (U)	—	25.2	—	—	—	—	0.914 (U)	—	—

Table 6.2-2 (continued)

Location ID	Sample ID	Antimony	Cadmium	Chromium	Copper	Lead	Molybdenum	Perchlorate	Selenium	Silver	Zinc
SA-614462	CASA-11-22358	0.955 (U)	—	23.2	—	26.5	0.639 (J)	—	0.904 (U)	—	—
BV (mg/kg)^b		0.83	0.4	10.5	11.2	19.7	na ^c	na	0.3	1	60.2
Phase II maximum detect		ND ^d	0.488	40.4	31.3	28.9	0.645	0.000892	ND	1.3	87.2
Phase I maximum detect		0.64	8.69	3740	223	690	44.4	0.0041	5.07	87.3	1140
% of Maximum		na	6%	1%	14%	4%	1%	22%	na	1%	8%

Notes: Values are in mg/kg. Values are maximum values greater than the sediment BV for analytes with a BV, and the maximum detected value for analytes without a BV. Data qualifiers are defined in Appendix A.

^a — = Not a COPC (not detected, not detected above BV).

^b BVs are from LANL (1998, 059730).

^c na = Not available.

^d ND = Not detected

Table 6.2-3
Organic COPCs in Sandia Canyon Phase II Sediment Samples

Sample Group	Field Sample ID	Location ID	Acenaphthene	Acetone	Aroclor-1254	Aroclor-1260	Benzo(a)anthracene	Benzo(a)pyrene	Benzo(b)fluoranthene	Benzo(g,h,i)perylene	Benzo(k)fluoranthene	Butanone[2-]	Chrysene	DDD[4,4'-]	DDE[4,4'-]	DDT[4,4'-]
Organic Chemical Detects per Sample, Standard UOM = mg/kg																
S-5EC	CASA-11-22339	SA-614443	— ^a	—	0.0748 (J)	0.0362	0.00172	—	—	—	—	—	—	—	—	—
S-5EC	CASA-11-22340	SA-614444	—	—	0.0327 (J)	0.0516	0.0195	0.0144 (J)	0.0211 (J)	0.021	—	—	0.0225	—	—	—
S-5EC	CASA-11-22342	SA-614446	—	—	—	0.0174	0.0121 (J)	0.0142	0.0248	0.0106	—	—	0.019	—	—	—
S-5EC	CASA-11-22343	SA-614447	—	—	—	0.0053	—	—	—	—	—	—	—	—	—	—
S-5EC	CASA-11-22344	SA-614448	0.0303 (J)	—	—	0.0127	—	—	—	—	—	—	—	—	—	—
S-5EC	CASA-11-22345	SA-614448	—	—	—	—	—	—	—	—	—	—	—	0.00045 (J)	—	0.00046 (J)
S-5EC	CASA-11-22346	SA-614450	—	—	—	0.0032 (J)	—	—	—	—	—	—	—	—	0.000393 (J)	0.00119 (J)
S-5EC	CASA-11-22347	SA-614451	—	0.0173	0.0419 (J)	0.0556	0.0366	0.0334	0.0328 (J)	0.0232	0.0147 (J)	0.00375 (J)	0.0433	—	—	—
S-5EC	CASA-11-22348	SA-614451	—	—	—	0.0023 (J)	—	—	—	—	—	—	—	—	—	—
S-5EC	CASA-11-22349	SA-614453	—	0.00771	0.0421 (J)	0.0544	0.0301	0.0264	0.0343	0.0216	0.0158 (J)	0.00181 (J)	0.0449	—	—	—
S-5EC	CASA-11-22350	SA-614453	—	0.00258 (J)	—	0.0016 (J)	—	—	—	—	—	—	—	—	—	—
S-5EC	CASA-11-22351	SA-614455	—	—	0.0592 (J)	0.0813	0.0527	0.0457	0.0724	0.0332	0.0251 (J)	—	0.0624	—	—	—
S-5EC	CASA-11-22352	SA-614455	—	—	0.0442 (J)	0.0575	0.0406	0.0268 (J)	0.0447	0.0234 (J)	0.0183 (J)	—	0.0271 (J)	—	—	—
S-5EC	CASA-11-22353	SA-614457	—	—	—	0.004	0.00239	—	—	—	—	—	—	—	—	—
S-5EC	CASA-11-22354	SA-614457	—	—	—	0.0091	—	0.00287	—	—	—	—	—	—	—	—
S-5EC	CASA-11-22355	SA-614459	—	0.00503 (J)	0.0427 (J)	0.0593	0.0324 (J)	0.0378	0.0605	0.0244 (J)	0.0214 (J)	0.00188 (J)	0.0368	—	—	—
S-5EC	CASA-11-22356	SA-614460	—	—	—	0.0062	—	—	—	—	—	—	—	—	—	—
S-5EC	CASA-11-22357	SA-614461	0.0306 (J)	—	—	0.0188	0.0118 (J)	0.0128 (J)	0.0175 (J)	0.00674	—	—	0.0104 (J)	—	—	—
S-5EC	CASA-11-22358	SA-614462	—	—	0.0286 (J)	0.0422	0.0202 (J)	0.0192 (J)	0.0351	0.0158 (J)	0.0132 (J)	—	0.0266	—	—	—
Phase II maximum detect			0.0306	0.0173	0.0748	0.0813	0.0527	0.0457	0.0724	0.0332	0.0251	0.00375	0.0624	0.00045	0.000393	0.00119
Phase I maximum detect			9.45	0.207	2.53	11	17	10.4	18.2	4.54	2.8	0.0339	13.4	0.036	ND ^b	ND
% of maximum			<1%	8%	3%	<1%	<1%	<1%	<1%	<1%	<1%	11%	<1%	1%	na ^c	na

Table 6.2-3 (continued)

Sample Group	Field Sample ID	Location ID	Diphenylamine	Fluoranthene	Fluorene	Indeno(1,2,3-cd)pyrene	Isopropyltoluene[4-]	Methylene Chloride	Phenanthrene	Pyrene	Tetrachloroethene	Total Petroleum Hydrocarbons Diesel Range Organics
Organic Chemical Detects per Sample, Standard UOM = mg/kg												
S-5EC	CASA-11-22339	SA-614443	—	0.00323	—	—	—	—	0.00198 (J)	0.00355	—	—
S-5EC	CASA-11-22340	SA-614444	—	0.0299	—	0.0104 (J)	—	—	0.0148 (J)	0.0354	0.000384 (J)	28.4 (J+)
S-5EC	CASA-11-22342	SA-614446	—	0.0275	—	—	—	0.00218 (J)	0.014 (J)	0.0242	0.000614 (J)	21 (J+)
S-5EC	CASA-11-22343	SA-614447	—	—	—	—	—	—	—	—	—	—
S-5EC	CASA-11-22344	SA-614448	—	—	—	—	—	—	—	—	0.000324 (J)	—
S-5EC	CASA-11-22345	SA-614448	—	—	0.00796 (J)	—	—	—	—	—	—	—
S-5EC	CASA-11-22346	SA-614450	—	—	—	—	0.000462 (J)	0.00385 (J)	—	—	0.000633 (J)	99.2 (J+)
S-5EC	CASA-11-22347	SA-614451	0.0693 (J)	0.0669	-	0.0137 (J)	—	0.00387 (J)	0.0334 (J)	0.0604	0.000614 (J)	35.5 (J+)
S-5EC	CASA-11-22348	SA-614451	—	—	—	—	—	—	—	—	—	—
S-5EC	CASA-11-22349	SA-614453	0.0948 (J)	0.0607	—	0.0128 (J)	—	0.00413 (J)	0.0269 (J)	0.0522	0.000465 (J)	29.4 (J+)
S-5EC	CASA-11-22350	SA-614453	—	—	—	—	0.00195	—	—	—	0.000581 (J)	24.5 (J+)
S-5EC	CASA-11-22351	SA-614455	—	0.0829	—	0.0231 (J)	—	—	0.0428	0.0845	0.000398 (J)	36 (J+)
S-5EC	CASA-11-22352	SA-614455	0.121 (J)	0.0607	—	0.0207 (J)	—	—	0.0268 (J)	0.06	0.000449 (J)	—
S-5EC	CASA-11-22353	SA-614457	—	0.00563	—	—	—	—	0.00222 (J)	0.00453	—	—
S-5EC	CASA-11-22354	SA-614457	—	-	—	—	—	—	—	0.00422	—	—
S-5EC	CASA-11-22355	SA-614459	—	0.0682	—	0.0244 (J)	—	0.00256 (J)	0.0355	0.0726	0.000524 (J)	25.3 (J+)
S-5EC	CASA-11-22356	SA-614460	—	0.00373	—	—	—	—	—	0.00235	—	—
S-5EC	CASA-11-22357	SA-614461	—	0.0215 (J)	—	—	0.00181	—	0.0178 (J)	0.0188 (J)	0.000595 (J)	—
S-5EC	CASA-11-22358	SA-614462	—	0.0397	—	0.0132 (J)	—	—	0.0199 (J)	0.0356	0.000456 (J)	—
Phase II maximum detect			0.121	0.0829	0.00796	0.0244	0.00195	0.00413	0.0428	0.0845	0.000633	99.2
Phase I maximum detect			ND	57.7	6.28	1.23	0.0798	ND	44.7	59.2	ND	2700
% of maximum			na	<1%	<1%	2%	2%	na	<1%	<1%	na	4%

Note: Values are in mg/kg. Data qualifiers are defined in Appendix A.

^a — = Not a COPC (not detected).

^b ND = Not detected.

^c na = Not available.

Table 6.3-1
Phase II Samples Collected and Analyses Performed for Surface Water Associated with Sandia Canyon

Location ID	Media Code	Media Description	Sample ID	Field Prep	Field QC Type	Collection Date	Dioxins Furans	DRO	General Chemistry	GRO	HERB	HEXP	Inorganic	LCMS MS. High Explosives	LCMS MS. Perchlorate	PCB congeners	PESTPCB	RAD	SVOC	VOC
Sandia above Firing Range	WT	WT	GF091100E12401	F	— ^a	10/13/2009	—	—	—	—	—	—	X ^b	—	—	—	—	—	—	—
Sandia above Firing Range	WT	WT	GU091100E12401	UF	—	10/13/2009	—	—	X	—	—	—	X	—	—	—	—	X	—	—
Sandia below Wetlands	WS	WS	CASA-09-10307	F	—	8/7/2009	—	—	X	—	—	—	X	—	X	—	—	—	—	—
Sandia below Wetlands	WS	WS	CASA-09-10309	UF	—	8/7/2009	—	—	X	—	—	—	X	—	—	—	X	X	X	X
Sandia below Wetlands	WT	WT	GF090800E12301	F	—	8/12/2009	—	—	—	—	—	—	X	—	—	—	—	—	—	—
Sandia below Wetlands	WT	WT	GU090800E12301	UF	—	8/12/2009	—	—	X	—	—	—	X	—	—	—	—	X	—	—
Sandia below Wetlands	WT	WT	GF090900E12301	F	—	8/23/2009	—	—	—	—	—	—	X	—	—	—	—	—	—	—
Sandia below Wetlands	WT	WT	GU090900E12301	UF	—	8/23/2009	—	—	X	—	—	—	X	—	—	—	—	X	—	—
Sandia below Wetlands	WT	WT	GF090900E12302	F	—	8/30/2009	—	—	—	—	—	—	X	—	—	—	—	—	—	—
Sandia below Wetlands	WT	WT	GU090900E12303	UF	—	9/6/2009	—	—	X	—	—	—	—	—	—	—	—	X	—	—
Sandia below Wetlands	WT	WT	GF090900E12303	F	—	9/10/2009	—	—	—	—	—	—	X	—	—	—	—	—	—	—
Sandia below Wetlands	WT	WT	GU090900E12304	UF	—	9/10/2009	—	—	X	—	—	—	X	—	—	—	—	X	—	—
Sandia below Wetlands	WT	WT	GF091000E12301	F	—	10/7/2009	—	—	—	—	—	—	X	—	—	—	—	—	—	—
Sandia below Wetlands	WT	WT	GU091000E12301	UF	—	10/7/2009	—	—	X	—	—	—	X	—	—	—	—	X	—	—
Sandia below Wetlands	WS	WS	CASA-10-3594	F	—	11/4/2009	—	—	X	—	—	—	X	—	X	—	—	—	—	—
Sandia below Wetlands	WS	WS	CASA-10-3595	UF	—	11/4/2009	—	—	X	—	—	—	X	—	—	—	X	—	—	X
Sandia below Wetlands	WS	WS	CASA-10-3892	F	—	11/11/2009	—	—	—	—	—	—	X	—	—	—	—	—	—	—
Sandia below Wetlands	WS	WS	CASA-10-9411	F	—	1/29/2010	—	—	X	—	—	—	X	—	X	—	—	—	—	—
Sandia below Wetlands	WS	WS	CASA-10-9412	UF	—	1/29/2010	—	—	X	—	—	—	X	—	—	—	X	—	—	X
Sandia below Wetlands	WS	WS	CASA-10-9834	F	—	1/29/2010	—	—	—	—	—	—	X	—	—	—	—	—	—	—
Sandia below Wetlands	WS	WS	CASA-10-16687	F	—	5/13/2010	—	—	X	—	—	—	X	—	X	—	—	—	—	—
Sandia below Wetlands	WS	WS	CASA-10-16688	UF	—	5/13/2010	—	—	X	—	—	—	X	—	—	—	X	—	—	X
Sandia below Wetlands	WS	WS	CASA-10-16691	F	Field Duplicate	5/13/2010	—	—	X	—	—	—	X	—	X	—	—	—	—	—
Sandia below Wetlands	WS	WS	CASA-10-16692	UF	Field Duplicate	5/13/2010	—	—	X	—	—	—	X	—	—	—	X	—	—	X
Sandia below Wetlands	WS	WS	CASA-10-22573	UF	—	7/12/2010	—	—	—	—	—	—	—	—	—	—	—	X	X	X
Sandia below Wetlands	WS	WS	CASA-10-22575	UF	Field Duplicate	7/12/2010	—	—	—	—	—	—	—	—	—	—	—	X	X	X
Sandia below Wetlands	WT	WT	WTESR-10-19794	UF	—	10/2/2010	—	—	X	—	—	—	—	—	—	—	—	—	—	—
Sandia below Wetlands	WT	WT	WTESR-10-19978	F	—	10/2/2010	—	—	—	—	—	—	X	—	—	—	—	—	—	—

Table 6.3-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Prep	Field QC Type	Collection Date	Dioxins Furans	DRO	General Chemistry	GRO	HERB	HEXP	Inorganic	LCMS MS. High Explosives	LCMS MS. Perchlorate	PCB congeners	PESTPCB	RAD	SVOC	VOC
Sandia below Wetlands	WT	WT	WTESR-10-19982	UF	—	10/2/2010	—	—	—	—	—	—	X	—	—	—	—	—	—	—
Sandia below Wetlands	WT	WT	WTESR-10-20050	UF	—	10/2/2010	—	—	—	—	—	—	—	—	—	X	—	—	—	—
Sandia below Wetlands	WT	WT	WTESR-10-20090	UF	—	10/2/2010	—	—	—	—	—	—	—	—	—	—	—	X	—	—
Sandia below Wetlands	WT	WT	WTESR-10-20130	UF	—	10/2/2010	—	—	—	—	—	—	—	—	—	—	—	X	—	—
Sandia below Wetlands	WT	WT	WTESR-10-20170	UF	—	10/2/2010	—	—	X	—	—	—	—	—	—	—	—	—	—	—
Sandia below Wetlands	WS	WS	CASA-11-1334	UF	—	11/11/2010	—	—	X	—	—	—	X	—	—	X	X	X	X	X
Sandia below Wetlands	WS	WS	CASA-11-1335	F	—	11/11/2010	—	—	X	—	—	—	X	—	X	—	—	—	—	—
Sandia below Wetlands	WS	WS	CASA-11-10788	UF	—	5/17/2011	—	—	X	—	—	—	X	—	—	X	X	—	—	—
Sandia below Wetlands	WS	WS	CASA-11-10789	F	—	5/17/2011	—	—	X	—	—	—	X	—	X	—	—	—	—	—
Sandia below Wetlands	WT	WT	WTESR-11-16366	UF	—	7/28/2011	—	—	X	—	—	—	—	—	—	—	—	—	—	—
Sandia below Wetlands	WT	WT	WTESR-11-16419	UF	—	7/28/2011	—	—	X	—	—	—	—	—	—	—	—	—	—	—
Sandia below Wetlands	WT	WT	WTESR-11-16562	F	—	7/28/2011	—	—	—	—	—	—	X	—	—	—	—	—	—	—
Sandia below Wetlands	WT	WT	WTESR-11-16566	UF	—	7/28/2011	—	—	—	—	—	—	X	—	—	—	—	—	—	—
Sandia below Wetlands	WT	WT	WTESR-11-16886	UF	—	7/28/2011	—	—	—	—	—	—	—	—	—	X	—	—	—	—
Sandia below Wetlands	WT	WT	WTESR-11-17002	UF	—	7/28/2011	—	—	—	—	—	—	—	—	—	—	—	X	—	—
Sandia below Wetlands	WT	WT	WTESR-11-17230	UF	—	7/28/2011	—	—	—	—	—	—	—	—	—	—	—	X	—	—
Sandia below Wetlands	WT	WT	WTESR-11-25750	UF	—	7/28/2011	—	—	X	—	—	—	—	—	—	—	—	—	—	—
Sandia below Wetlands	WT	WT	WTESR-11-25751	UF	—	7/28/2011	—	—	X	—	—	—	—	—	—	—	—	—	—	—
Sandia below Wetlands	WT	WT	WTESR-11-25752	UF	—	7/28/2011	—	—	X	—	—	—	—	—	—	—	—	—	—	—
Sandia below Wetlands	WT	WT	WTESR-11-25753	UF	—	7/28/2011	—	—	X	—	—	—	—	—	—	—	—	—	—	—
Sandia below Wetlands	WT	WT	WTESR-11-25754	UF	—	7/28/2011	—	—	X	—	—	—	—	—	—	—	—	—	—	—
Sandia below Wetlands	WT	WT	WTESR-11-16367	UF	—	8/4/2011	—	—	X	—	—	—	—	—	—	—	—	—	—	—
Sandia below Wetlands	WT	WT	WTESR-11-16418	UF	—	8/4/2011	—	—	X	—	—	—	—	—	—	—	—	—	—	—
Sandia below Wetlands	WT	WT	WTESR-11-16563	F	—	8/4/2011	—	—	—	—	—	—	X	—	—	—	—	—	—	—
Sandia below Wetlands	WT	WT	WTESR-11-16567	UF	—	8/4/2011	—	—	—	—	—	—	X	—	—	—	—	—	—	—
Sandia below Wetlands	WT	WT	WTESR-11-16887	UF	—	8/4/2011	—	—	—	—	—	—	—	—	—	X	—	—	—	—
Sandia below Wetlands	WT	WT	WTESR-11-17003	UF	—	8/4/2011	—	—	—	—	—	—	—	—	—	—	—	X	—	—
Sandia below Wetlands	WT	WT	WTESR-11-17231	UF	—	8/4/2011	—	—	—	—	—	—	—	—	—	—	—	X	—	—
Sandia left fork at Asphalt Plant	WT	WT	GU090800E12201	UF	—	8/12/2009	—	—	X	—	—	—	X	—	—	—	—	—	—	—

Table 6.3-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Prep	Field QC Type	Collection Date	Dioxins Furans	DRO	General Chemistry	GRO	HERB	HEXP	Inorganic	LCMS MS. High Explosives	LCMS MS. Perchlorate	PCB congeners	PESTPCB	RAD	SVOC	VOC
Sandia left fork at Asphalt Plant	WT	WT	GU091000E12201	UF	—	10/7/2009	—	—	X	—	—	—	X	—	—	—	—	—	—	—
Sandia right fork at Power Plant	WS	WS	CASA-09-10304	UF	—	8/7/2009	—	—	X	—	—	—	X	—	—	—	X	X	X	X
Sandia right fork at Power Plant	WS	WS	CASA-09-10305	F	—	8/7/2009	—	—	X	—	—	—	X	—	X	—	—	—	—	—
Sandia right fork at Power Plant	WS	WS	CASA-10-3558	UF	—	11/2/2009	—	—	X	—	—	—	X	—	—	—	X	—	—	X
Sandia right fork at Power Plant	WS	WS	CASA-10-3559	F	—	11/2/2009	—	—	X	—	—	—	X	—	X	—	—	—	—	—
Sandia right fork at Power Plant	WS	WS	CASA-10-9111	UF	—	2/1/2010	—	—	X	—	—	—	X	—	—	—	X	—	—	X
Sandia right fork at Power Plant	WS	WS	CASA-10-9112	F	—	2/1/2010	—	—	X	—	—	—	X	—	X	—	—	—	—	—
Sandia right fork at Power Plant	WS	WS	CASA-10-16680	UF	—	5/7/2010	—	—	X	—	—	—	X	—	—	—	X	—	—	X
Sandia right fork at Power Plant	WS	WS	CASA-10-16681	F	—	5/7/2010	—	—	X	—	—	—	X	—	X	—	—	—	—	—
Sandia right fork at Power Plant	WS	WS	CASA-10-22569	UF	—	7/12/2010	—	—	—	—	—	—	—	—	—	—	—	X	X	X
Sandia right fork at Power Plant	WS	WS	CASA-11-1337	UF	—	11/9/2010	—	—	X	—	—	—	X	—	—	X	X	X	X	X
Sandia right fork at Power Plant	WS	WS	CASA-11-1339	F	—	11/9/2010	—	—	X	—	—	—	X	—	X	—	—	—	—	—
Sandia right fork at Power Plant	WS	WS	CASA-11-1340	UF	Field Duplicate	11/9/2010	—	—	X	—	—	—	X	—	—	X	X	X	X	X
Sandia right fork at Power Plant	WS	WS	CASA-11-1341	F	Field Duplicate	11/9/2010	—	—	X	—	—	—	X	—	X	—	—	—	—	—
Sandia right fork at Power Plant	WS	WS	CASA-11-10791	UF	—	5/19/2011	—	—	X	—	—	—	X	—	—	X	X	—	—	—
Sandia right fork at Power Plant	WS	WS	CASA-11-10792	F	—	5/19/2011	—	—	X	—	—	—	X	—	X	—	—	—	—	—
Sandia Spring	WG	WGRS	CAWR-09-12481	UF	—	9/23/2009	—	—	X	—	—	—	X	—	—	—	—	X	X	X
Sandia Spring	WG	WGRS	CAWR-09-12483	F	—	9/23/2009	—	—	X	—	—	—	X	—	X	—	—	—	—	—
Sandia Spring	WG	WGRS	CAWR-10-14081	UF	—	3/23/2010	—	—	X	—	—	—	X	—	—	—	—	X	X	X
Sandia Spring	WG	WGRS	CAWR-10-14082	F	—	3/23/2010	—	—	X	—	—	—	X	—	X	—	—	—	—	—
Sandia Spring	WG	WGRS	CAWR-10-14084	UF	Field Duplicate	3/23/2010	—	—	X	—	—	—	X	—	—	—	—	X	X	X
Sandia Spring	WG	WGRS	CAWR-10-14085	F	Field Duplicate	3/23/2010	—	—	X	—	—	—	X	—	X	—	—	—	—	—
South Fork of Sandia at E122	WS	WS	CASA-09-10313	UF	—	8/13/2009	—	—	X	—	—	—	X	—	—	—	X	X	X	X
South Fork of Sandia at E122	WS	WS	CASA-09-10315	F	—	8/13/2009	—	—	X	—	—	—	X	—	X	—	—	—	—	—
South Fork of Sandia at E122	WS	WS	CASA-09-10317	F	Field Duplicate	8/13/2009	—	—	X	—	—	—	X	—	X	—	—	—	—	—
South Fork of Sandia at E122	WS	WS	CASA-09-10318	UF	Field Duplicate	8/13/2009	—	—	X	—	—	—	X	—	—	—	X	X	X	X
South Fork of Sandia at E122	WS	WS	CASA-10-3561	F	—	11/2/2009	—	—	X	—	—	—	X	—	X	—	—	—	—	—
South Fork of Sandia at E122	WS	WS	CASA-10-3562	UF	—	11/2/2009	—	—	X	—	—	—	X	—	—	—	X	—	—	X
South Fork of Sandia at E122	WS	WS	CASA-10-3592	F	Field Duplicate	11/2/2009	—	—	X	—	—	—	X	—	X	—	—	—	—	—

Table 6.3-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Prep	Field QC Type	Collection Date	Dioxins Furans	DRO	General Chemistry	GRO	HERB	HEXP	Inorganic	LCMS MS. High Explosives	LCMS MS. Perchlorate	PCB congeners	PESTPCB	RAD	SVOC	VOC
South Fork of Sandia at E122	WS	WS	CASA-10-3593	UF	Field Duplicate	11/2/2009	—	—	X	—	—	—	X	—	—	—	X	—	—	X
South Fork of Sandia at E122	WS	WS	CASA-10-3891	F	—	11/20/2009	—	—	—	—	—	—	X	—	—	—	—	—	—	—
South Fork of Sandia at E122	WS	WS	CASA-10-9405	F	—	2/1/2010	—	—	X	—	—	—	X	—	X	—	—	—	—	—
South Fork of Sandia at E122	WS	WS	CASA-10-9406	UF	—	2/1/2010	—	—	X	—	—	—	X	—	—	—	X	—	—	X
South Fork of Sandia at E122	WS	WS	CASA-10-9409	F	Field Duplicate	2/1/2010	—	—	X	—	—	—	X	—	X	—	—	—	—	—
South Fork of Sandia at E122	WS	WS	CASA-10-9410	UF	Field Duplicate	2/1/2010	—	—	X	—	—	—	X	—	—	—	X	—	—	X
South Fork of Sandia at E122	WS	WS	CASA-10-9841	F	—	2/1/2010	—	—	—	—	—	—	X	—	—	—	—	—	—	—
South Fork of Sandia at E122	WS	WS	CASA-10-9833	F	—	3/1/2010	—	—	—	—	—	—	X	—	—	—	—	—	—	—
South Fork of Sandia at E122	WS	WS	CASA-10-16683	UF	—	5/7/2010	—	—	X	—	—	—	X	—	—	—	X	—	—	X
South Fork of Sandia at E122	WS	WS	CASA-10-16685	F	—	5/7/2010	—	—	X	—	—	—	X	—	X	—	—	—	—	—
South Fork of Sandia at E122	WS	WS	CASA-10-22572	UF	—	7/12/2010	—	—	—	—	—	—	-	—	—	—	—	X	X	X
South Fork of Sandia at E122	WS	WS	CASA-11-1342	UF	—	11/9/2010	—	—	X	—	—	—	X	—	—	X	X	X	X	X
South Fork of Sandia at E122	WS	WS	CASA-11-1343	F	—	11/9/2010	—	—	X	—	—	—	X	—	X	—	—	—	—	—
South Fork of Sandia at E122	WS	WS	CASA-11-10793	UF	—	5/19/2011	—	—	X	—	—	—	X	—	—	X	X	—	—	—
South Fork of Sandia at E122	WS	WS	CASA-11-10794	F	—	5/19/2011	—	—	X	—	—	—	X	—	X	—	—	—	—	—

^a — = analysis was not performed.

^b X = analysis was performed.

Table 6.3-2
Stormwater Screen for Phase II Samples from Sandia Canyon

Location	Class	Analyte	Field Prep	Units	Total Samples	Number of Detects	Average Detects	Minimum Detect	Maximum Detect	Comparison Value	Count Greater than Value
Sandia above Firing Range	RAD	Gross alpha	UF	pCi/L	1	1	57.6	57.6	57.6	15	1
Sandia below Wetlands	INORGANIC	Copper	F	µg/L	8	8	8.61	4.7	17.5	9	2
Sandia below Wetlands	ORGANIC	Total PCB	UF	µg/L	3	3	0.721	0.464	0.903	0.00064	3
Sandia below Wetlands	RAD	Gross alpha	UF	pCi/L	8	7	9.56	5.79	17.7	15	2

Notes: UF = Unfiltered; F = filtered.

Table 6.3-3
Inorganic COPCs in Phase II Filtered Nonstorm-Related Surface-Water Samples from Sandia Canyon

Location	Aluminum	Ammonia as Nitrogen	Antimony	Arsenic	Barium	Boron	Bromide	Calcium	Chloride	Chromium	Cobalt	Copper	Fluoride	Iron	Lead	Magnesium	Manganese	Molybdenum	Nickel	Nitrate-Nitrite as Nitrogen	Perchlorate	Potassium	Selenium	Silicon Dioxide	Sodium	Strontium	Sulfate	Thallium	Total Phosphate as Phosphorus	Uranium	Vanadium	Zinc
	µg/L	mg/L	µg/L	µg/L	µg/L	µg/L	mg/L	mg/L	mg/L	µg/L	µg/L	µg/L	mg/L	µg/L	µg/L	mg/L	ug/L	µg/L	µg/L	mg/L	µg/L	mg/L	µg/L	mg/L	mg/L	µg/L	mg/L	µg/L	mg/L	µg/L	µg/L	µg/L
Designated Perennial																																
Comparison Value	1370	3.2	640	9	na ^a	5000	na	na	na	74	1000	9	na	na	3	na	1650	na	52	132	na	na	50	na	na	na	na	0.47	na	na	100	121
Middle Sandia at WP terminus	— ^b	0.058 (J-)	—	3.31 (J)	36.7	79	0.361	35.1	90.1	7.66 (J)	—	6.5 (J)	0.419	133	—	9.61	5.31 (J)	9.83	2.27	1.1 (J)	3.4	17.8	—	105	94.2	156	34.4	0.541 (J)	3.08 (J)	1.5	12.4	18.8
Sandia below Wetlands	121 (J)	0.184 (J)	0.601 (J)	5.57	233 (J)	71	0.667	71.4	1820	5.95 (J)	—	6.72 (J)	0.855	281	0.687 (J)	46.6	103	12	5.63 (J-)	1 (J)	2.72	571	—	139	912	461	424	0.499 (J)	2.68	1.37	19.2	42.9
Sandia right fork at Power Plant	75.5 (J)	0.059 (J-)	—	3.75 (J)	64	90.1	0.434	37	176	5.19 (J)	1.8 (J)	6.39 (J)	0.575	130	—	10.2	15 (J)	29.6	1.48 (J)	3.64	5.77	18.7	1.16 (J)	130	149	182	22	—	2.89	1.17	19.2 (J)	52.6
South Fork of Sandia at E122	137 (J)	0.303 (J)	0.985 (J)	9.39	103	99	9.11	47.6	64	13.7	—	32.8	0.963	95.5 (J)	0.797 (J)	13.6	74.6 (J)	6.62	1.1 (J)	1.19 (J)	1.13 (J)	46.6	18.6	196	77.9	245	123	—	2.79	1.7	38	21.3
Ephemeral																																
Comparison Value	—	—	—	—	na	5000	—	na	na	570	—	—	na	—	—	na	2986	na	470	132	na	na	—	na	na	na	na	—	—	na	100	—
Sandia Spring	—	—	—	—	77.8	18.6 (J)	—	27.6	3.23	5.15 (J)	—	—	0.644 (J-)	—	—	1.91	16.7	1.07	0.844 (J)	0.41	0.482	2.65	—	48.7	15	340	7.41	—	—	2.28	10.9	—

Note: Highlighted values are greater than the comparison value. Data qualifiers are defined in Appendix A.

^a na = Not available.

^b — = Not a COPC at that location (not above comparison value, not detected, or not analyzed).

Table 6.3-4
Inorganic COPCs in Phase II Nonfiltered Nonstorm-Related Surface-Water Samples from Sandia Canyon

Locations	Aluminum	Antimony	Arsenic	Barium	Beryllium	Boron	Calcium	Chromium	Cobalt	Copper	Cyanide (Total)	Iron	Lead	Magnesium	Manganese	Molybdenum	Nickel	Potassium	Selenium	Silver	Sodium	Strontium	Thallium	Total Kjeldahl Nitrogen	Uranium	Vanadium	Zinc
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	mg/L	µg/L	µg/L	µg/L	mg/L	µg/L	µg/L	mg/L	µg/L	µg/L	µg/L	mg/L	µg/L	µg/L	mg/L	µg/L	µg/L	mg/L	µg/L	µg/L	µg/L
Designated Perennial																											
Comparison Value	na ^a	na	na	na	na	na	na	na	na	na	0.0052	na	na	na	na	1895	na	na	5	na	na	na	na	na	na	na	na
Middle Sandia at WP terminus	970	— ^b	4.89 (J)	41.9	1.54 (J)	82.9	35.7	11.5	—	8.54 (J)	—	711	1.1 (J)	9.91	17.3	10.1	1.95 (J)	18.1	—	—	96.3	159	0.487 (J)	0.463	1.51	16.9	20.4
Sandia below Wetlands	517	0.712 (J)	5.59	237 (J)	—	68	72.4	39.1	—	13.9	0.00266 (J)	703 (J)	2.59	46.6	113	10.5	5.12 (J)	599	—	1.01	963	467	—	0.447	1.53	19	63.3
Sandia right fork at Power Plant	106 (J)	—	3.13 (J)	64.6	1.03 (J)	86.6	36.6	5.83 (J)	2.7 (J)	8.94 (J)	0.00247 (J)	227	1.21 (J)	10.8	44.4 (J)	30.4	1.46 (J)	24.3	1.05 (J)	—	121	174	0.49 (J)	0.687 (J)	0.84	15.7	85.3
South Fork of Sandia at E122	275	1.03 (J)	7.87	105	—	100	48.6	13.9	—	60.8	0.00244 (J)	201	0.989 (J)	13.8	67.9 (J)	6.36	1.23 (J)	46.3	15.3	—	78.9	251	—	3.43	1.77	39.4	24.7
Ephemeral																											
Comparison Value	—	—	na	na	—	na	na	na	—	—	—	na	—	na	na	7920	na	na	—	—	na	na	—	—	na	na	—
Sandia Spring	—	—	2.32 (J)	77.9	—	19.4 (J)	27.8	5.26 (J)	—	—	—	31.5 (J)	—	1.94	17	1.07	0.781 (J)	2.66	—	—	15.1	343	—	—	2.26	11	—

Note: Highlighted values are greater than the comparison value. Data qualifiers are defined in Appendix A.

^a na = Not available.

^b — = Not a COPC at that location (not above comparison value, not detected, or not analyzed).

Table 6.3-5
Organic COPCs in Phase II Nonfiltered
Nonstorm-Related Surface-Water Samples from Sandia Canyon

Locations	Acetone	Benzene	Benzoic Acid	Bromodichloromethane	Bromoform	Chlorodibromomethane	Chloroform	Chloromethane	Total PCB
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Designated Perennial									
Comparison Value	na ^a	510	na	170	1400	130	4700	na	0.00064
Middle Sandia at WP terminus	— ^b	—	—	—	—	—	—	0.36 (J)	0.00248
Sandia below Wetlands	—	—	14.8 (J)	—	—	—	0.443 (J)	—	0.0512
Sandia right fork at Power Plant	—	—	—	7.07	2.99	4.76	7.63	—	0.00938
South Fork of Sandia at E122	11	0.32 (J)	—	—	—	—	—	—	0.00339
Ephemeral									
Comparison Value	—	—	—	—	—	—	—	—	—
Sandia Spring	—	—	—	—	—	—	—	—	—

Note: Highlighted values are greater than the comparison value. Data qualifiers are defined in Appendix A.

^a na = Not available.

^b — = Not a COPC at that location (not above comparison value, not detected, or not analyzed).

Table 6.3-6
Radionuclide COPCs in Phase II Nonfiltered
Nonstorm-Related Surface-Water Samples from Sandia Canyon

Locations	Gross alpha	Gross beta	Uranium-234	Uranium-238
	pCi/L	pCi/L	pCi/L	pCi/L
Designated Perennial				
Comparison Value	— ^a	na ^b	200	200
Middle Sandia at WP terminus	—	12.5	0.732	0.428
Sandia below Wetlands	—	14.9	0.813	0.386
Sandia right fork at Power Plant	—	13	0.564	0.265
South Fork of Sandia at E122	—	22.5	1.07	0.53
Ephemeral				
Comparison Value	15	na	200	200
Sandia Spring	3.6	7.15	0.707	0.322

^a — = Not a COPC at that location (not above comparison value, not detected, or not analyzed).

^b na = Not available.

Table 6.4-1
Phase II Samples Collected and Analyses Performed for Groundwater Associated with Sandia Canyon

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
O-4	WG	Supply	CALA-09-11583	UF	— ^a	8/11/2009	—	—	X ^b	—	—	—	X	X	—	—	X	—	—
O-4	WG	Supply	CALA-09-11584	F	—	8/11/2009	—	—	—	—	—	—	X	—	—	—	—	—	—
O-4	WG	Supply	CALA-10-4779	UF	—	11/17/2009	—	X	—	—	—	—	X	X	—	—	X	—	—
O-4	WG	Supply	CALA-10-4780	F	—	11/17/2009	—	—	—	—	—	—	X	—	—	—	—	—	—
O-4	WG	Supply	CALA-10-12104	UF	—	3/2/2010	—	—	—	—	—	—	X	X	—	—	X	—	—
O-4	WG	Supply	CALA-10-12105	F	—	3/2/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
O-4	WG	Supply	CALA-10-17219	UF	—	5/19/2010	—	X	X	—	—	X	X	X	—	X	X	X	X
O-4	WG	Supply	CALA-10-17220	F	—	5/19/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
O-4	WG	Supply	CALA-10-17233	UF	Field Duplicate	5/19/2010	—	X	X	—	—	X	X	X	—	X	X	X	X
O-4	WG	Supply	CALA-10-17234	F	Field Duplicate	5/19/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
O-4	WG	Supply	CALA-10-25073	UF	—	9/14/2010	—	—	X	—	—	—	X	X	—	—	X	—	—
O-4	WG	Supply	CALA-10-25074	F	—	9/14/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
O-4	WG	Supply	CALA-11-4769	UF	—	2/15/2011	—	—	—	—	—	—	X	X	—	—	X	—	—
O-4	WG	Supply	CALA-11-4770	F	—	2/15/2011	—	—	—	—	—	—	X	—	—	—	—	—	—
O-4	WG	Supply	CALA-11-11731	UF	—	5/24/2011	—	X	X	—	—	X	X	X	—	X	X	X	X
O-4	WG	Supply	CALA-11-11732	F	—	5/24/2011	—	—	—	—	—	—	X	—	—	—	—	—	—
O-4	WG	Supply	CALA-11-11733	UF	Field Duplicate	5/24/2011	—	X	X	—	—	X	X	X	—	X	X	X	X
O-4	WG	Supply	CALA-11-11734	F	Field Duplicate	5/24/2011	—	—	—	—	—	—	X	—	—	—	—	—	—
O-4	WG	Supply	CALA-11-26771	UF	—	8/30/2011	—	—	—	—	—	—	X	X	—	—	X	—	—
O-4	WG	Supply	CALA-11-26772	F	—	8/30/2011	—	—	—	—	—	—	X	—	—	—	—	—	—
O-4	WG	Supply	CALA-11-26773	F	Field Duplicate	8/30/2011	—	—	—	—	—	—	X	—	—	—	—	—	—
O-4	WG	Supply	CALA-11-26774	UF	Field Duplicate	8/30/2011	—	—	—	—	—	—	X	X	—	—	X	—	—
O-4	WG	Supply	CALA-12-1739	UF	—	12/13/2011	—	X	—	—	—	—	X	X	—	—	X	—	—
O-4	WG	Supply	CALA-12-1740	F	—	12/13/2011	—	—	—	—	—	—	X	—	—	—	—	—	—
O-4	WG	Supply	CALA-12-1899	UF	Field Duplicate	12/13/2011	—	X	—	—	—	—	X	X	—	—	X	—	—
O-4	WG	Supply	CALA-12-1900	F	Field Duplicate	12/13/2011	—	—	—	—	—	—	X	—	—	—	—	—	—

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
O-4	W	Supply	CALA-12-12461	F	Field Duplicate	3/20/2012	—	—	—	—	—	—	X	—	—	—	—	—	—
O-4	W	Supply	CALA-12-12462	UF	Field Duplicate	3/20/2012	—	—	—	—	—	—	X	X	—	—	X	—	—
O-4	W	Supply	CALA-12-12465	UF	—	3/20/2012	—	—	—	—	—	—	X	X	—	—	X	—	—
O-4	W	Supply	CALA-12-12472	F	—	3/20/2012	—	—	—	—	—	—	X	—	—	—	—	—	—
O-4	WG	Supply	CALA-12-17384	UF	—	6/20/2012	—	X	X	—	—	X	X	X	—	X	X	X	X
O-4	WG	Supply	CALA-12-17396	F	—	6/20/2012	—	—	—	—	—	—	X	—	—	—	—	—	—
PM-1	WG	Supply	CALA-09-11586	F	—	8/11/2009	—	—	—	—	—	—	X	—	—	—	—	—	—
PM-1	WG	Supply	CALA-10-4783	UF	—	11/17/2009	—	—	—	—	—	—	-	X	—	—	X	—	—
PM-1	WG	Supply	CALA-10-4784	F	—	11/17/2009	—	—	—	—	—	—	X	—	—	—	—	—	—
PM-1	WG	Supply	CALA-10-12107	F	—	2/22/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
PM-1	WG	Supply	CALA-10-17223	UF	—	5/19/2010	—	—	X	—	—	X	X	X	—	X	X	X	X
PM-1	WG	Supply	CALA-10-17224	F	—	5/19/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
PM-1	WG	Supply	CALA-10-25071	F	—	9/14/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
PM-1	WG	Supply	CALA-11-2338	UF	—	11/16/2010	—	—	—	—	—	—	—	X	—	—	X	—	—
PM-1	WG	Supply	CALA-11-2339	F	—	11/16/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
PM-1	WG	Supply	CALA-11-4762	F	—	2/15/2011	—	—	—	—	—	—	X	—	—	—	—	—	—
PM-1	WG	Supply	CALA-11-11738	F	—	5/24/2011	—	—	—	—	—	—	X	—	—	—	—	—	—
PM-1	WG	Supply	CALA-11-11739	UF	—	5/24/2011	—	—	X	—	—	X	X	X	—	X	X	X	X
PM-1	WG	Supply	CALA-11-26776	F	—	8/30/2011	—	—	—	—	—	—	X	—	—	—	—	—	—
PM-1	WG	Supply	CALA-12-1742	F	—	12/13/2011	—	—	—	—	—	—	X	—	—	—	—	—	—
PM-1	WG	Supply	CALA-12-1743	UF	—	12/13/2011	—	—	—	—	—	—	—	X	—	—	X	—	—
PM-1	W	Supply	CALA-12-12473	F	—	3/21/2012	—	—	—	—	—	—	X	-	—	—	—	—	—
PM-1	WG	Supply	CALA-12-17385	UF	—	6/20/2012	—	—	X	—	—	X	X	X	—	X	X	X	X
PM-1	WG	Supply	CALA-12-17397	F	—	6/20/2012	—	—	—	—	—	—	X	—	—	—	—	—	—
PM-3	WG	Supply	CALA-09-11587	UF	—	8/11/2009	—	—	X	—	—	X	X	X	—	X	X	X	X

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
PM-3	WG	Supply	CALA-09-11588	F	—	8/11/2009	—	—	—	—	—	—	X	—	—	—	—	—	—
PM-3	WG	Supply	CALA-10-4787	UF	—	11/17/2009	—	—	—	—	—	—	—	X	—	—	X	—	—
PM-3	WG	Supply	CALA-10-4788	F	—	11/17/2009	—	—	—	—	—	—	X	—	—	—	—	—	—
PM-3	WG	Supply	CALA-10-12108	F	—	2/22/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
PM-3	WG	Supply	CALA-10-17227	UF	—	5/19/2010	—	—	X	—	—	X	X	X	—	X	X	X	X
PM-3	WG	Supply	CALA-10-17228	F	—	5/19/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
PM-3	WG	Supply	CALA-10-25070	F	—	9/14/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
PM-3	WG	Supply	CALA-11-2340	UF	—	11/16/2010	—	—	—	—	—	—	—	X	—	—	X	—	—
PM-3	WG	Supply	CALA-11-2341	F	—	11/16/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
PM-3	WG	Supply	CALA-11-4763	F	—	2/15/2011	—	—	—	—	—	—	X	—	—	—	—	—	—
PM-3	WG	Supply	CALA-11-11744	UF	—	5/24/2011	—	—	X	—	—	X	X	X	—	X	X	X	X
PM-3	WG	Supply	CALA-11-11745	F	—	5/24/2011	—	—	—	—	—	—	X	—	—	—	—	—	—
PM-3	WG	Supply	CALA-11-26780	F	—	8/30/2011	—	—	—	—	—	—	X	—	—	—	—	—	—
PM-3	WG	Supply	CALA-12-1748	UF	—	12/13/2011	—	—	—	—	—	—	—	X	—	—	X	—	—
PM-3	WG	Supply	CALA-12-1749	F	—	12/13/2011	—	—	—	—	—	—	X	—	—	—	—	—	—
PM-3	W	Supply	CALA-12-12475	F	—	3/20/2012	—	—	—	—	—	—	X	—	—	—	—	—	—
PM-3	WG	Supply	CALA-12-17362	UF	Field Duplicate	6/20/2012	—	—	X	—	—	X	X	X	—	X	X	X	X
PM-3	WG	Supply	CALA-12-17365	F	Field Duplicate	6/20/2012	—	—	—	—	—	—	X	—	—	—	—	—	—
PM-3	WG	Supply	CALA-12-17387	UF	—	6/20/2012	—	—	X	—	—	X	X	X	—	X	X	X	X
PM-3	WG	Supply	CALA-12-17399	F	—	6/20/2012	—	—	—	—	—	—	X	—	—	—	—	—	—
PM-5	WG	Supply	CALA-10-4791	UF	—	11/17/2009	—	—	X	—	—	X	—	X	—	—	X	—	—
PM-5	WG	Supply	CALA-10-4792	F	—	11/17/2009	—	—	—	—	—	—	X	—	—	—	—	—	—
PM-5	WG	Supply	CALA-10-12111	UF	—	3/2/2010	—	—	X	—	—	—	—	X	—	—	X	—	—
PM-5	WG	Supply	CALA-10-12112	F	—	3/2/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
PM-5	WG	Supply	CALA-10-12184	UF	Field Duplicate	3/2/2010	—	—	X	—	—	—	—	X	—	—	X	—	—
PM-5	WG	Supply	CALA-10-13005	F	Field Duplicate	3/2/2010	—	—	—	—	—	—	X	—	—	—	—	—	—

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
PM-5	WG	Supply	CALA-10-17231	UF	—	5/19/2010	—	—	X	—	—	X	X	X	—	X	X	X	X
PM-5	WG	Supply	CALA-10-17232	F	—	5/19/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
PM-5	WG	Supply	CALA-11-2344	UF	—	11/16/2010	—	—	X	—	—	X	—	X	—	—	X	—	—
PM-5	WG	Supply	CALA-11-2345	F	—	11/16/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
PM-5	WG	Supply	CALA-11-4766	UF	—	2/15/2011	—	—	X	—	—	—	—	X	—	—	X	—	—
PM-5	WG	Supply	CALA-11-4767	F	—	2/15/2011	—	—	—	—	—	—	X	—	—	—	—	—	—
PM-5	WG	Supply	CALA-11-11751	F	—	5/24/2011	—	—	—	—	—	—	X	—	—	—	—	—	—
PM-5	WG	Supply	CALA-11-11752	UF	—	5/24/2011	—	—	X	—	—	X	X	X	—	X	X	X	X
PM-5	WG	Supply	CALA-11-26783	UF	—	8/30/2011	—	—	X	—	—	—	—	X	—	—	X	—	—
PM-5	WG	Supply	CALA-11-26784	F	—	8/30/2011	—	—	—	—	—	—	X	—	—	—	—	—	—
PM-5	WG	Supply	CALA-12-1752	F	—	12/22/2011	—	—	—	—	—	—	X	—	—	—	—	—	—
PM-5	WG	Supply	CALA-12-1753	UF	—	12/22/2011	—	—	X	—	—	X	—	X	—	—	X	—	—
PM-5	W	Supply	CALA-12-12470	UF	—	3/21/2012	—	—	X	—	—	—	—	X	—	—	X	—	—
PM-5	W	Supply	CALA-12-12477	F	—	3/21/2012	—	—	—	—	—	—	X	—	—	—	—	—	—
PM-5	WG	Supply	CALA-12-17389	UF	—	6/21/2012	—	—	X	—	—	X	X	X	—	X	X	X	X
PM-5	WG	Supply	CALA-12-17401	F	—	6/21/2012	—	—	-	—	—	—	X	—	—	—	—	—	—
SCA-1	WG	WGA	CASA-09-10330	F	—	8/4/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
SCA-2	WG	WGA	CASA-09-10337	F	—	8/4/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
SCA-2	WG	WGA	CASA-09-10338	UF	—	8/4/2009	—	—	X	—	X	X	X	—	—	X	X	X	X
SCA-2	WG	WGA	CASA-09-10339	UF	Field Duplicate	8/4/2009	—	—	—	—	—	—	—	—	—	—	—	X	X
SCA-2	WG	WGA	CASA-10-3623	UF	—	11/3/2009	—	—	X	—	—	—	X	—	—	—	—	—	X
SCA-2	WG	WGA	CASA-10-3624	F	—	11/3/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
SCA-2	WG	WGA	CASA-10-16724	F	—	5/12/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
SCA-2	WG	WGA	CASA-10-16725	UF	—	5/12/2010	—	—	X	—	—	—	X	—	—	—	—	—	X
SCA-4	WG	WGA	CASA-09-10343	UF	Field Duplicate	8/5/2009	—	—	—	—	—	—	—	—	—	—	—	X	X
SCA-4	WG	WGA	CASA-09-10344	UF	—	8/5/2009	—	—	X	—	X	X	X	—	—	X	X	X	X

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
SCA-4	WG	WGA	CASA-09-10345	F	—	8/5/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
SCA-4	WG	WGA	CASA-10-3627	UF	—	11/3/2009	—	—	X	—	—	—	X	—	—	—	—	—	X
SCA-4	WG	WGA	CASA-10-3629	F	—	11/3/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
SCA-4	WG	WGA	CASA-10-3631	UF	Field Duplicate	11/3/2009	—	—	X	—	—	—	X	—	—	—	—	—	X
SCA-4	WG	WGA	CASA-10-3632	F	Field Duplicate	11/3/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
SCA-4	WG	WGA	CASA-10-16728	UF	—	5/10/2010	—	—	X	—	—	—	X	—	—	—	—	—	X
SCA-4	WG	WGA	CASA-10-16729	F	—	5/10/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
SCA-5	WG	WGA	CASA-09-10326	F	—	8/5/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
SCA-5	WG	WGA	CASA-09-10327	UF	—	8/5/2009	—	—	—	—	—	—	—	—	—	—	—	X	X
SCA-5	WG	WGA	CASA-10-3652	UF	—	11/4/2009	—	—	—	—	—	—	—	—	—	X	—	—	X
SCA-5	WG	WGA	CASA-10-3653	F	—	11/4/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
LADP-3	WG	WGI	CALA-09-11128	F	—	7/15/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
LADP-3	WG	WGI	CALA-09-11129	UF	—	7/15/2009	—	—	X	—	—	—	X	—	—	—	X	—	X
LADP-3	WG	WGI	CALA-10-9161	UF	Field Duplicate	1/7/2010	—	—	—	—	—	—	—	—	—	—	—	X	X
LADP-3	WG	WGI	CALA-10-9162	F	—	1/7/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
LADP-3	WG	WGI	CALA-10-9163	UF	—	1/7/2010	—	—	X	—	X	X	X	—	—	X	X	X	X
LADP-3	WG	WGI	CALA-10-24991	UF	—	8/20/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
LADP-3	WG	WGI	CALA-10-25198	F	—	8/20/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
LADP-3	WG	WGI	CALA-11-5094	UF	—	3/7/2011	—	—	X	—	—	—	X	—	—	—	X	X	X
LADP-3	WG	WGI	CALA-11-5095	F	—	3/7/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
LAOI-3.2	WG	WGI	CALA-09-11147	F	—	7/8/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
LAOI-3.2	WG	WGI	CALA-09-11149	UF	—	7/8/2009	—	—	X	—	—	—	X	—	—	—	X	—	X
LAOI-3.2	WG	WGI	CALA-10-9174	UF	—	1/8/2010	—	—	X	—	—	—	—	—	—	—	X	—	X
LAOI-3.2	WG	WGI	CALA-10-9175	F	—	1/8/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
LAOI-3.2	WG	WGI	CALA-10-25219	F	—	8/23/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
LAOI-3.2	WG	WGI	CALA-10-25220	UF	—	8/23/2010	—	—	X	—	—	—	X	—	—	—	X	X	X

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
LAOI-3.2	WG	WGI	CALA-11-5115	UF	—	3/22/2011	—	—	X	—	—	—	X	—	—	—	X	X	X
LAOI-3.2	WG	WGI	CALA-11-5116	F	—	3/22/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
LAOI-3.2a	WG	WGI	CALA-09-11150	UF	—	7/8/2009	—	—	X	—	—	—	X	—	—	—	X	—	X
LAOI-3.2a	WG	WGI	CALA-09-11152	F	—	7/8/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
LAOI-3.2a	WG	WGI	CALA-10-9169	UF	Field Duplicate	1/8/2010	—	—	-	—	—	—	—	—	—	—	—	X	X
LAOI-3.2a	WG	WGI	CALA-10-9171	UF	—	1/8/2010	—	—	X	—	X	X	X	—	—	X	X	X	X
LAOI-3.2a	WG	WGI	CALA-10-9172	F	—	1/8/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
LAOI-3.2a	WG	WGI	CALA-10-25221	UF	—	8/20/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
LAOI-3.2a	WG	WGI	CALA-10-25222	F	—	8/20/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
LAOI-3.2a	WG	WGI	CALA-11-5158	F	—	3/22/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
LAOI-3.2a	WG	WGI	CALA-11-5159	UF	—	3/22/2011	—	—	X	—	—	—	X	—	—	—	X	X	X
LAOI-7	WG	WGI	CALA-09-11153	F	—	7/13/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
LAOI-7	WG	WGI	CALA-09-11155	UF	—	7/13/2009	—	—	X	—	—	—	X	—	—	—	X	—	X
LAOI-7	WG	WGI	CALA-10-9165	UF	—	1/14/2010	—	—	X	—	X	X	X	—	—	X	X	X	X
LAOI-7	WG	WGI	CALA-10-9166	F	—	1/14/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
LAOI-7	WG	WGI	CALA-10-9168	UF	Field Duplicate	1/14/2010	—	—	-	—	—	—	—	—	—	—	—	X	X
LAOI-7	WG	WGI	CALA-10-25225	UF	—	8/26/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
LAOI-7	WG	WGI	CALA-10-25226	F	—	8/26/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
LAOI-7	WG	WGI	CALA-11-5160	UF	—	3/10/2011	—	—	X	—	—	—	X	—	—	—	X	X	X
LAOI-7	WG	WGI	CALA-11-5162	F	—	3/10/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
LAOI(a)-1.1	WG	WGI	CALA-09-11125	UF	—	7/7/2009	—	—	X	—	—	—	X	—	—	—	X	—	X
LAOI(a)-1.1	WG	WGI	CALA-09-11127	F	—	7/7/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
LAOI(a)-1.1	WG	WGI	CALA-10-9157	UF	—	1/13/2010	—	—	X	—	X	X	X	—	—	X	X	X	X
LAOI(a)-1.1	WG	WGI	CALA-10-9158	F	—	1/13/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
LAOI(a)-1.1	WG	WGI	CALA-10-9160	UF	Field Duplicate	1/13/2010	—	—	—	—	—	—	—	—	—	—	—	X	X
LAOI(a)-1.1	WG	WGI	CALA-10-25215	UF	—	8/19/2010	—	—	X	—	—	—	X	—	—	—	X	X	X

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
LAOI(a)-1.1	WG	WGI	CALA-10-25216	F	—	8/19/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
LAOI(a)-1.1	WG	WGI	CALA-11-5112	UF	—	3/8/2011	—	—	X	—	—	—	X	-	—	—	X	X	X
LAOI(a)-1.1	WG	WGI	CALA-11-5113	F	—	3/8/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
MCOI-4	WG	WGI	CAMO-09-9527	UF	—	8/7/2009	—	—	X	—	—	—	X	—	—	—	X	X	X
MCOI-4	WG	WGI	CAMO-09-9528	F	—	8/7/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
MCOI-4	WG	WGI	CAMO-10-3116	UF	—	11/5/2009	—	—	X	—	—	—	X	—	—	—	X	X	—
MCOI-4	WG	WGI	CAMO-10-3117	F	—	11/5/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
MCOI-4	WG	WGI	CAMO-10-9311	F	—	1/26/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
MCOI-4	WG	WGI	CAMO-10-9313	UF	—	1/26/2010	—	—	—	—	—	—	X	—	—	—	X	—	X
MCOI-4	WG	WGI	CAMO-10-16726	UF	—	5/4/2010	—	—	X	—	—	—	X	—	—	—	X	X	—
MCOI-4	WG	WGI	CAMO-10-16727	F	—	5/4/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
MCOI-4	WG	WGI	CAMO-10-22831	F	—	7/7/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
MCOI-4	WG	WGI	CAMO-10-22832	UF	—	7/7/2010	—	—	X	—	—	—	X	—	—	—	X	—	X
MCOI-4	WG	WGI	CAMO-11-4588	UF	—	2/16/2011	—	—	X	—	—	—	X	—	—	—	—	—	—
MCOI-4	WG	WGI	CAMO-11-4589	F	—	2/16/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
MCOI-5	WG	WGI	CAMO-09-10298	F	—	8/6/2009	—	—	—	—	—	—	X	—	—	—	—	—	—
MCOI-5	WG	WGI	CAMO-09-9531	F	—	8/6/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
MCOI-5	WG	WGI	CAMO-09-9532	UF	—	8/6/2009	—	—	X	—	—	—	X	—	—	—	X	X	X
MCOI-5	WG	WGI	CAMO-10-3118	F	—	11/3/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
MCOI-5	WG	WGI	CAMO-10-3119	UF	—	11/3/2009	—	—	X	—	—	—	X	—	—	—	X	X	—
MCOI-5	WG	WGI	CAMO-10-3898	F	—	11/3/2009	—	—	—	—	—	—	X	—	—	—	—	—	—
MCOI-5	WG	WGI	CAMO-10-9315	UF	—	1/25/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
MCOI-5	WG	WGI	CAMO-10-9316	F	—	1/25/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
MCOI-5	WG	WGI	CAMO-10-9726	F	—	1/25/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
MCOI-5	WG	WGI	CAMO-10-9737	F	—	1/25/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
MCOI-5	WG	WGI	CAMO-10-16734	F	—	5/3/2010	—	—	X	—	—	—	X	X	—	—	—	—	—

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
MCOI-5	WG	WGI	CAMO-10-16735	UF	—	5/3/2010	—	—	X	—	—	—	X	—	—	—	X	X	—
MCOI-5	WG	WGI	CAMO-10-22834	F	—	7/7/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
MCOI-5	WG	WGI	CAMO-10-22836	UF	—	7/7/2010	—	—	X	—	—	—	X	—	—	—	X	—	X
MCOI-5	WG	WGI	CAMO-11-1253	UF	—	11/15/2010	—	—	X	—	—	—	X	—	—	—	X	X	—
MCOI-5	WG	WGI	CAMO-11-1254	F	—	11/15/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
MCOI-5	WG	WGI	CAMO-11-4590	UF	—	2/28/2011	—	—	X	—	—	—	X	—	—	—	—	—	—
MCOI-5	WG	WGI	CAMO-11-4591	F	—	2/28/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
MCOI-5	WG	WGI	CAMO-11-10698	F	—	5/26/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
MCOI-5	WG	WGI	CAMO-11-10699	UF	—	5/26/2011	—	—	X	—	—	—	X	—	—	—	X	X	X
MCOI-5	WG	WGI	CAMO-11-24627	UF	—	8/10/2011	—	—	X	—	—	—	X	—	—	—	—	—	X
MCOI-5	WG	WGI	CAMO-11-24628	F	—	8/10/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
MCOI-5	WG	WGI	CAMO-12-1465	UF	—	11/8/2011	—	—	X	—	—	—	X	—	—	—	X	X	X
MCOI-5	WG	WGI	CAMO-12-1466	F	—	11/8/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
MCOI-5	WG	WGI	CAMO-12-14070	UF	—	6/4/2012	—	—	—	—	—	—	—	—	—	—	—	X	—
MCOI-5	WG	WGI	CAMO-12-14075	F	—	6/4/2012	—	—	—	—	—	—	X	—	—	—	—	—	—
MCOI-5	WG	WGI	CAMO-12-17124	UF	—	6/4/2012	—	—	X	—	—	—	—	—	—	—	—	—	—
MCOI-5	WG	WGI	CAMO-12-17129	F	—	6/4/2012	—	—	X	—	—	—	X	X	—	—	—	—	—
MCOI-6	WG	WGI	CAMO-09-10299	F	—	8/19/2009	—	—	—	—	—	—	X	—	—	—	—	—	—
MCOI-6	WG	WGI	CAMO-09-9533	UF	—	8/19/2009	—	—	X	—	—	—	X	—	—	—	X	X	X
MCOI-6	WG	WGI	CAMO-09-9535	F	—	8/19/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
MCOI-6	WG	WGI	CAMO-09-9536	F	Field Duplicate	8/19/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
MCOI-6	WG	WGI	CAMO-09-9537	UF	Field Duplicate	8/19/2009	—	—	X	—	—	—	X	—	—	—	X	X	X
MCOI-6	WG	WGI	CAMO-10-3120	F	—	11/6/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
MCOI-6	WG	WGI	CAMO-10-3121	UF	—	11/6/2009	—	—	X	—	—	—	X	—	—	—	X	X	—
MCOI-6	WG	WGI	CAMO-10-3123	UF	Field Duplicate	11/6/2009	—	—	X	—	—	—	X	—	—	—	X	X	—
MCOI-6	WG	WGI	CAMO-10-3124	F	Field Duplicate	11/6/2009	—	—	X	—	—	—	X	X	—	—	—	—	—

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
MCOI-6	WG	WGI	CAMO-10-9317	F	—	1/26/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
MCOI-6	WG	WGI	CAMO-10-9319	UF	—	1/26/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
MCOI-6	WG	WGI	CAMO-10-9320	UF	Field Duplicate	1/26/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
MCOI-6	WG	WGI	CAMO-10-9321	F	Field Duplicate	1/26/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
MCOI-6	WG	WGI	CAMO-10-16737	UF	—	5/11/2010	—	—	X	—	—	—	X	—	—	—	X	X	—
MCOI-6	WG	WGI	CAMO-10-16738	F	—	5/11/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
MCOI-6	WG	WGI	CAMO-10-16981	UF	Field Duplicate	5/11/2010	—	—	X	—	—	—	X	—	—	—	X	X	—
MCOI-6	WG	WGI	CAMO-10-16982	F	Field Duplicate	5/11/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
MCOI-6	WG	WGI	CAMO-10-22837	UF	—	7/6/2010	—	—	X	—	—	—	X	—	—	—	X	—	X
MCOI-6	WG	WGI	CAMO-10-22838	F	—	7/6/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
MCOI-6	WG	WGI	CAMO-11-1255	F	—	11/10/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
MCOI-6	WG	WGI	CAMO-11-1256	UF	—	11/10/2010	—	—	X	—	—	—	X	—	—	—	X	X	—
MCOI-6	WG	WGI	CAMO-11-1257	F	Field Duplicate	11/10/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
MCOI-6	WG	WGI	CAMO-11-1258	UF	Field Duplicate	11/10/2010	—	—	X	—	—	—	X	—	—	—	X	X	—
MCOI-6	WG	WGI	CAMO-11-4592	UF	—	2/9/2011	—	—	X	—	—	—	X	—	—	—	—	—	—
MCOI-6	WG	WGI	CAMO-11-4593	F	—	2/9/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
MCOI-6	WG	WGI	CAMO-11-10700	UF	—	5/31/2011	—	—	X	—	—	—	X	—	—	—	X	X	X
MCOI-6	WG	WGI	CAMO-11-10701	F	—	5/31/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
MCOI-6	WG	WGI	CAMO-11-24630	UF	—	8/10/2011	—	—	X	—	—	—	X	—	—	—	—	—	X
MCOI-6	WG	WGI	CAMO-11-24631	F	—	8/10/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
MCOI-6	WG	WGI	CAMO-12-1467	F	—	11/9/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
MCOI-6	WG	WGI	CAMO-12-1468	UF	—	11/9/2011	—	—	X	—	—	—	X	—	—	—	X	X	X
MCOI-6	WG	WGI	CAMO-12-1471	UF	Field Duplicate	11/9/2011	—	—	X	—	—	—	X	—	—	—	X	X	X
MCOI-6	WG	WGI	CAMO-12-1472	F	Field Duplicate	11/9/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
MCOI-6	WG	WGI	CAMO-12-12017	UF	—	3/5/2012	—	—	X	—	—	—	—	—	—	—	—	—	—
MCOI-6	WG	WGI	CAMO-12-12026	F	—	3/5/2012	—	—	X	—	—	—	X	X	—	—	—	—	—

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
MCOI-6	WG	WGI	CAMO-12-14006	UF	—	6/4/2012	—	—	X	—	—	—	—	—	—	—	—	—	—
MCOI-6	WG	WGI	CAMO-12-14021	F	—	6/4/2012	—	—	X	—	—	—	X	X	—	—	—	—	—
MCOI-6	WG	WGI	CAMO-12-14071	UF	—	6/4/2012	—	—	—	—	—	—	—	—	—	—	—	X	—
R-12 S1	WG	WGI	CASA-09-10379	F	—	8/5/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-12 S1	WG	WGI	CASA-09-10380	UF	—	8/5/2009	X	—	X	—	X	X	X	—	—	X	X	X	X
R-12 S1	WG	WGI	CASA-09-10382	UF	Field Duplicate	8/5/2009	—	—	—	—	—	—	—	—	—	—	—	X	X
R-12 S1	WG	WGI	CASA-10-3821	F	—	11/12/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-12 S1	WG	WGI	CASA-10-3822	UF	—	11/12/2009	X	—	X	—	—	X	X	—	—	X	X	X	X
R-12 S1	WG	WGI	CASA-10-9443	F	—	2/9/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-12 S1	WG	WGI	CASA-10-9444	UF	Field Duplicate	2/9/2010	—	—	—	—	—	—	—	—	—	—	—	X	—
R-12 S1	WG	WGI	CASA-10-9446	UF	—	2/9/2010	—	—	X	—	—	X	X	—	—	X	X	X	X
R-12 S1	WG	WGI	CASA-10-16747	UF	—	5/5/2010	—	—	X	—	—	—	X	—	—	—	X	—	X
R-12 S1	WG	WGI	CASA-10-16748	F	—	5/5/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-12 S1	WG	WGI	CASA-11-1356	UF	—	11/17/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
R-12 S1	WG	WGI	CASA-11-1357	F	—	11/17/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-12 S1	WG	WGI	CASA-11-10822	F	—	6/3/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-12 S1	WG	WGI	CASA-11-10823	UF	—	6/3/2011	—	—	X	—	—	—	X	—	—	—	X	—	—
R-12 S2	WG	WGI	CASA-09-10383	UF	—	8/5/2009	X	—	X	—	X	X	X	—	—	X	X	X	X
R-12 S2	WG	WGI	CASA-09-10384	F	—	8/5/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-12 S2	WG	WGI	CASA-09-10386	UF	Field Duplicate	8/5/2009	—	—	—	—	—	—	—	—	—	—	—	X	X
R-12 S2	WG	WGI	CASA-10-3824	F	—	11/12/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-12 S2	WG	WGI	CASA-10-3825	UF	—	11/12/2009	X	—	X	—	—	X	X	—	—	X	X	X	X
R-12 S2	WG	WGI	CASA-10-9447	UF	—	2/9/2010	—	—	X	—	—	X	X	—	—	X	X	X	X
R-12 S2	WG	WGI	CASA-10-9448	F	—	2/9/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-12 S2	WG	WGI	CASA-10-9450	UF	Field Duplicate	2/9/2010	—	—	—	—	—	—	—	—	—	—	—	X	X
R-12 S2	WG	WGI	CASA-10-16749	UF	—	5/17/2010	—	—	X	—	—	—	X	—	—	—	X	—	X

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
R-12 S2	WG	WGI	CASA-10-16751	F	—	5/17/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-12 S2	WG	WGI	CASA-11-1358	F	—	11/17/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-12 S2	WG	WGI	CASA-11-1359	UF	—	11/17/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
R-12 S2	WG	WGI	CASA-11-10824	UF	—	5/26/2011	—	—	X	—	—	—	X	—	—	—	X	—	—
R-12 S2	WG	WGI	CASA-11-10825	F	—	5/26/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-3i	WG	WGI	CAPU-09-11231	UF	—	7/22/2009	—	—	X	—	—	—	X	—	—	—	X	X	X
R-3i	WG	WGI	CAPU-09-11233	F	—	7/22/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-3i	WG	WGI	CAPU-09-11234	F	Field Duplicate	7/22/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-3i	WG	WGI	CAPU-09-11235	UF	Field Duplicate	7/22/2009	—	—	X	—	—	—	X	—	—	—	X	X	X
R-3i	WG	WGI	CAPU-11-5287	UF	—	3/22/2011	—	—	X	—	—	—	X	—	—	—	X	X	X
R-3i	WG	WGI	CAPU-11-5288	F	—	3/22/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-3i	WG	WGI	CAPU-12-12566	UF	—	4/13/2012	—	—	X	—	—	—	—	—	—	—	X	X	X
R-3i	WG	WGI	CAPU-12-12574	F	—	4/13/2012	—	—	X	—	—	—	X	X	—	—	—	—	—
R-9i S1	WG	WGI	CALA-09-11139	UF	—	7/8/2009	—	—	X	—	—	—	X	—	—	—	X	—	X
R-9i S1	WG	WGI	CALA-09-11142	F	—	7/8/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-9i S1	WG	WGI	CALA-10-9149	UF	—	1/8/2010	—	—	X	—	—	—	—	—	—	—	X	—	X
R-9i S1	WG	WGI	CALA-10-9151	F	—	1/8/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-9i S1	WG	WGI	CALA-10-25200	F	—	8/23/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-9i S1	WG	WGI	CALA-10-25201	UF	—	8/23/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
R-9i S1	WG	WGI	CALA-11-5106	UF	—	3/17/2011	—	—	X	—	—	—	X	—	—	—	X	X	X
R-9i S1	WG	WGI	CALA-11-5107	F	—	3/17/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-9i S2	WG	WGI	CALA-09-11145	F	—	7/8/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-9i S2	WG	WGI	CALA-09-11146	UF	—	7/8/2009	—	—	X	—	—	—	X	—	—	—	X	—	X
R-9i S2	WG	WGI	CALA-10-9154	UF	—	1/8/2010	—	—	X	—	—	—	—	—	—	—	X	—	X
R-9i S2	WG	WGI	CALA-10-9156	F	—	1/8/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-9i S2	WG	WGI	CALA-10-25203	F	—	8/24/2010	—	—	X	—	—	—	X	X	—	—	—	—	—

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
R-9i S2	WG	WGI	CALA-10-25204	UF	—	8/24/2010	—	—	X	—	—	-	X	—	—	—	X	X	X
R-9i S2	WG	WGI	CALA-11-5109	F	—	3/18/2011	—	—	X	—	—	-	X	X	—	—	—	—	—
R-9i S2	WG	WGI	CALA-11-5110	UF	—	3/18/2011	—	—	X	—	—	-	X	-	—	—	X	X	X
SCI-1	WG	WGI	CASA-09-10348	F	—	8/3/2009	—	—	X	—	—	-	X	X	—	—	—	—	—
SCI-1	WG	WGI	CASA-09-10349	UF	Field Duplicate	8/3/2009	—	—	—	—	—	—	—	—	—	—	—	X	X
SCI-1	WG	WGI	CASA-09-10350	UF	—	8/3/2009	—	—	X	—	X	X	X	—	—	X	X	X	X
SCI-1	WG	WGI	CASA-10-3665	UF	—	11/18/2009	—	—	X	—	—	-	X	—	—	—	X	—	X
SCI-1	WG	WGI	CASA-10-3667	F	—	11/18/2009	—	—	X	—	—	-	X	X	—	—	—	—	—
SCI-1	WG	WGI	CASA-10-9452	UF	—	2/5/2010	—	—	X	—	—	X	X	—	—	X	X	X	X
SCI-1	WG	WGI	CASA-10-9453	UF	Field Duplicate	2/5/2010	—	—	—	—	—	—	—	—	—	—	—	X	X
SCI-1	WG	WGI	CASA-10-9454	F	—	2/5/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
SCI-1	WG	WGI	CASA-10-16756	F	—	5/7/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
SCI-1	WG	WGI	CASA-10-16757	UF	—	5/7/2010	—	—	X	—	—	—	X	—	—	—	X	—	X
SCI-1	WG	WGI	CASA-10-22646	UF	—	7/12/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
SCI-1	WG	WGI	CASA-10-22647	F	—	7/12/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
SCI-1	WG	WGI	CASA-10-22648	UF	Field Duplicate	7/12/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
SCI-1	WG	WGI	CASA-10-22649	F	Field Duplicate	7/12/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
SCI-1	WG	WGI	CASA-11-1360	UF	—	11/16/2010	—	—	X	—	—	—	X	—	—	—	X	—	—
SCI-1	WG	WGI	CASA-11-1361	F	—	11/16/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
SCI-1	WG	WGI	CASA-11-4553	UF	—	2/18/2011	—	—	X	—	—	—	X	—	—	—	—	—	—
SCI-1	WG	WGI	CASA-11-4554	F	—	2/18/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
SCI-1	WG	WGI	CASA-11-10804	F	—	5/24/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
SCI-1	WG	WGI	CASA-11-10805	UF	—	5/24/2011	—	—	X	—	—	—	X	—	—	—	X	—	—
SCI-1	WG	WGI	CASA-11-24763	F	—	8/16/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
SCI-1	WG	WGI	CASA-11-24764	UF	—	8/16/2011	—	—	X	—	—	—	X	-	—	—	—	—	—
SCI-1	WG	WGI	CASA-12-1373	UF	—	11/16/2011	—	—	X	—	—	—	X	-	—	—	X	X	X

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
SCI-1	WG	WGI	CASA-12-1374	F	—	11/16/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
SCI-1	WG	WGI	CASA-12-14060	UF	—	5/21/2012	—	—	X	—	—	—	—	—	—	—	—	—	—
SCI-1	WG	WGI	CASA-12-14065	F	—	5/21/2012	—	—	X	—	—	—	X	X	—	—	—	—	—
SCI-2	WG	WGI	CASA-09-10367	UF	—	8/4/2009	X	—	X	—	—	X	X	—	—	X	X	X	X
SCI-2	WG	WGI	CASA-09-10368	F	—	8/4/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
SCI-2	WG	WGI	CASA-09-10371	UF	Field Duplicate	8/4/2009	X	-	X	—	—	X	X	—	—	X	X	X	X
SCI-2	WG	WGI	CASA-09-10372	F	Field Duplicate	8/4/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
SCI-2	WG	WGI	CASA-09-10406	F	—	8/4/2009	—	—	—	—	—	—	X	—	—	—	—	—	—
SCI-2	WG	WGI	CASA-10-3716	UF	—	11/17/2009	X	—	X	—	—	X	X	—	—	X	X	X	X
SCI-2	WG	WGI	CASA-10-3717	F	—	11/17/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
SCI-2	WG	WGI	CASA-10-3894	F	—	11/17/2009	—	—	—	—	—	—	X	—	—	—	—	—	—
SCI-2	WG	WGI	CASA-10-12689	F	—	2/8/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
SCI-2	WG	WGI	CASA-10-12690	F	—	2/8/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
SCI-2	WG	WGI	CASA-10-9489	UF	—	2/8/2010	X	—	X	—	—	X	X	—	—	X	X	X	X
SCI-2	WG	WGI	CASA-10-9490	F	—	2/8/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
SCI-2	WG	WGI	CASA-10-16761	F	—	5/6/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
SCI-2	WG	WGI	CASA-10-16763	UF	—	5/6/2010	—	—	X	—	—	X	X	—	—	—	X	—	X
SCI-2	WG	WGI	CASA-10-22650	UF	—	7/15/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
SCI-2	WG	WGI	CASA-10-22651	F	—	7/15/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
SCI-2	WG	WGI	CASA-11-1362	F	—	11/16/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
SCI-2	WG	WGI	CASA-11-1363	UF	—	11/16/2010	—	—	X	—	—	—	X	—	—	—	X	—	—
SCI-2	WG	WGI	CASA-11-4555	F	—	2/17/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
SCI-2	WG	WGI	CASA-11-4556	UF	—	2/17/2011	—	—	X	—	—	—	X	—	—	—	—	—	—
SCI-2	WG	WGI	CASA-11-4557	F	Field Duplicate	2/17/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
SCI-2	WG	WGI	CASA-11-4558	UF	Field Duplicate	2/17/2011	—	—	X	—	—	—	X	—	—	—	—	—	—
SCI-2	WG	WGI	CASA-11-10806	F	—	6/2/2011	—	—	X	—	—	—	X	X	—	—	—	—	—

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatle Organic Analytes	Volatile Organic Analytes
SCI-2	WG	WGI	CASA-11-10807	UF	—	6/2/2011	—	—	X	—	—	—	X	—	—	—	X	—	—
SCI-2	WG	WGI	CASA-11-10808	F	Field Duplicate	6/2/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
SCI-2	WG	WGI	CASA-11-10809	UF	Field Duplicate	6/2/2011	—	—	X	—	—	—	X	—	—	—	X	—	—
SCI-2	WG	WGI	CASA-11-24765	UF	—	8/11/2011	—	—	X	—	—	—	X	—	—	—	—	—	—
SCI-2	WG	WGI	CASA-11-24766	F	—	8/11/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
SCI-2	WG	WGI	CASA-11-24767	UF	Field Duplicate	8/11/2011	—	—	X	—	—	—	X	—	—	—	—	—	—
SCI-2	WG	WGI	CASA-11-24768	F	Field Duplicate	8/11/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
SCI-2	WG	WGI	CASA-12-1376	UF	—	11/14/2011	—	—	X	—	—	—	X	—	—	—	X	X	X
SCI-2	WG	WGI	CASA-12-1378	F	—	11/14/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
SCI-2	WG	WGI	CASA-12-11712	UF	—	3/5/2012	—	—	X	—	—	—	—	—	—	—	—	—	—
SCI-2	WG	WGI	CASA-12-11716	F	—	3/5/2012	—	—	X	—	—	—	X	X	—	—	—	—	—
SCI-2	WG	WGI	CASA-12-11739	UF	Field Duplicate	3/5/2012	—	—	X	—	—	—	—	—	—	—	—	—	—
SCI-2	WG	WGI	CASA-12-11740	F	Field Duplicate	3/5/2012	—	—	X	—	—	—	X	X	—	—	—	—	—
SCI-2	WG	WGI	CASA-12-14061	UF	—	5/23/2012	—	—	X	—	—	—	—	—	—	—	—	—	—
SCI-2	WG	WGI	CASA-12-14066	F	—	5/23/2012	—	—	X	—	—	—	X	X	—	—	—	—	—
SCI-2	WG	WGI	CASA-12-14067	F	Field Duplicate	5/23/2012	—	—	X	—	—	—	X	X	—	—	—	—	—
SCI-2	WG	WGI	CASA-12-14068	UF	Field Duplicate	5/23/2012	—	—	X	—	—	—	—	—	—	—	—	—	—
TA-53i	WG	WGI	CALA-10-6870	UF	—	11/30/2009	X	—	X	—	—	X	X	—	—	X	X	X	X
TA-53i	WG	WGI	CALA-10-6871	F	—	11/30/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
TA-53i	WG	WGI	CALA-10-9193	UF	—	1/7/2010	X	—	X	—	—	X	X	—	—	X	X	X	X
TA-53i	WG	WGI	CALA-10-9194	F	—	1/7/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
TA-53i	WG	WGI	CALA-10-9196	F	Field Duplicate	1/7/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
TA-53i	WG	WGI	CALA-10-9197	UF	Field Duplicate	1/7/2010	X	—	X	—	—	X	X	—	—	X	X	X	X
TA-53i	WG	WGI	CALA-10-25207	UF	—	8/25/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
TA-53i	WG	WGI	CALA-10-25208	F	—	8/25/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
TA-53i	WG	WGI	CALA-10-25209	F	Field Duplicate	8/25/2010	—	—	X	—	—	—	X	X	—	—	—	—	—

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
TA-53i	WG	WGI	CALA-10-25210	UF	Field Duplicate	8/25/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
TA-53i	WG	WGI	CALA-11-5167	F	—	3/18/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
TA-53i	WG	WGI	CALA-11-5168	UF	—	3/18/2011	—	—	X	—	—	—	X	—	—	—	X	X	X
TA-53i	WG	WGI	CALA-11-5169	F	Field Duplicate	3/18/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
TA-53i	WG	WGI	CALA-11-5170	UF	Field Duplicate	3/18/2011	—	—	X	—	—	—	X	—	—	—	X	X	X
R-1	WG	WGR	CAMO-09-9549	UF	—	8/13/2009	—	—	X	—	X	X	X	—	—	X	X	X	X
R-1	WG	WGR	CAMO-09-9551	F	—	8/13/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-1	WG	WGR	CAMO-09-9552	UF	Field Duplicate	8/13/2009	—	—	—	—	—	—	—	—	—	—	—	X	X
R-1	WG	WGR	CAMO-10-3125	UF	—	11/16/2009	—	—	X	—	—	—	X	—	—	—	—	—	X
R-1	WG	WGR	CAMO-10-3126	F	—	11/16/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-1	WG	WGR	CAMO-10-3899	F	—	11/16/2009	—	—	—	—	—	—	X	—	—	—	—	—	—
R-1	WG	WGR	CAMO-10-9329	UF	—	2/11/2010	—	—	X	—	—	X	X	—	—	X	X	X	X
R-1	WG	WGR	CAMO-10-9330	F	—	2/11/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-1	WG	WGR	CAMO-10-9332	UF	Field Duplicate	2/11/2010	—	—	—	—	—	—	—	—	—	—	—	X	X
R-1	WG	WGR	CAMO-10-9727	F	—	2/11/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
R-1	WG	WGR	CAMO-10-9733	F	—	2/11/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
R-1	WG	WGR	CAMO-10-16739	UF	—	5/3/2010	—	—	X	—	—	—	X	—	—	—	—	—	X
R-1	WG	WGR	CAMO-10-16740	F	—	5/3/2010	—	—	X	—	—	—	X	X	-	—	—	—	—
R-1	WG	WGR	CAMO-10-22843	F	—	7/13/2010	—	—	X	—	—	—	X	X	-	—	—	—	—
R-1	WG	WGR	CAMO-10-22844	UF	—	7/13/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
R-1	WG	WGR	CAMO-11-1260	F	—	11/12/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-1	WG	WGR	CAMO-11-1262	UF	—	11/12/2010	—	—	X	—	—	—	X	—	—	—	X	—	X
R-1	WG	WGR	CAMO-11-4636	UF	—	2/14/2011	—	—	X	—	—	—	X	—	—	—	—	—	X
R-1	WG	WGR	CAMO-11-4638	F	—	2/14/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-1	WG	WGR	CAMO-11-10747	UF	—	6/3/2011	—	—	X	—	—	—	X	—	—	—	X	—	X
R-1	WG	WGR	CAMO-11-10748	F	—	6/3/2011	—	—	X	—	—	—	X	X	—	—	—	—	—

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
R-1	WG	WGR	CAMO-11-24660	UF	—	8/2/2011	—	—	X	—	—	—	X	—	—	—	—	—	X
R-1	WG	WGR	CAMO-11-24661	F	—	8/2/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-1	WG	WGR	CAMO-12-1474	UF	—	11/18/2011	—	—	X	—	—	—	X	—	—	—	X	X	X
R-1	WG	WGR	CAMO-12-1475	F	—	11/18/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-1	WG	WGR	CAMO-12-1476	UF	Field Duplicate	11/18/2011	—	—	X	—	—	—	X	—	—	—	X	X	X
R-1	WG	WGR	CAMO-12-1478	F	Field Duplicate	11/18/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-10 S1	WG	WGR	CASA-09-12923	UF	—	9/23/2009	—	—	X	—	—	—	X	—	—	—	X	X	X
R-10 S1	WG	WGR	CASA-09-12924	F	—	9/23/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-10 S1	WG	WGR	CASA-10-3704	UF	—	11/10/2009	—	—	X	—	—	—	X	—	—	—	X	X	X
R-10 S1	WG	WGR	CASA-10-3705	F	—	11/10/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-10 S1	WG	WGR	CASA-10-9473	F	—	2/9/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-10 S1	WG	WGR	CASA-10-9475	UF	—	2/9/2010	—	—	X	—	X	X	X	—	—	X	X	X	X
R-10 S1	WG	WGR	CASA-10-9476	UF	Field Duplicate	2/9/2010	—	—	—	—	—	—	—	—	—	—	—	X	X
R-10 S1	WG	WGR	CASA-10-16767	UF	—	5/5/2010	—	—	X	—	—	—	X	—	—	—	X	—	X
R-10 S1	WG	WGR	CASA-10-16769	F	—	5/5/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-10 S1	WG	WGR	CASA-10-22713	UF	—	7/8/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
R-10 S1	WG	WGR	CASA-10-22715	F	—	7/8/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-10 S1	WG	WGR	CASA-11-1364	F	—	11/17/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-10 S1	WG	WGR	CASA-11-1365	UF	—	11/17/2010	—	—	X	—	—	—	X	—	—	—	X	—	—
R-10 S1	WG	WGR	CASA-11-4571	UF	—	2/15/2011	—	—	X	—	—	—	X	—	—	—	—	—	—
R-10 S1	WG	WGR	CASA-11-4572	F	—	2/15/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-10 S1	WG	WGR	CASA-11-10826	UF	—	5/26/2011	—	—	X	—	—	—	X	—	—	—	X	X	X
R-10 S1	WG	WGR	CASA-11-10827	F	—	5/26/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-10 S1	WG	WGR	CASA-11-24769	UF	—	8/9/2011	—	—	X	—	—	X	X	—	—	X	X	X	X
R-10 S1	WG	WGR	CASA-11-24770	F	—	8/9/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-10 S2	WG	WGR	CASA-09-12927	UF	—	9/23/2009	—	—	X	—	—	—	X	—	—	—	X	X	X

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
R-10 S2	WG	WGR	CASA-09-12928	F	—	9/23/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-10 S2	WG	WGR	CASA-10-3707	UF	—	11/10/2009	—	—	X	—	—	—	X	-	—	—	X	X	X
R-10 S2	WG	WGR	CASA-10-3709	F	—	11/10/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-10 S2	WG	WGR	CASA-10-9478	UF	Field Duplicate	2/9/2010	—	—	—	—	—	—	—	—	—	—	—	X	X
R-10 S2	WG	WGR	CASA-10-9479	UF	—	2/9/2010	—	—	X	—	X	X	X	-	—	X	X	X	X
R-10 S2	WG	WGR	CASA-10-9480	F	—	2/9/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-10 S2	WG	WGR	CASA-10-16771	UF	—	5/5/2010	—	—	X	—	—	—	X	—	—	—	X	—	X
R-10 S2	WG	WGR	CASA-10-16772	F	—	5/5/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-10 S2	WG	WGR	CASA-10-22716	F	—	7/8/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-10 S2	WG	WGR	CASA-10-22718	UF	—	7/8/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
R-10 S2	WG	WGR	CASA-11-1366	F	—	11/17/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-10 S2	WG	WGR	CASA-11-1367	UF	—	11/17/2010	—	—	X	—	—	—	X	-	—	—	X	—	—
R-10 S2	WG	WGR	CASA-11-4573	UF	—	2/15/2011	—	—	X	—	—	—	X	-	—	—	—	—	—
R-10 S2	WG	WGR	CASA-11-4574	F	—	2/15/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-10 S2	WG	WGR	CASA-11-10828	UF	—	5/26/2011	—	—	X	—	—	—	X	—	—	—	X	X	X
R-10 S2	WG	WGR	CASA-11-10829	F	—	5/26/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-10 S2	WG	WGR	CASA-11-24772	F	—	8/9/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-10 S2	WG	WGR	CASA-11-24773	UF	—	8/9/2011	—	—	X	—	—	X	X	-	—	X	X	X	X
R-10a	WG	WGR	CASA-09-10359	UF	—	8/12/2009	—	—	X	—	X	X	X	-	—	X	X	X	X
R-10a	WG	WGR	CASA-09-10360	UF	Field Duplicate	8/12/2009	—	—	—	—	—	—	—	—	—	—	—	X	X
R-10a	WG	WGR	CASA-09-10362	F	—	8/12/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-10a	WG	WGR	CASA-10-3710	UF	—	11/10/2009	—	—	X	—	—	—	X	-	—	—	X	—	X
R-10a	WG	WGR	CASA-10-3712	F	—	11/10/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-10a	WG	WGR	CASA-10-9456	UF	—	2/9/2010	—	—	X	—	—	X	X	—	—	X	X	X	X
R-10a	WG	WGR	CASA-10-9457	UF	Field Duplicate	2/9/2010	—	—	—	—	—	—	—	—	—	—	—	X	X
R-10a	WG	WGR	CASA-10-9458	F	—	2/9/2010	—	—	X	—	—	—	X	X	—	—	—	—	—

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
R-10a	WG	WGR	CASA-10-16773	UF	—	5/5/2010	—	—	X	—	—	—	X	—	—	—	X	—	X
R-10a	WG	WGR	CASA-10-16775	F	—	5/5/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-10a	WG	WGR	CASA-10-22719	UF	—	7/8/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
R-10a	WG	WGR	CASA-10-22720	F	—	7/8/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-10a	WG	WGR	CASA-11-1368	UF	—	11/9/2010	—	—	X	—	—	—	X	-	—	—	X	—	—
R-10a	WG	WGR	CASA-11-1369	F	—	11/9/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-10a	WG	WGR	CASA-11-4575	F	—	2/15/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-10a	WG	WGR	CASA-11-4576	UF	—	2/15/2011	—	—	X	—	—	—	X	—	—	—	—	—	—
R-10a	WG	WGR	CASA-11-10830	UF	—	5/26/2011	—	—	X	—	—	—	X	—	—	—	X	X	X
R-10a	WG	WGR	CASA-11-10831	F	—	5/26/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-10a	WG	WGR	CASA-11-24776	F	—	8/9/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-10a	WG	WGR	CASA-11-24777	UF	—	8/9/2011	—	—	X	—	—	X	X	—	—	X	X	X	X
R-11	WG	WGR	CASA-09-10363	UF	Field Duplicate	8/10/2009	—	—	—	—	—	—	—	—	—	—	—	X	X
R-11	WG	WGR	CASA-09-10364	F	—	8/10/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-11	WG	WGR	CASA-09-10366	UF	—	8/10/2009	—	—	X	—	X	X	X	—	—	X	X	X	X
R-11	WG	WGR	CASA-10-3714	UF	—	11/18/2009	—	—	X	—	—	—	X	—	—	—	X	—	X
R-11	WG	WGR	CASA-10-3715	F	—	11/18/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-11	WG	WGR	CASA-10-9459	UF	—	1/29/2010	—	—	X	—	—	X	X	—	—	X	X	X	X
R-11	WG	WGR	CASA-10-9461	F	—	1/29/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-11	WG	WGR	CASA-10-9462	UF	Field Duplicate	1/29/2010	—	—	—	—	—	—	—	—	—	—	—	X	X
R-11	WG	WGR	CASA-10-16777	F	—	5/5/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-11	WG	WGR	CASA-10-16778	UF	—	5/5/2010	—	—	X	—	—	—	X	—	—	—	X	—	X
R-11	WG	WGR	CASA-10-22657	UF	—	7/8/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
R-11	WG	WGR	CASA-10-22658	F	—	7/8/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-11	WG	WGR	CASA-11-1370	F	—	11/11/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-11	WG	WGR	CASA-11-1371	UF	—	11/11/2010	—	—	X	—	—	—	X	—	—	—	X	—	—

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
R-11	WG	WGR	CASA-11-4559	F	—	2/25/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-11	WG	WGR	CASA-11-4560	UF	—	2/25/2011	—	—	X	—	—	—	X	—	—	—	—	—	—
R-11	WG	WGR	CASA-11-10810	F	—	5/23/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-11	WG	WGR	CASA-11-10811	UF	—	5/23/2011	—	—	X	—	—	—	X	—	—	—	X	—	—
R-11	WG	WGR	CASA-11-24778	UF	—	8/12/2011	—	—	X	—	—	—	X	—	—	—	—	—	—
R-11	WG	WGR	CASA-11-24779	F	—	8/12/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-11	WG	WGR	CASA-12-1379	UF	—	11/16/2011	—	—	X	—	—	—	X	—	—	—	X	X	X
R-11	WG	WGR	CASA-12-1380	F	—	11/16/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-11	WG	WGR	CASA-12-11709	UF	—	3/7/2012	—	—	X	—	—	—	—	—	—	—	—	—	—
R-11	WG	WGR	CASA-12-11713	F	—	3/7/2012	—	—	X	—	—	—	X	X	—	—	—	—	—
R-11	WG	WGR	CASA-12-14057	UF	—	5/21/2012	—	—	X	—	—	—	—	—	—	—	—	—	—
R-11	WG	WGR	CASA-12-14062	F	—	5/21/2012	—	—	X	—	—	—	X	X	—	—	—	—	—
R-13	WG	WGR	CAMO-09-9557	UF	Field Duplicate	8/6/2009	—	—	—	—	—	—	—	—	—	—	—	X	X
R-13	WG	WGR	CAMO-09-9558	UF	—	8/6/2009	—	—	X	—	X	X	X	—	—	X	X	X	X
R-13	WG	WGR	CAMO-09-9560	F	—	8/6/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-13	WG	WGR	CAMO-10-3134	UF	—	11/12/2009	—	—	X	—	—	—	X	-	—	—	—	—	X
R-13	WG	WGR	CAMO-10-3135	F	—	11/12/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-13	WG	WGR	CAMO-10-9341	F	—	2/11/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-13	WG	WGR	CAMO-10-9343	UF	—	2/11/2010	—	—	X	—	—	X	X	—	—	X	X	X	X
R-13	WG	WGR	CAMO-10-9345	F	Field Duplicate	2/11/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-13	WG	WGR	CAMO-10-9346	UF	Field Duplicate	2/11/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
R-13	WG	WGR	CAMO-10-16786	F	—	5/6/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-13	WG	WGR	CAMO-10-16787	UF	—	5/6/2010	—	—	X	—	—	—	X	—	—	—	—	—	X
R-13	WG	WGR	CAMO-10-16812	UF	Field Duplicate	5/6/2010	—	—	X	—	—	—	X	—	—	—	—	—	X
R-13	WG	WGR	CAMO-10-16814	F	Field Duplicate	5/6/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-13	WG	WGR	CAMO-10-22846	F	—	7/13/2010	—	—	X	—	—	—	X	X	—	—	—	—	—

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
R-13	WG	WGR	CAMO-10-22848	UF	—	7/13/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
R-13	WG	WGR	CAMO-11-1269	UF	—	11/9/2010	—	—	X	—	—	—	X	—	—	—	X	—	—
R-13	WG	WGR	CAMO-11-1270	F	—	11/9/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-13	WG	WGR	CAMO-11-4594	F	—	2/18/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-13	WG	WGR	CAMO-11-4595	UF	—	2/18/2011	—	—	X	—	—	—	X	—	—	—	—	—	—
R-13	WG	WGR	CAMO-11-10702	F	—	5/25/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-13	WG	WGR	CAMO-11-10703	UF	—	5/25/2011	—	—	X	—	—	—	X	—	—	—	X	—	—
R-13	WG	WGR	CAMO-11-24633	UF	—	8/1/2011	—	—	X	—	—	—	X	—	—	—	—	—	—
R-13	WG	WGR	CAMO-11-24634	F	—	8/1/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-13	WG	WGR	CAMO-12-1480	UF	—	11/22/2011	—	—	X	—	—	—	X	—	—	—	X	X	X
R-13	WG	WGR	CAMO-12-1482	F	—	11/22/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-13	WG	WGR	CAMO-12-17126	UF	—	6/5/2012	—	—	X	—	—	—	—	—	—	—	—	—	—
R-13	WG	WGR	CAMO-12-17131	F	—	6/5/2012	—	—	X	—	—	—	X	X	—	—	—	—	—
R-15	WG	WGR	CAMO-09-9540	F	—	8/6/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-15	WG	WGR	CAMO-09-9542	UF	—	8/6/2009	—	—	X	—	—	—	X	—	—	—	X	X	X
R-15	WG	WGR	CAMO-09-9543	F	Field Duplicate	8/6/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-15	WG	WGR	CAMO-09-9544	UF	Field Duplicate	8/6/2009	—	—	X	—	—	—	X	—	—	—	X	X	X
R-15	WG	WGR	CAMO-10-3137	F	—	11/5/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-15	WG	WGR	CAMO-10-3138	UF	—	11/5/2009	—	—	X	—	—	—	X	—	—	—	—	—	X
R-15	WG	WGR	CAMO-10-3141	F	Field Duplicate	11/5/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-15	WG	WGR	CAMO-10-3142	UF	Field Duplicate	11/5/2009	—	—	X	—	—	—	X	—	—	—	—	—	X
R-15	WG	WGR	CAMO-10-9323	F	—	2/11/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-15	WG	WGR	CAMO-10-9324	UF	—	2/11/2010	—	—	X	—	—	—	X	—	—	—	X	—	X
R-15	WG	WGR	CAMO-10-16759	UF	—	5/17/2010	—	—	X	—	—	—	X	—	—	—	—	—	X
R-15	WG	WGR	CAMO-10-16760	F	—	5/17/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-15	WG	WGR	CAMO-10-22856	F	—	7/14/2010	—	—	X	—	—	—	X	X	—	—	—	—	—

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatle Organic Analytes	Volatile Organic Analytes
R-15	WG	WGR	CAMO-10-22857	UF	—	7/14/2010	—	—	X	—	—	—	X	—	—	—	X	—	X
R-15	WG	WGR	CAMO-11-1267	F	—	11/9/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-15	WG	WGR	CAMO-11-1268	UF	—	11/9/2010	—	—	X	—	—	—	X	—	—	—	X	X	—
R-15	WG	WGR	CAMO-11-4596	F	—	2/28/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-15	WG	WGR	CAMO-11-4597	UF	—	2/28/2011	—	—	X	—	—	—	X	—	—	—	—	—	—
R-15	WG	WGR	CAMO-11-10714	F	—	5/31/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-15	WG	WGR	CAMO-11-10715	UF	—	5/31/2011	—	—	X	—	—	—	X	-	—	—	X	X	—
R-15	WG	WGR	CAMO-11-24635	F	—	8/15/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-15	WG	WGR	CAMO-11-24636	UF	—	8/15/2011	—	—	X	—	—	—	X	—	—	—	—	—	—
R-15	WG	WGR	CAMO-12-1483	F	—	11/10/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-15	WG	WGR	CAMO-12-1485	UF	—	11/10/2011	—	—	X	—	—	—	X	-	—	—	X	X	X
R-15	WG	WGR	CAMO-12-14007	UF	—	5/29/2012	—	—	X	—	—	—	—	—	—	—	—	—	—
R-15	WG	WGR	CAMO-12-14022	F	—	5/29/2012	—	—	X	—	—	—	X	X	—	—	—	—	—
R-28	WG	WGR	CAMO-09-9546	UF	—	8/13/2009	—	—	X	—	—	—	X	—	—	—	X	X	X
R-28	WG	WGR	CAMO-09-9547	F	—	8/13/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-28	WG	WGR	CAMO-10-3130	UF	—	11/5/2009	—	—	X	—	—	—	X	—	—	—	—	—	X
R-28	WG	WGR	CAMO-10-3132	F	—	11/5/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-28	WG	WGR	CAMO-10-9326	UF	—	2/3/2010	—	—	X	—	—	—	X	—	—	—	X	—	X
R-28	WG	WGR	CAMO-10-9328	F	—	2/3/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-28	WG	WGR	CAMO-10-16764	UF	—	5/13/2010	—	—	X	—	—	—	X	—	—	—	—	—	X
R-28	WG	WGR	CAMO-10-16765	F	—	5/13/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-28	WG	WGR	CAMO-10-22859	F	—	7/14/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-28	WG	WGR	CAMO-10-22860	UF	—	7/14/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
R-28	WG	WGR	CAMO-11-1271	UF	—	11/10/2010	—	—	X	—	—	—	X	—	—	—	X	—	—
R-28	WG	WGR	CAMO-11-1272	F	—	11/10/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-28	WG	WGR	CAMO-11-4598	UF	—	2/14/2011	—	—	X	—	—	—	X	—	—	—	—	—	—

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
R-28	WG	WGR	CAMO-11-4599	F	—	2/14/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-28	WG	WGR	CAMO-11-10704	F	—	6/1/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-28	WG	WGR	CAMO-11-10705	UF	—	6/1/2011	—	—	X	—	—	—	X	—	—	—	X	—	—
R-28	WG	WGR	CAMO-11-24637	UF	—	8/2/2011	—	—	X	—	—	—	X	—	—	—	—	—	—
R-28	WG	WGR	CAMO-11-24638	F	—	8/2/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-28	WG	WGR	CAMO-12-1486	UF	—	11/15/2011	—	—	X	—	—	—	X	—	—	—	X	X	X
R-28	WG	WGR	CAMO-12-1487	F	—	11/15/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-28	WG	WGR	CAMO-12-12018	UF	—	3/13/2012	—	—	X	—	—	—	—	—	—	—	—	—	—
R-28	WG	WGR	CAMO-12-12027	F	—	3/13/2012	—	—	X	—	—	—	X	X	—	—	—	—	—
R-28	WG	WGR	CAMO-12-14008	UF	—	5/24/2012	—	—	X	—	—	—	—	—	—	—	—	—	—
R-28	WG	WGR	CAMO-12-14023	F	—	5/24/2012	—	—	X	—	—	—	X	X	—	—	—	—	—
R-33 S1	WG	WGR	CAMO-09-9575	F	—	8/14/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-33 S1	WG	WGR	CAMO-09-9577	UF	Field Duplicate	8/14/2009	—	—	-	—	—	—	—	—	—	—	—	X	X
R-33 S1	WG	WGR	CAMO-09-9578	UF	—	8/14/2009	X	—	X	—	X	X	X	—	—	X	X	X	X
R-33 S1	WG	WGR	CAMO-10-3195	F	—	11/9/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-33 S1	WG	WGR	CAMO-10-3196	UF	—	11/9/2009	X	—	X	—	—	X	X	—	—	X	X	X	X
R-33 S1	WG	WGR	CAMO-10-3199	UF	Field Duplicate	11/9/2009	X	—	X	—	—	X	X	—	—	X	X	X	X
R-33 S1	WG	WGR	CAMO-10-3200	F	Field Duplicate	11/9/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-33 S1	WG	WGR	CAMO-10-9361	UF	—	1/28/2010	X	—	X	—	—	X	X	—	—	X	X	X	X
R-33 S1	WG	WGR	CAMO-10-9363	F	—	1/28/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-33 S1	WG	WGR	CAMO-10-9364	UF	Field Duplicate	1/28/2010	—	—	-	—	—	—	—	—	—	—	—	X	X
R-33 S1	WG	WGR	CAMO-10-16816	UF	—	5/12/2010	—	—	X	—	—	—	X	—	—	—	X	—	X
R-33 S1	WG	WGR	CAMO-10-16817	F	—	5/12/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-33 S1	WG	WGR	CAMO-10-22883	UF	—	7/9/2010	—	—	X	—	—	—	X	—	—	—	X	—	X
R-33 S1	WG	WGR	CAMO-10-22884	F	—	7/9/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-33 S1	WG	WGR	CAMO-11-1296	F	—	11/18/2010	—	—	X	—	—	—	X	X	—	—	—	—	—

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
R-33 S1	WG	WGR	CAMO-11-1297	UF	—	11/18/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
R-33 S1	WG	WGR	CAMO-11-4661	UF	—	2/10/2011	—	—	X	—	—	—	X	—	—	—	—	—	X
R-33 S1	WG	WGR	CAMO-11-4664	F	—	2/10/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-33 S1	WG	WGR	CAMO-11-4665	UF	Field Duplicate	2/10/2011	—	—	X	—	—	—	X	—	—	—	—	—	X
R-33 S1	WG	WGR	CAMO-11-4666	F	Field Duplicate	2/10/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-33 S1	WG	WGR	CAMO-11-10762	UF	—	5/16/2011	—	—	X	—	—	—	X	—	—	—	X	X	X
R-33 S1	WG	WGR	CAMO-11-10763	F	—	5/16/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-33 S1	WG	WGR	CAMO-11-10765	UF	Field Duplicate	5/16/2011	—	—	X	—	—	—	X	-	—	—	X	X	X
R-33 S1	WG	WGR	CAMO-11-10766	F	Field Duplicate	5/16/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-33 S1	WG	WGR	CAMO-11-24662	F	—	8/4/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-33 S1	WG	WGR	CAMO-11-24664	UF	—	8/4/2011	—	—	X	—	—	—	X	—	—	—	—	—	X
R-33 S1	WG	WGR	CAMO-11-24666	UF	Field Duplicate	8/4/2011	—	—	X	—	—	—	X	—	—	—	—	—	X
R-33 S1	WG	WGR	CAMO-11-24667	F	Field Duplicate	8/4/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-33 S2	WG	WGR	CAMO-09-9579	F	—	8/14/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-33 S2	WG	WGR	CAMO-09-9580	UF	—	8/14/2009	X	—	X	—	X	X	X	—	—	X	X	X	X
R-33 S2	WG	WGR	CAMO-09-9582	UF	Field Duplicate	8/14/2009	—	—	—	—	—	—	—	—	—	—	—	X	X
R-33 S2	WG	WGR	CAMO-10-3211	UF	—	11/6/2009	X	—	X	—	—	X	X	—	—	X	X	X	X
R-33 S2	WG	WGR	CAMO-10-3213	F	—	11/6/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-33 S2	WG	WGR	CAMO-10-9365	F	—	1/28/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-33 S2	WG	WGR	CAMO-10-9366	UF	Field Duplicate	1/28/2010	—	—	—	—	—	—	—	—	—	—	—	X	X
R-33 S2	WG	WGR	CAMO-10-9367	UF	—	1/28/2010	X	—	X	—	—	X	X	—	—	X	X	X	X
R-33 S2	WG	WGR	CAMO-10-16818	UF	—	5/12/2010	—	—	X	—	—	—	X	—	—	—	X	—	X
R-33 S2	WG	WGR	CAMO-10-16820	F	—	5/12/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-33 S2	WG	WGR	CAMO-10-22885	UF	—	7/9/2010	—	—	X	—	—	—	X	—	—	—	X	—	X
R-33 S2	WG	WGR	CAMO-10-22887	F	—	7/9/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-33 S2	WG	WGR	CAMO-11-1300	UF	—	11/18/2010	—	—	X	—	—	—	X	—	—	—	X	X	X

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
R-33 S2	WG	WGR	CAMO-11-1301	F	—	11/18/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-33 S2	WG	WGR	CAMO-11-4667	UF	—	2/11/2011	—	—	X	—	—	—	X	—	—	—	—	—	X
R-33 S2	WG	WGR	CAMO-11-4668	F	—	2/11/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-33 S2	WG	WGR	CAMO-11-10768	UF	—	5/16/2011	—	—	X	—	—	—	X	—	—	—	X	X	X
R-33 S2	WG	WGR	CAMO-11-10770	F	—	5/16/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-33 S2	WG	WGR	CAMO-11-24669	UF	—	8/4/2011	—	—	X	—	—	—	X	—	—	—	—	—	X
R-33 S2	WG	WGR	CAMO-11-24670	F	—	8/4/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-35a	WG	WGR	CASA-10-3826	F	—	11/4/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-35a	WG	WGR	CASA-10-3827	UF	—	11/4/2009	—	—	X	—	—	X	X	—	—	X	X	X	X
R-35a	WG	WGR	CASA-10-3895	F	—	11/4/2009	—	—	—	—	—	—	X	—	—	—	—	—	—
R-35a	WG	WGR	CASA-10-9463	UF	Field Duplicate	2/11/2010	—	—	—	—	—	—	-	—	—	—	—	X	X
R-35a	WG	WGR	CASA-10-9464	UF	—	2/11/2010	—	—	X	—	—	X	X	—	—	X	X	X	X
R-35a	WG	WGR	CASA-10-9465	F	—	2/11/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-35a	WG	WGR	CASA-10-9837	F	—	2/11/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
R-35a	WG	WGR	CASA-10-9846	F	—	2/11/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
R-35a	WG	WGR	CASA-10-16779	UF	—	5/14/2010	—	—	X	—	—	—	X	—	—	—	X	—	X
R-35a	WG	WGR	CASA-10-16781	F	—	5/14/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-35a	WG	WGR	CASA-10-22660	UF	—	7/7/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
R-35a	WG	WGR	CASA-10-22662	F	—	7/7/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-35a	WG	WGR	CASA-11-1372	F	—	11/11/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-35a	WG	WGR	CASA-11-1373	UF	—	11/11/2010	—	—	X	—	—	—	X	—	—	—	X	—	—
R-35a	WG	WGR	CASA-11-4561	UF	—	2/24/2011	—	—	X	—	—	—	X	—	—	—	—	—	—
R-35a	WG	WGR	CASA-11-4562	F	—	2/24/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-35a	WG	WGR	CASA-11-10812	F	—	5/23/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-35a	WG	WGR	CASA-11-10813	UF	—	5/23/2011	—	—	X	—	—	—	X	—	—	—	X	—	—
R-35a	WG	WGR	CASA-11-24780	F	—	8/17/2011	—	—	X	—	—	—	X	X	—	—	—	—	—

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
R-35a	WG	WGR	CASA-11-24781	UF	—	8/17/2011	—	—	X	—	—	—	X	—	—	—	—	—	—
R-35a	WG	WGR	CASA-12-1383	UF	—	11/17/2011	—	—	X	—	—	—	X	—	—	—	X	X	X
R-35a	WG	WGR	CASA-12-1384	F	—	11/17/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-35a	WG	WGR	CASA-12-17133	UF	—	6/5/2012	—	—	X	—	—	—	—	—	—	—	—	—	—
R-35a	WG	WGR	CASA-12-17136	F	—	6/5/2012	—	—	X	—	—	—	X	X	—	—	—	—	—
R-35b	WG	WGR	CASA-09-10392	UF	—	8/4/2009	X	—	X	—	X	X	X	—	—	X	X	X	X
R-35b	WG	WGR	CASA-09-10393	UF	Field Duplicate	8/4/2009	—	—	-	—	—	—	—	—	—	—	—	X	X
R-35b	WG	WGR	CASA-09-10394	F	—	8/4/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-35b	WG	WGR	CASA-10-3830	UF	—	11/3/2009	X	—	X	—	—	X	X	—	—	X	X	X	X
R-35b	WG	WGR	CASA-10-3831	F	—	11/3/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-35b	WG	WGR	CASA-10-9467	F	—	2/11/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-35b	WG	WGR	CASA-10-9469	UF	—	2/11/2010	—	—	X	—	—	X	X	—	—	X	X	X	X
R-35b	WG	WGR	CASA-10-9470	UF	Field Duplicate	2/11/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
R-35b	WG	WGR	CASA-10-9471	F	Field Duplicate	2/11/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-35b	WG	WGR	CASA-10-16782	F	—	5/12/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-35b	WG	WGR	CASA-10-16783	UF	—	5/12/2010	—	—	X	—	—	—	X	—	—	—	X	—	X
R-35b	WG	WGR	CASA-10-16789	F	Field Duplicate	5/12/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-35b	WG	WGR	CASA-10-16790	UF	Field Duplicate	5/12/2010	—	—	X	—	—	—	X	—	—	—	X	—	X
R-35b	WG	WGR	CASA-10-22663	UF	—	7/13/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
R-35b	WG	WGR	CASA-10-22664	F	—	7/13/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-35b	WG	WGR	CASA-10-22690	UF	Field Duplicate	7/13/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
R-35b	WG	WGR	CASA-10-22691	F	Field Duplicate	7/13/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-35b	WG	WGR	CASA-11-1374	UF	—	11/11/2010	—	—	X	—	—	—	X	—	—	—	X	—	—
R-35b	WG	WGR	CASA-11-1375	F	—	11/11/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-35b	WG	WGR	CASA-11-4563	UF	—	2/28/2011	—	—	X	—	—	—	X	—	—	—	—	—	—
R-35b	WG	WGR	CASA-11-4564	F	—	2/28/2011	—	—	X	—	—	—	X	X	—	—	—	—	—

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
R-35b	WG	WGR	CASA-11-10814	F	—	6/1/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-35b	WG	WGR	CASA-11-10815	UF	—	6/1/2011	—	—	X	—	—	—	X	—	—	—	X	—	—
R-35b	WG	WGR	CASA-11-24782	F	—	8/12/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-35b	WG	WGR	CASA-11-24783	UF	—	8/12/2011	—	—	X	—	—	—	X	—	—	—	—	—	—
R-35b	WG	WGR	CASA-12-1386	F	—	11/9/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-35b	WG	WGR	CASA-12-1387	UF	—	11/9/2011	—	—	X	—	—	—	X	—	—	—	X	X	X
R-35b	WG	WGR	CASA-12-17134	UF	—	6/6/2012	—	—	X	—	—	—	—	—	—	—	—	—	—
R-35b	WG	WGR	CASA-12-17137	F	—	6/6/2012	—	—	X	—	—	—	X	X	—	—	—	—	—
R-36	WG	WGR	CASA-09-10373	UF	Field Duplicate	8/5/2009	X	—	X	—	—	X	X	—	—	X	X	X	X
R-36	WG	WGR	CASA-09-10375	F	Field Duplicate	8/5/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-36	WG	WGR	CASA-09-10376	UF	—	8/5/2009	X	—	X	—	—	X	X	—	—	X	X	X	X
R-36	WG	WGR	CASA-09-10377	F	—	8/5/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-36	WG	WGR	CASA-10-3833	F	—	11/4/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-36	WG	WGR	CASA-10-3834	UF	—	11/4/2009	X	—	X	—	—	X	X	—	—	X	X	X	X
R-36	WG	WGR	CASA-10-3854	UF	Field Duplicate	11/4/2009	X	—	X	—	—	X	X	—	—	X	X	X	X
R-36	WG	WGR	CASA-10-3855	F	Field Duplicate	11/4/2009	—	—	X	—	—	-	X	X	—	—	—	—	—
R-36	WG	WGR	CASA-10-9493	UF	—	2/4/2010	X	—	X	—	—	X	X	—	—	X	X	X	X
R-36	WG	WGR	CASA-10-9494	F	—	2/4/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-36	WG	WGR	CASA-10-16792	F	—	5/12/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-36	WG	WGR	CASA-10-16793	UF	—	5/12/2010	—	—	X	—	—	X	X	—	—	—	X	—	X
R-36	WG	WGR	CASA-10-22702	UF	—	7/12/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
R-36	WG	WGR	CASA-10-22703	F	—	7/12/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-36	WG	WGR	CASA-11-1376	UF	—	11/11/2010	—	—	X	—	—	—	X	—	—	—	X	—	—
R-36	WG	WGR	CASA-11-1377	F	—	11/11/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-36	WG	WGR	CASA-11-4565	UF	—	2/25/2011	—	—	X	—	—	—	X	—	—	—	—	—	—
R-36	WG	WGR	CASA-11-4566	F	—	2/25/2011	—	—	X	—	—	—	X	X	—	—	—	—	—

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
R-36	WG	WGR	CASA-11-10816	UF	—	6/2/2011	—	—	X	—	—	—	X	—	—	—	X	—	—
R-36	WG	WGR	CASA-11-10817	F	—	6/2/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-36	WG	WGR	CASA-11-24788	F	—	8/15/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-36	WG	WGR	CASA-11-24789	UF	—	8/15/2011	—	—	X	—	—	—	X	—	—	—	—	—	—
R-36	WG	WGR	CASA-12-1388	UF	—	11/16/2011	—	—	X	—	—	—	X	—	—	—	X	X	X
R-36	WG	WGR	CASA-12-1390	F	—	11/16/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-36	WG	WGR	CASA-12-12037	UF	—	3/8/2012	—	—	X	—	—	—	—	—	—	—	—	—	—
R-36	WG	WGR	CASA-12-12038	F	—	3/8/2012	—	—	X	—	—	—	X	X	—	—	—	—	—
R-36	WG	WGR	CASA-12-17135	UF	—	5/30/2012	—	—	X	—	—	—	—	—	—	—	—	—	—
R-36	WG	WGR	CASA-12-17138	F	—	5/30/2012	—	—	X	—	—	—	X	X	—	—	—	—	—
R-42	WG	WGR	CAMO-09-10297	F	—	8/14/2009	—	—	—	—	—	—	X	—	—	—	—	—	—
R-42	WG	WGR	CAMO-09-9568	UF	—	8/14/2009	X	—	X	—	—	X	X	—	—	X	X	X	X
R-42	WG	WGR	CAMO-09-9570	F	—	8/14/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-42	WG	WGR	CAMO-10-3218	UF	—	11/5/2009	X	—	X	—	—	X	X	—	—	X	X	X	X
R-42	WG	WGR	CAMO-10-3219	F	—	11/5/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-42	WG	WGR	CAMO-10-3900	F	—	11/5/2009	—	—	-	—	—	—	X	-	—	—	—	—	—
R-42	WG	WGR	CAMO-10-9355	F	—	2/10/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-42	WG	WGR	CAMO-10-9357	UF	—	2/10/2010	X	—	X	—	—	X	X	—	—	X	X	X	X
R-42	WG	WGR	CAMO-10-9728	F	—	2/10/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
R-42	WG	WGR	CAMO-10-9739	F	—	2/10/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
R-42	WG	WGR	CAMO-10-16821	F	—	5/13/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-42	WG	WGR	CAMO-10-16822	UF	—	5/13/2010	—	—	X	—	—	X	X	—	—	—	X	—	X
R-42	WG	WGR	CAMO-10-22891	UF	—	7/13/2010	—	—	X	—	—	—	X	—	—	—	X	—	X
R-42	WG	WGR	CAMO-10-22893	F	—	7/13/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-42	WG	WGR	CAMO-11-1273	UF	—	11/10/2010	—	—	X	—	—	—	X	—	—	—	X	X	—
R-42	WG	WGR	CAMO-11-1274	F	—	11/10/2010	—	—	X	—	—	—	X	X	—	—	—	—	—

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
R-42	WG	WGR	CAMO-11-4600	F	—	2/18/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-42	WG	WGR	CAMO-11-4601	UF	—	2/18/2011	—	—	X	—	—	—	X	—	—	—	—	—	—
R-42	WG	WGR	CAMO-11-10717	UF	—	5/31/2011	—	—	X	—	—	—	X	—	—	—	X	X	—
R-42	WG	WGR	CAMO-11-10718	F	—	5/31/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-42	WG	WGR	CAMO-11-24639	UF	—	8/2/2011	—	—	X	—	—	—	X	—	—	—	—	—	—
R-42	WG	WGR	CAMO-11-24640	F	—	8/2/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-42	WG	WGR	CAMO-12-1490	F	—	11/10/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-42	WG	WGR	CAMO-12-1491	UF	—	11/10/2011	—	—	X	—	—	—	X	—	—	—	X	X	X
R-42	WG	WGR	CAMO-12-12020	UF	—	3/9/2012	—	—	X	—	—	—	—	—	—	—	—	—	—
R-42	WG	WGR	CAMO-12-12029	F	—	3/9/2012	—	—	X	—	—	—	X	X	—	—	—	—	—
R-42	WG	WGR	CAMO-12-14009	UF	—	5/23/2012	—	—	X	—	—	—	—	—	—	—	—	—	—
R-42	WG	WGR	CAMO-12-14024	F	—	5/23/2012	—	—	X	—	—	—	X	X	—	—	—	—	—
R-43 S1	WG	WGR	CAMO-09-10501	UF	—	6/19/2009	X	—	X	—	—	X	X	—	—	X	X	X	X
R-43 S1	WG	WGR	CAMO-09-10502	F	—	6/19/2009	—	—	X	—	—	—	X	X	—	-	X	—	—
R-43 S1	WG	WGR	CAMO-09-10504	F	—	6/19/2009	—	—	—	—	—	—	X	—	—	—	—	—	—
R-43 S1	WG	WGR	CAMO-09-10505	UF	Field Duplicate	6/19/2009	—	—	—	—	—	—	—	—	—	—	—	X	X
R-43 S1	WG	WGR	CAMO-09-10506	UF	Field Split	6/19/2009	—	—	—	—	—	—	—	—	—	—	—	—	X
R-43 S1	WG	WGR	CASA-09-10396	F	—	8/18/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-43 S1	WG	WGR	CASA-09-10397	UF	—	8/18/2009	X	—	X	—	X	X	X	—	—	X	X	X	X
R-43 S1	WG	WGR	CASA-09-10398	UF	Field Duplicate	8/18/2009	—	—	—	—	—	—	—	—	—	—	—	X	X
R-43 S1	WG	WGR	CASA-09-10403	F	—	8/18/2009	—	—	—	—	—	—	X	—	—	—	—	—	—
R-43 S1	WG	WGR	CASA-10-3857	F	—	11/19/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-43 S1	WG	WGR	CASA-10-3858	UF	—	11/19/2009	X	—	X	—	—	X	X	—	—	X	X	X	X
R-43 S1	WG	WGR	CASA-10-3896	F	—	11/19/2009	—	—	—	—	—	—	X	—	—	—	—	—	—
R-43 S1	WG	WGR	CASA-10-4776	F	—	11/19/2009	—	—	—	—	—	—	X	—	—	—	—	—	—
R-43 S1	WG	WGR	CASA-10-9481	F	—	2/2/2010	—	—	X	—	—	—	X	X	—	—	—	—	—

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
R-43 S1	WG	WGR	CASA-10-9483	UF	Field Duplicate	2/2/2010	—	—	—	—	—	—	—	—	—	—	—	X	X
R-43 S1	WG	WGR	CASA-10-9484	UF	—	2/2/2010	X	—	X	—	—	X	X	—	—	X	X	X	X
R-43 S1	WG	WGR	CASA-10-9838	F	—	2/2/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
R-43 S1	WG	WGR	CASA-10-9842	F	—	2/2/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
R-43 S1	WG	WGR	CASA-10-16794	F	—	5/10/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-43 S1	WG	WGR	CASA-10-16795	UF	—	5/10/2010	—	—	X	—	—	X	X	—	—	—	X	—	X
R-43 S1	WG	WGR	CASA-10-22705	UF	—	7/15/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
R-43 S1	WG	WGR	CASA-10-22706	F	—	7/15/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-43 S1	WG	WGR	CASA-11-1378	F	—	11/16/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-43 S1	WG	WGR	CASA-11-1379	UF	—	11/16/2010	—	—	X	—	—	—	X	—	—	—	X	—	—
R-43 S1	WG	WGR	CASA-11-4567	UF	—	2/23/2011	—	—	X	—	—	—	X	—	—	—	—	—	—
R-43 S1	WG	WGR	CASA-11-4568	F	—	2/23/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-43 S1	WG	WGR	CASA-11-10818	UF	—	5/18/2011	—	—	X	—	—	—	X	—	—	—	X	—	—
R-43 S1	WG	WGR	CASA-11-10819	F	—	5/18/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-43 S1	WG	WGR	CASA-11-24784	F	—	8/16/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-43 S1	WG	WGR	CASA-11-24785	UF	—	8/16/2011	—	—	X	—	—	—	X	—	—	—	—	—	—
R-43 S1	WG	WGR	CASA-12-1391	UF	—	11/15/2011	—	—	X	—	—	—	X	—	—	—	X	X	X
R-43 S1	WG	WGR	CASA-12-1393	F	—	11/15/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-43 S1	WG	WGR	CASA-12-11710	UF	—	3/9/2012	—	—	X	—	—	—	—	—	—	—	—	—	—
R-43 S1	WG	WGR	CASA-12-11714	F	—	3/9/2012	—	—	X	—	—	—	X	X	—	—	—	—	—
R-43 S1	WG	WGR	CASA-12-14058	UF	—	5/22/2012	—	—	X	—	—	—	—	—	—	—	—	—	—
R-43 S1	WG	WGR	CASA-12-14063	F	—	5/22/2012	—	—	X	—	—	—	X	X	—	—	—	—	—
R-43 S2	WG	WGR	CAMO-09-10508	UF	—	6/18/2009	X	—	X	—	—	X	X	—	—	X	X	X	X
R-43 S2	WG	WGR	CAMO-09-10509	F	—	6/18/2009	—	—	X	—	—	—	X	X	—	—	X	—	—
R-43 S2	WG	WGR	CAMO-09-10512	F	—	6/18/2009	—	—	-	—	—	—	X	—	—	—	—	—	—
R-43 S2	WG	WGR	CAMO-09-10513	UF	Field Duplicate	6/18/2009	—	—	-	—	—	—	—	—	—	—	—	X	X

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
R-43 S2	WG	WGR	CAMO-09-10514	UF	Field Split	6/18/2009	—	—	—	—	—	—	—	—	—	—	—	—	X
R-43 S2	WG	WGR	CASA-09-10399	UF	Field Duplicate	8/18/2009	—	—	—	—	—	—	—	—	—	—	—	X	X
R-43 S2	WG	WGR	CASA-09-10401	F	—	8/18/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-43 S2	WG	WGR	CASA-09-10402	UF	—	8/18/2009	X	—	X	—	X	X	X	—	—	X	X	X	X
R-43 S2	WG	WGR	CASA-09-10404	F	—	8/18/2009	—	—	—	—	—	—	X	—	—	—	—	—	—
R-43 S2	WG	WGR	CASA-10-3860	F	—	11/19/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-43 S2	WG	WGR	CASA-10-3861	UF	—	11/19/2009	X	—	X	—	—	X	X	—	—	X	X	X	X
R-43 S2	WG	WGR	CASA-10-3897	F	—	11/19/2009	—	—	—	—	—	—	X	—	—	—	—	—	—
R-43 S2	WG	WGR	CASA-10-9485	UF	Field Duplicate	2/2/2010	—	—	—	—	—	—	—	—	—	—	—	X	X
R-43 S2	WG	WGR	CASA-10-9486	UF	—	2/2/2010	X	—	X	—	—	X	X	—	—	X	X	X	X
R-43 S2	WG	WGR	CASA-10-9488	F	—	2/2/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-43 S2	WG	WGR	CASA-10-9839	F	—	2/2/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
R-43 S2	WG	WGR	CASA-10-9845	F	—	2/2/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
R-43 S2	WG	WGR	CASA-10-16798	F	—	5/10/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-43 S2	WG	WGR	CASA-10-16799	UF	—	5/10/2010	—	—	X	—	—	X	X	-	—	—	X	-	X
R-43 S2	WG	WGR	CASA-10-22709	UF	—	7/15/2010	—	—	X	—	—	—	X	-	—	—	X	X	X
R-43 S2	WG	WGR	CASA-10-22710	F	—	7/15/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-43 S2	WG	WGR	CASA-11-1380	UF	—	11/16/2010	—	—	X	—	—	—	X	-	—	—	X	—	—
R-43 S2	WG	WGR	CASA-11-1381	F	—	11/16/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-43 S2	WG	WGR	CASA-11-4569	F	—	2/22/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-43 S2	WG	WGR	CASA-11-4570	UF	—	2/22/2011	—	—	X	—	—	—	X	-	—	—	—	—	—
R-43 S2	WG	WGR	CASA-11-10820	UF	—	5/18/2011	—	—	X	—	—	—	X	-	—	—	X	—	—
R-43 S2	WG	WGR	CASA-11-10821	F	—	5/18/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-43 S2	WG	WGR	CASA-11-24786	F	—	8/16/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-43 S2	WG	WGR	CASA-11-24787	UF	—	8/16/2011	—	—	X	—	—	—	X	—	—	—	—	—	—
R-43 S2	WG	WGR	CASA-12-1395	F	—	11/15/2011	—	—	X	—	—	—	X	X	—	—	—	—	—

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
R-43 S2	WG	WGR	CASA-12-1396	UF	—	11/15/2011	—	—	X	—	—	—	X	—	—	—	X	X	X
R-43 S2	WG	WGR	CASA-12-1397	UF	Field Duplicate	11/15/2011	—	—	X	—	—	—	X	—	—	—	X	X	X
R-43 S2	WG	WGR	CASA-12-1398	F	Field Duplicate	11/15/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-43 S2	WG	WGR	CASA-12-11711	UF	—	3/12/2012	—	—	X	—	—	—	—	—	—	—	—	—	—
R-43 S2	WG	WGR	CASA-12-11715	F	—	3/12/2012	—	—	X	—	—	—	X	X	—	—	—	—	—
R-43 S2	WG	WGR	CASA-12-14059	UF	—	5/22/2012	—	—	X	—	—	—	—	—	—	—	—	—	—
R-43 S2	WG	WGR	CASA-12-14064	F	—	5/22/2012	—	—	X	—	—	—	X	X	—	—	—	—	—
R-44 S1	WG	WGR	CAMO-09-10295	F	—	8/17/2009	—	—	-	—	—	—	X	—	—	—	—	—	—
R-44 S1	WG	WGR	CAMO-09-9919	F	—	8/17/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-44 S1	WG	WGR	CAMO-09-9920	UF	Field Duplicate	8/17/2009	—	—	—	—	—	—	—	—	—	—	—	X	X
R-44 S1	WG	WGR	CAMO-09-9922	UF	—	8/17/2009	X	—	X	—	X	X	X	—	—	X	X	X	X
R-44 S1	WG	WGR	CAMO-10-3224	F	—	11/13/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-44 S1	WG	WGR	CAMO-10-3225	UF	—	11/13/2009	X	—	X	—	—	X	X	—	—	X	X	X	X
R-44 S1	WG	WGR	CAMO-10-3901	F	—	11/13/2009	—	—	—	—	—	—	X	—	—	—	—	—	—
R-44 S1	WG	WGR	CAMO-10-4774	F	—	11/13/2009	—	—	—	—	—	—	X	—	—	—	—	—	—
R-44 S1	WG	WGR	CAMO-10-9369	UF	Field Duplicate	2/10/2010	—	—	—	—	—	—	—	—	—	—	—	—	X
R-44 S1	WG	WGR	CAMO-10-9370	UF	—	2/10/2010	X	—	X	—	—	X	X	—	—	X	X	—	X
R-44 S1	WG	WGR	CAMO-10-9372	F	—	2/10/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-44 S1	WG	WGR	CAMO-10-9729	F	—	2/10/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
R-44 S1	WG	WGR	CAMO-10-9738	F	—	2/10/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
R-44 S1	WG	WGR	CAMO-10-16840	UF	—	5/4/2010	—	—	X	—	—	X	X	—	—	X	X	X	X
R-44 S1	WG	WGR	CAMO-10-16841	F	—	5/4/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-44 S1	WG	WGR	CAMO-10-16842	UF	Field Duplicate	5/4/2010	—	—	—	—	—	—	—	—	—	—	—	X	—
R-44 S1	WG	WGR	CAMO-10-22864	F	—	7/14/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-44 S1	WG	WGR	CAMO-10-22866	UF	—	7/14/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
R-44 S1	WG	WGR	CAMO-11-1275	F	—	11/18/2010	—	—	X	—	—	—	X	X	—	—	—	—	—

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
R-44 S1	WG	WGR	CAMO-11-1276	UF	—	11/18/2010	—	—	X	—	—	—	X	—	—	—	X	—	—
R-44 S1	WG	WGR	CAMO-11-4602	F	—	2/25/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-44 S1	WG	WGR	CAMO-11-4603	UF	—	2/25/2011	—	—	X	—	—	—	X	—	—	—	—	—	—
R-44 S1	WG	WGR	CAMO-11-10706	UF	—	5/19/2011	—	—	X	—	—	—	X	—	—	—	X	—	—
R-44 S1	WG	WGR	CAMO-11-10707	F	—	5/19/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-44 S1	WG	WGR	CAMO-11-24645	UF	—	8/5/2011	—	—	X	—	—	—	X	—	—	—	—	—	—
R-44 S1	WG	WGR	CAMO-11-24646	F	—	8/5/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-44 S1	WG	WGR	CAMO-12-1498	F	—	11/17/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-44 S1	WG	WGR	CAMO-12-1500	UF	—	11/17/2011	—	—	X	—	—	—	X	-	—	—	X	X	X
R-44 S1	WG	WGR	CAMO-12-14010	UF	—	5/24/2012	—	—	X	—	—	—	—	—	—	—	—	—	—
R-44 S1	WG	WGR	CAMO-12-14025	F	—	5/24/2012	—	—	X	—	—	—	X	X	—	—	—	—	—
R-44 S2	WG	WGR	CAMO-09-10296	F	—	8/17/2009	—	—	—	—	—	—	X	—	—	—	—	—	—
R-44 S2	WG	WGR	CAMO-09-9924	UF	Field Duplicate	8/17/2009	—	—	—	—	—	—	—	—	—	—	—	X	X
R-44 S2	WG	WGR	CAMO-09-9925	F	—	8/17/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-44 S2	WG	WGR	CAMO-09-9927	UF	—	8/17/2009	X	—	X	—	X	X	X	—	—	X	X	X	X
R-44 S2	WG	WGR	CAMO-10-3227	F	—	11/13/2009	—	—	X	—	—	-	X	X	—	—	—	—	—
R-44 S2	WG	WGR	CAMO-10-3228	UF	—	11/13/2009	X	—	X	—	—	X	X	—	—	X	X	X	X
R-44 S2	WG	WGR	CAMO-10-3902	F	—	11/13/2009	—	—	—	—	—	—	X	—	—	—	—	—	—
R-44 S2	WG	WGR	CAMO-10-4772	F	—	11/13/2009	—	—	—	—	—	—	X	—	—	—	—	—	—
R-44 S2	WG	WGR	CAMO-10-9373	UF	—	2/10/2010	X	—	X	—	—	X	X	—	—	X	X	—	X
R-44 S2	WG	WGR	CAMO-10-9374	F	—	2/10/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-44 S2	WG	WGR	CAMO-10-9376	UF	Field Duplicate	2/10/2010	—	—	—	—	—	—	—	—	—	—	—	—	X
R-44 S2	WG	WGR	CAMO-10-9730	F	—	2/10/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
R-44 S2	WG	WGR	CAMO-10-9736	F	—	2/10/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
R-44 S2	WG	WGR	CAMO-10-16843	UF	—	5/4/2010	—	—	X	—	—	X	X	—	—	X	X	X	X
R-44 S2	WG	WGR	CAMO-10-16844	F	—	5/4/2010	—	—	X	—	—	—	X	X	—	—	—	—	—

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
R-44 S2	WG	WGR	CAMO-10-16846	F	Field Duplicate	5/4/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-44 S2	WG	WGR	CAMO-10-16847	UF	Field Duplicate	5/4/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
R-44 S2	WG	WGR	CAMO-10-22868	UF	—	7/14/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
R-44 S2	WG	WGR	CAMO-10-22869	F	—	7/14/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-44 S2	WG	WGR	CAMO-10-22870	F	Field Duplicate	7/14/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-44 S2	WG	WGR	CAMO-10-22871	UF	Field Duplicate	7/14/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
R-44 S2	WG	WGR	CAMO-11-1277	F	—	11/18/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-44 S2	WG	WGR	CAMO-11-1278	UF	—	11/18/2010	—	—	X	—	—	—	X	—	—	—	X	—	—
R-44 S2	WG	WGR	CAMO-11-4604	F	—	2/25/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-44 S2	WG	WGR	CAMO-11-4605	UF	—	2/25/2011	—	—	X	—	—	—	X	—	—	—	—	—	—
R-44 S2	WG	WGR	CAMO-11-10708	F	—	5/19/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-44 S2	WG	WGR	CAMO-11-10709	UF	—	5/19/2011	—	—	X	—	—	—	X	—	—	—	X	—	—
R-44 S2	WG	WGR	CAMO-11-24647	F	—	8/5/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-44 S2	WG	WGR	CAMO-11-24648	UF	—	8/5/2011	—	—	X	—	—	—	X	—	—	—	—	—	—
R-44 S2	WG	WGR	CAMO-12-1501	F	—	11/17/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-44 S2	WG	WGR	CAMO-12-1502	UF	—	11/17/2011	—	—	X	—	—	—	X	—	—	—	X	X	X
R-44 S2	WG	WGR	CAMO-12-14011	UF	—	5/24/2012	—	—	X	—	—	—	-	—	—	—	—	—	—
R-44 S2	WG	WGR	CAMO-12-14026	F	—	5/24/2012	—	—	X	—	—	—	X	X	—	—	—	—	—
R-45 S1	WG	WGR	CAMO-09-10251	UF	Field Duplicate	8/19/2009	—	—	—	—	—	—	—	—	—	—	—	X	X
R-45 S1	WG	WGR	CAMO-09-10252	F	—	8/19/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-45 S1	WG	WGR	CAMO-09-10254	UF	—	8/19/2009	X	—	X	—	X	X	X	—	—	X	X	X	X
R-45 S1	WG	WGR	CAMO-09-10293	F	—	8/19/2009	—	—	—	—	—	—	X	—	—	—	—	—	—
R-45 S1	WG	WGR	CAMO-10-3229	F	—	11/16/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-45 S1	WG	WGR	CAMO-10-3231	UF	—	11/16/2009	X	—	X	—	—	X	X	—	—	X	X	X	X
R-45 S1	WG	WGR	CAMO-10-3903	F	—	11/16/2009	—	—	—	—	—	—	X	—	—	—	—	—	—
R-45 S1	WG	WGR	CAMO-10-4769	F	—	11/16/2009	—	—	—	—	—	—	X	—	—	—	—	—	—

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
R-45 S1	WG	WGR	CAMO-10-9377	UF	Field Duplicate	1/27/2010	—	—	—	—	—	—	—	—	—	—	—	X	X
R-45 S1	WG	WGR	CAMO-10-9378	F	—	1/27/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-45 S1	WG	WGR	CAMO-10-9379	UF	—	1/27/2010	X	—	X	—	—	X	X	—	—	X	X	X	X
R-45 S1	WG	WGR	CAMO-10-9731	F	—	1/27/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
R-45 S1	WG	WGR	CAMO-10-9734	F	—	1/27/2010	—	—	—	—	—	—	X	-	—	—	—	—	—
R-45 S1	WG	WGR	CAMO-10-16824	F	—	5/13/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-45 S1	WG	WGR	CAMO-10-16825	UF	—	5/13/2010	—	—	X	—	—	X	X	—	—	—	X	-	X
R-45 S1	WG	WGR	CAMO-10-22876	F	—	7/2/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-45 S1	WG	WGR	CAMO-10-22877	UF	—	7/2/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
R-45 S1	WG	WGR	CAMO-11-1279	UF	—	11/19/2010	—	—	X	—	—	—	X	—	—	—	X	—	—
R-45 S1	WG	WGR	CAMO-11-1280	F	—	11/19/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-45 S1	WG	WGR	CAMO-11-4606	F	—	2/10/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-45 S1	WG	WGR	CAMO-11-4607	UF	—	2/10/2011	—	—	X	—	—	—	X	—	—	—	—	—	—
R-45 S1	WG	WGR	CAMO-11-10710	UF	—	5/20/2011	—	—	X	—	—	—	X	—	—	—	X	—	—
R-45 S1	WG	WGR	CAMO-11-10711	F	—	5/20/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-45 S1	WG	WGR	CAMO-11-24641	F	—	8/1/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-45 S1	WG	WGR	CAMO-11-24642	UF	—	8/1/2011	—	—	X	—	—	—	X	—	—	—	—	—	—
R-45 S1	WG	WGR	CAMO-12-1492	F	—	11/16/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-45 S1	WG	WGR	CAMO-12-1494	UF	—	11/16/2011	—	—	X	—	—	—	X	—	—	—	X	X	X
R-45 S1	WG	WGR	CAMO-12-14012	UF	—	5/22/2012	—	—	X	—	—	—	—	—	—	—	—	—	—
R-45 S1	WG	WGR	CAMO-12-14027	F	—	5/22/2012	—	—	X	—	—	—	X	X	—	—	—	—	—
R-45 S2	WG	WGR	CAMO-09-10255	F	—	8/19/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-45 S2	WG	WGR	CAMO-09-10256	UF	—	8/19/2009	X	—	X	—	X	X	X	—	—	X	X	X	X
R-45 S2	WG	WGR	CAMO-09-10258	UF	Field Duplicate	8/19/2009	—	—	—	—	—	—	—	—	—	—	—	X	X
R-45 S2	WG	WGR	CAMO-09-10294	F	—	8/19/2009	—	—	—	—	—	—	X	—	—	—	—	—	—
R-45 S2	WG	WGR	CAMO-10-3233	F	—	11/16/2009	—	—	X	—	—	—	X	X	—	—	—	—	—

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
R-45 S2	WG	WGR	CAMO-10-3234	UF	—	11/16/2009	X	—	X	—	—	X	X	—	—	X	X	X	X
R-45 S2	WG	WGR	CAMO-10-3904	F	—	11/16/2009	—	—	—	—	—	—	X	—	—	—	—	—	—
R-45 S2	WG	WGR	CAMO-10-4771	F	—	11/16/2009	—	—	—	—	—	—	X	—	—	—	—	—	—
R-45 S2	WG	WGR	CAMO-10-9383	F	—	1/27/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-45 S2	WG	WGR	CAMO-10-9384	UF	—	1/27/2010	X	—	X	—	—	X	X	—	—	X	X	X	X
R-45 S2	WG	WGR	CAMO-10-9385	UF	Field Duplicate	1/27/2010	X	—	X	—	—	X	X	—	—	X	X	X	X
R-45 S2	WG	WGR	CAMO-10-9386	F	Field Duplicate	1/27/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-45 S2	WG	WGR	CAMO-10-9732	F	—	1/27/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
R-45 S2	WG	WGR	CAMO-10-9735	F	—	1/27/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
R-45 S2	WG	WGR	CAMO-10-16828	UF	—	5/14/2010	—	—	X	—	—	X	X	—	—	—	X	—	X
R-45 S2	WG	WGR	CAMO-10-16829	F	—	5/14/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-45 S2	WG	WGR	CAMO-10-22873	F	—	7/2/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-45 S2	WG	WGR	CAMO-10-22874	UF	—	7/2/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
R-45 S2	WG	WGR	CAMO-11-1281	F	—	11/19/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-45 S2	WG	WGR	CAMO-11-1282	UF	—	11/19/2010	—	—	X	—	—	—	X	—	—	—	X	—	—
R-45 S2	WG	WGR	CAMO-11-4608	F	—	2/11/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-45 S2	WG	WGR	CAMO-11-4609	UF	—	2/11/2011	—	—	X	—	—	—	X	—	—	—	—	—	—
R-45 S2	WG	WGR	CAMO-11-10712	F	—	5/20/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-45 S2	WG	WGR	CAMO-11-10713	UF	—	5/20/2011	—	—	X	—	—	—	X	—	—	—	X	—	—
R-45 S2	WG	WGR	CAMO-11-24643	F	—	8/1/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-45 S2	WG	WGR	CAMO-11-24644	UF	—	8/1/2011	—	—	X	—	—	—	X	—	—	—	—	—	—
R-45 S2	WG	WGR	CAMO-12-1496	F	—	11/16/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-45 S2	WG	WGR	CAMO-12-1497	UF	—	11/16/2011	—	—	X	—	—	—	X	—	—	—	X	X	X
R-45 S2	WG	WGR	CAMO-12-14013	UF	—	5/22/2012	—	—	X	—	—	—	—	—	—	—	—	—	—
R-45 S2	WG	WGR	CAMO-12-14028	F	—	5/22/2012	—	—	X	—	—	—	X	X	—	—	—	—	—
R-50 S1	WG	WGR	CAMO-10-13852	UF	—	3/6/2010	X	—	X	—	—	X	X	—	—	X	X	X	X

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
R-50 S1	WG	WGR	CAMO-10-13853	F	—	3/6/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-50 S1	WG	WGR	CAMO-10-17420	UF	—	5/27/2010	X	—	X	—	—	X	X	—	—	X	X	X	X
R-50 S1	WG	WGR	CAMO-10-17421	F	—	5/27/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-50 S1	WG	WGR	CAMO-10-18481	F	—	5/27/2010	—	—	-	—	—	—	X	—	—	—	—	—	—
R-50 S1	WG	WGR	CAMO-10-18974	UF	—	5/27/2010	—	—	-	—	—	—	X	—	—	—	—	—	—
R-50 S1	WG	WGR	CAMO-10-18975	F	—	5/27/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-50 S1	WG	WGR	CAMO-10-19012	UF	Field Duplicate	5/27/2010	—	—	—	—	—	—	—	—	—	—	—	X	X
R-50 S1	WG	WGR	CAMO-10-22902	UF	—	7/2/2010	X	—	X	—	—	X	X	—	—	X	X	X	X
R-50 S1	WG	WGR	CAMO-10-22903	UF	Field Duplicate	7/2/2010	—	—	-	—	—	—	—	—	—	—	—	X	X
R-50 S1	WG	WGR	CAMO-10-22904	F	—	7/2/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-50 S1	WG	WGR	CAMO-11-1312	UF	—	11/16/2010	X	—	X	—	—	X	X	—	—	X	X	X	X
R-50 S1	WG	WGR	CAMO-11-1313	F	—	11/16/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-50 S1	WG	WGR	CAMO-11-4610	F	—	2/23/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-50 S1	WG	WGR	CAMO-11-4611	UF	—	2/23/2011	—	—	X	—	—	—	X	—	—	—	X	—	X
R-50 S1	WG	WGR	CAMO-11-4614	UF	Field Duplicate	2/23/2011	—	—	X	—	—	—	X	—	—	—	X	—	X
R-50 S1	WG	WGR	CAMO-11-4615	F	Field Duplicate	2/23/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-50 S1	WG	WGR	CAMO-11-10719	F	—	5/25/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-50 S1	WG	WGR	CAMO-11-10720	UF	—	5/25/2011	X	—	X	—	—	X	X	—	—	X	X	X	X
R-50 S1	WG	WGR	CAMO-11-10722	UF	Field Duplicate	5/25/2011	X	—	X	—	—	X	X	—	—	X	X	X	X
R-50 S1	WG	WGR	CAMO-11-10723	F	Field Duplicate	5/25/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-50 S1	WG	WGR	CAMO-11-24671	F	—	8/4/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-50 S1	WG	WGR	CAMO-11-24673	UF	—	8/4/2011	—	—	X	—	—	—	X	—	—	—	X	—	X
R-50 S1	WG	WGR	CAMO-11-24675	UF	Field Duplicate	8/4/2011	—	—	X	—	—	—	X	—	—	—	X	—	X
R-50 S1	WG	WGR	CAMO-11-24676	F	Field Duplicate	8/4/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-50 S1	WG	WGR	CAMO-12-1504	F	—	11/18/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-50 S1	WG	WGR	CAMO-12-1505	UF	—	11/18/2011	—	—	X	—	—	—	X	—	—	—	X	X	X

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
R-50 S1	WG	WGR	CAMO-12-12021	UF	—	3/8/2012	—	—	X	—	—	—	—	—	—	—	—	—	—
R-50 S1	WG	WGR	CAMO-12-12030	F	—	3/8/2012	—	—	X	—	—	—	X	X	—	—	—	—	—
R-50 S1	WG	WGR	CAMO-12-14014	UF	—	5/31/2012	—	—	X	—	—	—	—	—	—	—	X	—	—
R-50 S1	WG	WGR	CAMO-12-14029	F	—	5/31/2012	—	—	X	—	—	—	X	X	—	—	—	—	—
R-50 S2	WG	WGR	CAMO-10-13924	UF	—	3/11/2010	X	—	X	—	—	X	X	—	—	X	X	X	X
R-50 S2	WG	WGR	CAMO-10-13926	F	—	3/11/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-50 S2	WG	WGR	CAMO-10-18976	F	—	5/27/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-50 S2	WG	WGR	CAMO-10-18977	UF	—	5/27/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
R-50 S2	WG	WGR	CAMO-10-18978	F	—	5/27/2010	—	—	—	—	—	—	X	—	—	—	—	—	—
R-50 S2	WG	WGR	CAMO-10-18979	UF	—	5/27/2010	X	—	X	—	—	X	X	—	—	X	X	X	X
R-50 S2	WG	WGR	CAMO-10-18980	F	—	5/27/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-50 S2	WG	WGR	CAMO-10-19013	UF	Field Duplicate	5/27/2010	—	—	—	—	—	—	—	—	—	—	—	X	X
R-50 S2	WG	WGR	CAMO-10-22906	F	—	7/2/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-50 S2	WG	WGR	CAMO-10-22907	UF	—	7/2/2010	X	—	X	—	—	X	X	—	—	X	X	X	X
R-50 S2	WG	WGR	CAMO-10-23271	UF	Field Duplicate	7/2/2010	—	—	—	—	—	—	—	—	—	—	—	X	X
R-50 S2	WG	WGR	CAMO-11-1315	F	—	11/16/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-50 S2	WG	WGR	CAMO-11-1316	UF	—	11/16/2010	X	—	X	—	—	X	X	—	—	X	X	X	X
R-50 S2	WG	WGR	CAMO-11-1317	UF	Field Duplicate	11/16/2010	X	—	X	—	—	X	X	—	—	X	X	X	X
R-50 S2	WG	WGR	CAMO-11-1319	F	Field Duplicate	11/16/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
R-50 S2	WG	WGR	CAMO-11-4617	UF	—	2/24/2011	—	—	X	—	—	—	X	—	—	—	X	—	X
R-50 S2	WG	WGR	CAMO-11-4618	F	—	2/24/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-50 S2	WG	WGR	CAMO-11-10726	UF	—	5/24/2011	X	—	X	—	—	X	X	—	—	X	X	X	X
R-50 S2	WG	WGR	CAMO-11-10727	F	—	5/24/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-50 S2	WG	WGR	CAMO-11-24679	UF	—	8/8/2011	—	—	X	—	—	—	X	—	—	—	X	—	X
R-50 S2	WG	WGR	CAMO-11-24680	F	—	8/8/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-50 S2	WG	WGR	CAMO-12-1509	UF	—	11/21/2011	—	—	—	—	—	—	—	—	—	—	X	—	—

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
R-50 S2	WG	WGR	CAMO-12-1808	F	—	11/28/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-50 S2	WG	WGR	CAMO-12-1809	UF	—	11/28/2011	—	—	X	—	—	—	X	—	—	—	X	X	X
R-50 S2	WG	WGR	CAMO-12-12022	UF	—	3/7/2012	—	—	X	—	—	—	—	—	—	—	—	—	—
R-50 S2	WG	WGR	CAMO-12-12031	F	—	3/7/2012	—	—	X	—	—	—	X	X	—	—	—	—	—
R-50 S2	WG	WGR	CAMO-12-14015	UF	—	5/31/2012	—	—	X	—	—	—	—	—	—	—	X	—	—
R-50 S2	WG	WGR	CAMO-12-14030	F	—	5/31/2012	—	—	X	—	—	—	X	X	—	—	—	—	—
R-61 S1	WG	WGR	CAMO-11-10852	UF	—	5/20/2011	X	—	X	—	—	X	X	—	—	X	X	X	X
R-61 S1	WG	WGR	CAMO-11-10853	F	—	5/20/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-61 S1	WG	WGR	CAMO-11-11687	UF	Field Duplicate	5/20/2011	—	—	-	—	—	—	—	—	—	—	—	X	X
R-61 S1	WG	WGR	CAMO-11-24696	F	—	8/18/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-61 S1	WG	WGR	CAMO-11-24698	UF	—	8/18/2011	X	—	X	—	—	X	X	—	—	X	X	X	X
R-61 S1	WG	WGR	CAMO-11-24699	UF	Field Duplicate	8/18/2011	—	—	—	—	—	—	—	—	—	—	—	X	X
R-61 S1	WG	WGR	CAMO-12-1510	F	—	11/21/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-61 S1	WG	WGR	CAMO-12-1511	UF	—	11/21/2011	X	X	X	X	—	X	X	—	—	X	X	X	X
R-61 S1	WG	WGR	CAMO-12-1513	UF	Field Duplicate	11/21/2011	X	—	X	—	—	X	X	—	—	X	X	X	X
R-61 S1	WG	WGR	CAMO-12-1515	F	Field Duplicate	11/21/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-61 S2	WG	WGR	CAMO-11-11688	UF	Field Duplicate	5/24/2011	—	—	—	—	—	—	—	—	—	—	—	X	X
R-61 S2	WG	WGR	CAMO-11-11689	UF	—	5/24/2011	X	—	X	—	—	X	X	—	—	X	X	X	X
R-61 S2	WG	WGR	CAMO-11-11691	F	—	5/24/2011	—	—	X	—	—	-	X	X	—	—	—	—	—
R-61 S2	WG	WGR	CAMO-11-24700	UF	Field Duplicate	8/19/2011	—	—	—	—	—	—	—	—	—	—	—	X	X
R-61 S2	WG	WGR	CAMO-11-24702	F	—	8/19/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-61 S2	WG	WGR	CAMO-11-24703	UF	—	8/19/2011	X	—	X	—	—	X	X	—	—	X	X	X	X
R-61 S2	WG	WGR	CAMO-12-1516	UF	—	11/18/2011	X	X	X	X	—	X	X	—	—	X	X	X	X
R-61 S2	WG	WGR	CAMO-12-1518	F	—	11/18/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-62	W	WGR	RE05-11-27116	UF	—	9/2/2011	—	—	—	—	—	—	—	—	—	—	—	X	X
R-62	W	WGR	RE05-11-27117	UF	—	9/2/2011	—	—	—	—	—	—	—	—	—	—	—	X	X

Table 6.4-1 (continued)

Location ID	Media Code	Media Description	Sample ID	Field Preparation	Field QC Type	Collection Date	Dioxins/Furans	Diesel Range Organic Analytes	General Inorganics	GRO	Herbicides	High Explosives	Metals	Perchlorate	Polychlorinated Biphenyl congeners	Pesticides/Polychlorinated Biphenyls	Radionuclides	Semivolatile Organic Analytes	Volatile Organic Analytes
R-62	W	WGR	RE05-11-27118	UF	—	9/20/2011	—	—	—	—	—	—	—	—	—	—	—	X	X
R-62	W	WGR	RE05-11-27119	UF	—	9/22/2011	—	—	—	—	—	—	—	—	—	—	—	X	X
R-62	W	WGR	RE05-11-27120	UF	—	9/30/2011	—	—	—	—	—	—	—	—	—	—	—	—	X
R-62	W	WGR	RE05-11-27121	UF	—	10/3/2011	—	—	—	—	—	—	—	—	—	—	—	X	X
R-62	W	WGR	RE05-11-27122	UF	—	1/24/2012	—	—	—	—	—	—	—	—	—	—	—	X	X
R-62	WG	WGR	CAMO-12-12014	UF	Field Duplicate	3/26/2012	—	—	—	—	—	—	—	—	—	—	—	X	X
R-62	WG	WGR	CAMO-12-12025	UF	—	3/26/2012	—	—	X	—	—	X	—	—	—	—	X	X	X
R-62	WG	WGR	CAMO-12-12034	F	—	3/26/2012	—	—	X	—	—	—	X	X	—	—	—	—	—
R-62	WG	WGR	CAMO-12-13999	UF	Field Duplicate	6/6/2012	—	—	X	—	—	X	—	—	—	—	X	X	X
R-62	WG	WGR	CAMO-12-14000	F	Field Duplicate	6/6/2012	—	—	X	—	—	—	X	X	—	—	—	—	—
R-62	WG	WGR	CAMO-12-14018	UF	—	6/6/2012	—	—	X	—	—	X	—	—	—	—	X	X	X
R-62	WG	WGR	CAMO-12-14033	F	—	6/6/2012	—	—	X	—	—	—	X	X	—	—	—	—	—
R-9	WG	WGR	CALA-09-11165	UF	—	7/13/2009	—	—	X	—	—	—	X	—	—	—	X	—	X
R-9	WG	WGR	CALA-09-11166	F	—	7/13/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-9	WG	WGR	CALA-09-11168	UF	Field Duplicate	7/13/2009	—	—	X	—	—	—	X	—	—	—	X	—	X
R-9	WG	WGR	CALA-09-11169	F	Field Duplicate	7/13/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
R-9	WG	WGR	CALA-11-5175	F	—	3/7/2011	—	—	X	—	—	—	X	X	—	—	—	—	—
R-9	WG	WGR	CALA-11-5176	UF	—	3/7/2011	—	—	X	—	—	—	X	—	—	—	X	—	X
Sandia Spring	WG	WGRS	CAWR-09-12481	UF	—	9/23/2009	—	—	X	—	—	—	X	—	—	—	X	X	X
Sandia Spring	WG	WGRS	CAWR-09-12483	F	—	9/23/2009	—	—	X	—	—	—	X	X	—	—	—	—	—
Sandia Spring	WG	WGRS	CAWR-10-14081	UF	—	3/23/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
Sandia Spring	WG	WGRS	CAWR-10-14082	F	—	3/23/2010	—	—	X	—	—	—	X	X	—	—	—	—	—
Sandia Spring	WG	WGRS	CAWR-10-14084	UF	Field Duplicate	3/23/2010	—	—	X	—	—	—	X	—	—	—	X	X	X
Sandia Spring	WG	WGRS	CAWR-10-14085	F	Field Duplicate	3/23/2010	—	—	X	—	—	—	X	X	—	—	—	—	—

^a — = analysis was not performed.

^b X = analysis was performed.

Table 6.4-2
Inorganic COPCs in Filtered Alluvial Groundwater from the Sandia Canyon Watershed

Location	Antimony	Arsenic	Barium	Boron	Chromium	Copper	Manganese	Molybdenum	Nickel	Perchlorate	Strontium	Uranium	Vanadium	Zinc
LANL Alluvial GW BV ^a	0.5	6	68.57	51.89	1	3	2	2	1	0.05	120	1.03	1	2
Comparison Value	6	10	1000	750	50	1000	200	1000	200	25.6	21900	30	183	10000
Comparison Source	MCL ^b	MCL	NMGSF ^c	NMGSF	NMGSF	NMGSF	NMGSF	NMGSF	NMGSF	tapNMED ^d	tapNMED	NMGSF	tapNMED	NMGSF
SCA-1	— ^e	—	—	—	—	—	—	—	—	—	—	—	—	—
SCA-2	0.761 (J)	—	—	59.6	7.69 (J)	3.19 (J)	4.02 (J)	14.7	1.8 (J)	2.68	—	—	14.1	30.7
SCA-4	—	8.68	137	59	15.7	—	8 (J)	32.9	5.25	1.74	163	—	9.76	22.1
SCA-5	—	—	79	—	13.7	—	46.7	6.84	19.4	0.477	167	2.09	5.03	144

Notes: Values are in µg/L. Values are maximum values greater than the alluvial groundwater BV for analytes with a BV, and the maximum detected value for analytes without a BV. No comparison value was exceeded. All standards adjusted to a target risk of 10⁻⁵. Data qualifiers are defined in Appendix A.

^a Alluvial groundwater (GW) BVs are from LANL (LANL 2007, 096665).

^b MCL = EPA maximum contaminant level.

^c NMGSF, NM Groundwater Standards (dissolved fraction, filtered sample), NMAC 20.6.2.3103 (<http://www.nmcpr.state.nm.us/nmac/parts/title20/20.006.0002.htm>).

^d tapNMED = NMED tap water from NMED Risk Assessment Guidance for Investigations and Remediation, Volume I, February 2012 (updated June 2012) (NMED 2012, 219971).

^e — = Not a COPC at that location (not detected if no BV, not detected above BV, or not analyzed).

Table 6.4-3
Inorganic COPCs in Nonfiltered Alluvial Groundwater from the Sandia Canyon Watershed

Location	Aluminum	Arsenic	Barium	Boron	Chromium	Copper	Iron	Lead	Manganese	Molybdenum	Nickel	Strontium	Uranium	Vanadium	Zinc
LANL Alluvial GW BV ^a	na ^b	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Comparison Value	36500	10	7300	7300	100	1460	25600	15	876	183	730	21900	30	183	11000
Comparison Source	tapNMED ^c	MCL ^d	tapNMED	tapNMED	MCL	tapNMED	tapNMED	MCL	tapNMED	tapNMED	tapNMED	tapNMED	MCL	tapNMED	tapNMED
SCA-1	— ^e	—	—	—	—	—	—	—	—	—	—	—	—	—	—
SCA-2	207	2.62 (J)	44.4	60.7	8.4 (J)	4.05 (J)	210	0.938 (J)	18.9	14.2	1.92 (J)	104	0.902	14.4	43.4
SCA-4	854	8.42	135	58.8	59.8	3.95 (J)	603	—	6.84 (J)	31.6	4.79	159	0.286	10.2	48.1
SCA-5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Notes: Values are in µg/L. Values are maximum values greater than the alluvial groundwater BV for analytes with a BV, and the maximum detected value for analytes without a BV. No comparison value was exceeded. All standards adjusted to a target risk of 10⁻⁵. Data qualifiers are defined in Appendix A.

^a Alluvial groundwater (GW) BVs are from LANL (LANL 2007, 096665).

^b na = Not available.

^c tapNMED = NMED tap water from NMED Risk Assessment Guidance for Investigations and Remediation, Volume I, February 2012 (updated June 2012) (NMED 2012, 219971).

^d MCL = EPA maximum contaminant level.

^e — = Not a COPC at that location (not detected if no BV, not detected above BV, or not analyzed).

Table 6.4-4
Organic COPCs in Nonfiltered Alluvial
Groundwater from the Sandia Canyon Watershed

Location	Chloroform
Comparison Value	80
Comparison Source	MCL ^a
SCA-1	— ^b
SCA-2	0.28 (J)
SCA-4	0.4 (J)
SCA-5	—

Notes: Values are in µg/L. Values are the maximum detected value. No comparison value was exceeded. All standards adjusted to a target risk of 10⁻⁵. Data qualifiers are defined in Appendix A.

^a MCL = EPA maximum contaminant level.

^b — = Not a COPC at that location (not detected if no BV, not detected above BV, or not analyzed).

Table 6.4-5
Radionuclide COPCs in Nonfiltered Alluvial Groundwater from the Sandia Canyon Watershed

Location	Gross Alpha	Gross Beta	Radium-228	Tritium	Uranium-234	Uranium-238
LANL Alluvial GW BV ^c	na ^b	na	na	57	na	na
Comparison Value	15	50	5	20000	20	24
Comparison Source	MCL ^b	SMCL ^d	MCL	MCL	DCG ^e	DCG
SCA-1	— ^f	—	—	—	—	—
SCA-2	4.55	14.1	1.19	—	0.145	0.107
SCA-4	—	2.25	2.81	81.466	0.0878	0.0813
SCA-5	—	—	—	—	—	—

Notes: Values are in pCi/L. Values are maximum values greater than the LANL BV; if no BV, value is maximum detected value. No comparison value was exceeded.

^a Regional Groundwater BVs are from LANL (2007, 096665).

^b na = Not available.

^c MCL = EPA maximum contaminant level.

^d SMCL = EPA secondary maximum contaminant level.

^e DCG = DOE DCGs based on 4 mrem/yr.

^f — = Not a COPC at that location (not detected if no BV, not detected above BV, or not analyzed).

Table 6.4-6
General Inorganic COPCs in Filtered Alluvial Groundwater from the Sandia Canyon Watershed

Location	Alkalinity-CO ₃ +HCO ₃	Ammonia as Nitrogen	Bromide	Calcium	Chloride	Fluoride	Hardness	Nitrate-Nitrite as Nitrogen	Potassium	Silicon Dioxide	Sodium	Total Phosphate as Phosphorus
LANL Alluvial GW BV ^a	76	0.04	0.07	26.36	69.76	0.27	na	0.57	5.21	64.21	15.54	0.05
Comparison Value	na ^b	na	na	na	250	1.6	na	10	na	na	na	na
Comparison Source	na	na	na	na	NMGSF ^c	NMGSF	na	NMGSF	na	na	na	na
SCA-1	272	— ^d	0.551	—	72	0.598	—	—	—	133	—	—
SCA-2	123	—	0.423	—	83.6 (J+)	0.708	84.4	1.53 (J)	17.5	101	89.1	3.04
SCA-4	94.6	0.16 (J)	0.323	27.3	132	1.06	93.7	1.72	—	67.4	102	7.56
SCA-5	97.7	—	0.298	27.4	—	1.06	95.4	—	—	—	42.6	—

Notes: Values are in mg/L. Values are maximum values greater than the alluvial groundwater BV for analytes with a BV, and the maximum detected value for analytes without a BV. No comparison value was exceeded. All standards adjusted to a target risk of 10⁻⁵. Data qualifiers are defined in Appendix A.

^a Alluvial groundwater (GW) BVs are from LANL (LANL 2007, 096665).

^b na = Not available.

^c NMGSF, NM Groundwater Standards (dissolved fraction, filtered sample), NMAC 20.6.2.3103 (<http://www.nmcpr.state.nm.us/nmac/parts/title20/20.006.0002.htm>).

^d — = Not a COPC at that location (not detected if no BV, not detected above BV, or not analyzed).

Table 6.4-7
General Inorganic COPCs in Nonfiltered
Alluvial Groundwater from the Sandia Canyon Watershed

Location	Calcium	Hardness	Magnesium	Potassium	Sodium	Total Kjeldahl Nitrogen
Comparison Value	na ^a	na	na	na	na	na
Comparison Source	na	na	na	na	na	na
SCA-1	— ^b	—	—	—	—	—
SCA-2	23.4	85.3	6.52	17.5	87.1	0.159
SCA-4	26.7	91.7	6.06	4.61	99.6	0.276
SCA-5	—	—	—	—	—	—

Notes: Values are in mg/L. Values are maximum values greater than the alluvial groundwater BV for analytes with a BV, and the maximum detected value for analytes without a BV. No comparison value was exceeded. All standards adjusted to a target risk of 10-5.

a na = Not available.

b — = Not a COPC at that location (not detected if no BV, not detected above BV, or no analyzed).

Table 6.4-8
Inorganic COPCs in Filtered Intermediate Groundwater from the Sandia Canyon Watershed

Location	Antimony	Arsenic	Barium	Boron	Chromium	Cobalt	Copper	Iron	Lead	Manganese	Molybdenum	Nickel	Perchlorate	Strontium	Uranium	Zinc
LANL Intermediate GW BV ^a	0.5	4.32	71.83	15.12	1	0.5	5.32	840	0.5	2	2	1	0.05	154.8	0.72	2
Comparison Value	6	10	1000	750	50	50	1000	1000	15	200	1000	200	25.6	21900	30	10000
Comparison Source	MCL ^b	MCL	NMGSF ^c	NMGSF	NMGSF	NMGSF	NMGSF	NMGSF	MCL	NMGSF	NMGSF	NMGSF	tapNMED ^d	tapNMED	NMGSF	NMGSF
LADP-3	— ^e	—	—	23.8 (J)	11.4	—	—	—	—	2.01 (J)	2.35	1.7 (J)	0.161 (J)	—	0.842	14
LAOI(a)-1.1	—	—	—	16.2 (J)	—	—	7.65 (J)	—	0.516 (J)	2.52 (J)	2.06	—	0.237 (J+)	—	—	45.6
LAOI-3.2	—	—	—	17.1 (J)	—	—	—	—	—	10.4	—	—	5.32	—	1.42	6.07 (J)
LAOI-3.2a	—	—	—	16.7 (J)	5.05 (J)	—	—	—	—	—	—	—	2.96	159	1.95	3.41 (J)
LAOI-7	—	—	—	18.8 (J)	4.77 (J)	2.19 (J)	—	—	—	12.6	—	2.75	0.756	—	0.768	8.13 (J)
MCOI-4	—	—	—	24.3 (J)	16.9	—	38.3	—	4.04	4.69 (J)	—	21.4	73	—	—	170
MCOI-5	—	—	—	25 (J)	6.65 (J)	—	—	—	—	-	3.41 (J)	1.18 (J)	99.2	—	—	7.16 (J)
MCOI-6	0.581 (J)	—	—	51.3	65.5	1.41 (J)	16.2	—	—	6.76 (J)	—	40.8	104	339	1.53	39.4
R-12 S1	—	—	—	54.2	4.92 (J)	—	—	—	—	167	2.61 (J)	3.44	0.417	—	1.07	3.85 (J)
R-12 S2	—	—	—	20.7 (J)	4 (J)	—	—	—	—	38	—	1.1 (J)	1	—	—	—
R-3i	—	—	105	101	2.9 (J)	—	5.52 (J)	—	—	-	—	9.54 (J)	3.45	287	9.71	49.7
R-9i S1	—	—	—	24.2 (J)	—	1.85 (J)	8.73 (J)	—	—	244	13.6	123	0.243	—	1.37	12.5
R-9i S2	—	—	—	17.7 (J)	—	—	—	1110	—	18.6	3.36	6.94	2.37	—	1.72	42.2
SCI-1	—	8.56	—	99.4	16.8	—	8.13	—	—	—	97	6.62	0.983	338	3.09	8.78 (J)
SCI-2	—	4.62	—	21.8 (J)	637	—	—	—	—	4.07	—	19.3	1.12	350	1.96	5.44 (J)
TA-53i	—	—	—	29.4 (J)	4.25 (J)	1.29 (J)	—	—	—	9.68 (J)	107	21.9	0.68	203	0.898	11.8

Notes: Values are in µg/L. Values are maximum values greater than the intermediate groundwater BV for analytes with a BV, and the maximum detected value for analytes without a BV. Grey shading indicates a comparison value was exceeded.
All standards adjusted to a target risk of 10⁻⁵. Data qualifiers are defined in Appendix A.

^a Intermediate groundwater (GW) BVs are from LANL (LANL 2007, 096665).

^b MCL = EPA maximum contaminant level.

^c NMGSF, NM Groundwater Standards (dissolved fraction, filtered sample), NMAC 20.6.2.3103 (<http://www.nmcpr.state.nm.us/nmac/parts/title20/20.006.0004.htm>).

^d tapNMED = NMED tap water from NMED Risk Assessment Guidance for Investigations and Remediation, Volume I, February 2012 (updated June 2012) (NMED 2012, 219971).

^e — = Not a COPC at that location (not detected if no BV, not detected above BV, or not analyzed).

Table 6.4-9
Inorganic COPCs in Nonfiltered Intermediate Groundwater from the Sandia Canyon Watershed

Location	Aluminum	Arsenic	Barium	Beryllium	Boron	Chromium	Cobalt	Copper	Iron	Lead	Manganese	Molybdenum	Nickel	Strontium	Thallium	Uranium	Vanadium	Zinc
LANL Intermediate GW BV ^a	na ^b	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Comparison Value	36500	10	7300	4	7300	100	4.7	1460	25600	15	876	183	730	21900	2	30	183	11000
Comparison Source	tapNMED ^c	MCL	tapNMED ^d	MCL	tapNMED	MCL	EPATap	tapNMED	tapNMED	MCL	tapNMED	tapNMED	tapNMED	tapNMED	MCL	MCL	tapNMED	tapNMED
LADP-3	— ^e	—	29	—	27 (J)	11.3	—	—	108	2.42	2.84 (J)	2.46	2.92	114	0.562 (J)	0.86	1.89 (J)	33
LAOI(a)-1.1	2780	2.99 (J)	47.8	1.74 (J)	18.7 (J)	—	—	11	1280	7.95	19.4	2.32	0.983 (J)	124	0.306 (J)	2.7	1.82 (J)	57.2
LAOI-3.2	—	4.35 (J)	49.6	—	16.6 (J)	2.07 (J)	—	—	—	—	9.72 (J)	0.744	0.554 (J)	108	—	1.44	—	7.19 (J)
LAOI-3.2a	—	2.57 (J)	19	—	21.4 (J)	5.46 (J)	—	—	—	—	—	0.442 (J)	0.947 (J)	154	—	1.89	—	—
LAOI-7	—	5.31	27.4	—	19.2 (J)	5.43 (J)	—	—	807	—	13.6	1.07	3.41	101	—	0.775	1.95 (J)	8.25 (J)
MCOI-4	—	3.04 (J)	13.1	—	23.6 (J)	19.3	—	26.2	156	6.82	6.96 (J)	1	20.3	140	—	0.123 (J)	1.53 (J)	71.2
MCOI-5	83.3 (J)	—	18.9	—	24.9 (J)	11.5	—	6.12 (J)	108	—	—	3.61 (J)	4.33	99.1	—	0.2	2.73 (J)	11.3
MCOI-6	84.2 (J)	1.65 (J)	47.7	—	55.4	64.5	—	18.7	86.6 (J)	0.592 (J)	4.94 (J)	2.27	37.8	334	—	1.52	1.81 (J)	38.5
R-12 S1	—	3.17 (J)	54.3	—	55.3	4.68 (J)	—	—	114	—	168	2.65 (J)	3.68	140	—	1.08	—	10.1
R-12 S2	82.3 (J)	2.21 (J)	13.2	—	22.3 (J)	4.01 (J)	—	—	—	—	38.7	1.69	1.02 (J)	75	—	0.586	4.33 (J)	3.68 (J)
R-3i	—	—	105	—	98.9	2.58 (J)	—	7.4 (J)	379	—	—	—	9.92 (J)	301	—	9.68	3.4 (J)	320
R-9i S1	—	—	58.9	—	25.2 (J)	4.08 (J)	1.68 (J)	13.3	442	—	245	14.7	127	129	0.346 (J)	1.48	—	18.4
R-9i S2	163 (J)	3.18 (J)	25	—	15.9 (J)	4.56 (J)	—	4.42 (J)	32.5 (J)	—	18.5	3.45	8.58	99.6	—	1.74	1.87 (J)	5.02 (J)
SCI-1	70.9 (J)	6.68	49.6	—	96	21.9	—	17.2	235	—	—	96.8	6.36 (J)	337	—	3.45	1.68 (J)	11.4
SCI-2	93.2 (J)	2.8	67	—	23.3 (J)	627	—	4.23 (J)	158	0.768 (J)	4.4	1.26	18.4	346 (J)	—	1.63	2.61 (J)	10.8
TA-53i	107 (J)	—	41	—	28.9 (J)	24.7 (J)	—	6.92 (J)	322	—	10.8	107	30.6	213	—	0.947	1.92 (J)	13.3

Notes: Values are in µg/L. Values are maximum values greater than the intermediate groundwater BV for analytes with a BV, and the maximum detected value for analytes without a BV. Grey shading indicates a comparison value was exceeded. All standards adjusted to a target risk of 10⁻⁵. Data qualifiers are defined in Appendix A.

^a Intermediate groundwater (GW) BVs are from LANL (LANL 2007, 096665).
^b na = Not available.
^c tapNMED = NMED tap water from NMED Risk Assessment Guidance for Investigations and Remediation, Volume I, February 2012 (updated June 2012) (NMED 2012, 219971).
^d MCL = EPA maximum contaminant level.
^e — = Not a COPC at that location (not detected if no BV, not detected above BV, or not analyzed).

Table 6.4-10
Organic COPCs in Nonfiltered Intermediate Groundwater from the Sandia Canyon Watershed

Location	Aroclor-1260	Benzo(a)anthracene	Benzo(a)pyrene	Benzo(b)fluoranthene	Benzo(k)fluoranthene	Benzoic Acid	Bis(2-ethylhexyl)phthalate	Chloroform	Chloromethane	Diethyl Ether	Diethylphthalate	Dioxane[1,4-]	Heptachlorodibenzodioxin[1,2,3,4,6,7,8-]	Heptachlorodibenzodioxins (Total)	Hexachlorodibenzodioxins (Total)	Methylene Chloride	Octachlorodibenzodioxin[1,2,3,4,6,7,8,9-]	Toluene
Comparison Value	0.5	0.295	0.2	0.295	2.95	58000	6	80	188	7300	29200	6.72	na ^a	na	na	5	na	750
Comparison Source	MCL ^b	tapNMED ^c	MCL	tapNMED	tapNMED	tapRSL ^d	MCL	MCL	tapNMED	tapNMED	tapNMED	tapNMED	na	na	na	MCL	na	NMGSU ^e
LADP-3	— ^f	—	—	—	—	17.5 (J)	—	—	—	—	—	—	—	—	—	—	—	—
LAOI(a)-1.1	—	—	—	—	—	—	—	—	0.39 (J)	—	—	—	—	—	—	—	—	—
LAOI-3.2	—	—	—	—	—	—	—	—	0.47 (J)	—	—	—	—	—	—	—	—	—
LAOI-3.2a	—	—	—	—	—	—	—	0.47 (J)	0.34 (J)	—	—	—	—	—	—	—	—	—
LAOI-7	—	—	—	—	—	—	—	—	—	—	23.9	—	—	—	—	—	—	—
MCOI-4	—	—	—	—	—	—	—	—	—	—	—	34.1 (J)	—	—	—	—	—	—
MCOI-5	—	—	—	—	—	—	—	—	—	—	5.28 (J)	9.09 (J)	—	—	—	6.97 (J)	—	—
MCOI-6	—	0.266 (J)	0.245 (J)	0.239 (J)	0.26 (J)	—	3.39 (J)	0.35 (J)	—	—	24.5	23.2 (J)	—	—	—	—	—	—
R-12 S1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2.83e-006 (J)	0.4 (J)
R-12 S2	—	—	—	—	—	—	—	—	—	—	—	—	—	1.68E-06	—	—	3.35e-006 (J)	—
R-3i	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
R-9i S1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
R-9i S2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
SCI-1	—	—	—	—	—	—	—	0.56 (J-)	0.534 (J)	—	—	—	—	—	—	3.24 (J)	—	—
SCI-2	0.064 (J)	—	—	—	—	—	—	0.37 (J)	—	0.301 (J)	—	—	2.86e-005 (J)	5.54E-05	1.42E-05	—	7.47E-05	—
TA-53i	—	—	—	—	—	—	2.91 (J)	—	—	—	—	—	—	—	—	—	1.25e-005 (J)	—

Notes: Values are in µg/L. Values are the maximum detected value. Grey shading indicates a comparison value was exceeded. All standards adjusted to a target risk of 10-5.

^a na = Not available.

^b MCL = EPA maximum contaminant level.

^c tapNMED = NMED tap water from NMED Risk Assessment Guidance for Investigations and Remediation, Volume I, February 2012 (updated June 2012) (NMED 2012, 219971).

^d tapRSL= EPA tap water from the EPA regional screening level publication (http://www.epa.gov/earth1r6/6pd/rcra_c/pd-n/screen.htm).

^e NMGSU, NM Groundwater Standards (nonfiltered sample), NMAC 20.6.2.3103 (<http://www.nmcpr.state.nm.us/nmac/parts/title20/20.006.0004.htm>).

^f — = Not a COPC at that location (not detected if no BV, not detected above BV, or not analyzed).

Table 6.4-11
Radionuclide COPCs in Nonfiltered Intermediate Groundwater from the Sandia Canyon Watershed

Location	Gross alpha	Gross beta	Gross gamma	Radium-226	Radium-228	Strontium-90	Tritium	Uranium-234	Uranium-235/236	Uranium-238
LANL Intermediate GW BV ^a	na ^b	na	na	na	na	0.29	7.54	0.18	na	0.19
Comparison Value	15	50	na	5	5	8	20000	20	24	24
Comparison Source	MCL ^c	SMCL ^d	na	MCL	MCL	MCL	MCL	DCG ^e	DCG	DCG
LADP-3	— ^f	7.5	158	—	0.68	—	114.63	0.305	—	0.293
LAOI(a)-1.1	10.3	13.6	86	0.88	0.97	—	11.399	0.412	0.0684	0.467
LAOI-3.2	3.82	8.32	—	—	—	—	1940	0.544	0.0529	0.483
LAOI-3.2a	2.75	10.9	—	0.7	1.29	—	2140	0.649	0.0646	0.63
LAOI-7	—	7.65	215	—	—	—	952	0.304	—	0.252
MCOI-4	6.35	36	—	—	—	—	6710	—	—	—
MCOI-5	—	4.11	179	—	—	—	3920	—	—	—
MCOI-6	—	3.64	—	—	—	—	8420	1.11	0.0541	0.432
R-12 S1	—	3.06	—	0.63	—	—	76.636	0.481	—	0.224
R-12 S2	—	5.75	53	—	—	—	54.998	0.319	—	0.196
R-3i	5.4	10.3	204	—	—	—	78.89	4.62	0.206	3.04
R-9i S1	4.94	4.98	—	0.62	—	—	113.67	0.584	0.0322	0.394
R-9i S2	—	4.15	—	—	1.09	1.21	119.14	0.788	0.0406	0.521
SCI-1	5.45	6.11	—	0.35	—	—	98.532	1.91	0.0722	0.915
SCI-2	—	7.58	246	1.26	—	—	680.05	0.97 (J+)	0.0346	0.532 (J+)
TA-53i	—	5.19	221	—	—	—	766.36	0.717	—	0.34

Notes: Values are in pCi/L. Values are maximum values greater than the intermediate groundwater BV for analytes with a BV, and the maximum detected value for analytes without a BV. No comparison value was exceeded. All standards adjusted to a target risk of 10⁻⁵. Data qualifiers are defined in Appendix A.

^a Intermediate groundwater (GW) BVs are from LANL (LANL 2007, 096665).

^b na = Not available.

^c MCL = EPA maximum contaminant level.

^d SMCL = EPA secondary maximum contaminant level.

^e DCG = DOE DCGs based on 4 mrem/yr.

^f — = Not a COPC at that location (not detected if no BV, not detected above BV, or not analyzed).

Table 6.4-12
General Inorganic COPCs in Filtered Intermediate Groundwater from the Sandia Canyon Watershed

Location	Alkalinity-CO3	Alkalinity-CO3+HCO3	Bromide	Calcium	Chlorate	Chloride	Fluoride	Hardness	Magnesium	Nitrate-Nitrite as Nitrogen	Potassium	Silicon Dioxide	Sodium	Sulfate	Total Phosphate as Phosphorus
LANL Intermediate GW BV ^a	na ^b	52	0.03	17.31	na	7.78	0.23	na	6.12	2.41	10.03	50.72	12.19	40.03	0.08
Comparison Value	na	na	na	na	na	250	1.6	na	na	10	na	na	na	600	na
Comparison Source	na	na	na	na	na	NMGSC ^c	NMGSC	na	na	NMGSC	na	na	na	NMGSC	na
LADP-3	— ^d	53.1	0.0756 (J)	—	—	32	0.347	58.5	—	—	—	59.4	28.1 (J+)	—	—
LAOI(a)-1.1	—	—	0.0697 (J)	—	—	—	0.258	23.8	—	—	—	71.5	—	—	—
LAOI-3.2	—	82.2	0.106 (J)	20.3	—	18.2 (J+)	0.282	72	—	2.9	—	75.8	20.8	—	0.085
LAOI-3.2a	—	78.5	0.454	24.6	—	23.4 (J+)	—	83.5	—	—	10.6	73.7	17	—	—
LAOI-7	—	54.9	0.164 (J)	18	—	28.5	—	76.3	7.7	—	—	59.8	—	—	—
MCOI-4	—	—	0.408	30	—	21.5 (J+)	0.323	94.2	—	9.68	—	72.7	22.3	—	0.097 (J-)
MCOI-5	—	55.5	0.143 (J)	21.2	0.059	—	0.504	69.4	—	5.28	—	70.2	14.3	—	0.136
MCOI-6	—	102	0.692	75.5	0.016	64.8	0.562	253	15.7	11.7	—	72.4	28.3	77.6	0.139
R-12 S1	0.953 (J)	86.2	0.12 (J)	31	—	19.6 (J+)	0.396	103	6.28	—	—	—	14.7	—	—
R-12 S2	1.91	60.8	0.103 (J)	18.6	—	—	0.423	63	—	—	—	—	—	—	—
R-3i	—	157	0.196 (J)	59.5	—	42.3	0.356	217	16.6	7.65 (J-)	—	52.5	18.7	—	0.107
R-9i S1	—	65.9	0.181 (J)	22.1	—	42.2	0.447	86.8	7.81 (J)	—	—	—	24.8	—	0.09
R-9i S2	13.7	63.5	—	19.5	—	12.7	0.284	73	—	—	—	—	—	—	0.188 (J)
SCI-1	—	112	1.11	77.4	0.15 (J)	97.6	0.32	241	11.5	2.83	—	69.3	65.1	102	1.45 (J)
SCI-2	—	83.1	0.583	71.7	0.013 (J)	67.8	0.337	247	16.6	4.78 (J)	—	68.3	23.4	92.2	1.31 (J)
TA-53i	—	92.7	1.79	37.1	—	31	0.307	124	7.68	—	—	66	16.5	—	—

Notes: Values are in mg/L. Values are maximum values greater than the intermediate groundwater BV for analytes with a BV, and the maximum detected value for analytes without a BV. Grey shading indicates a comparison value was exceeded. All standards adjusted to a target risk of 10⁻⁵. Data qualifiers are defined in Appendix A.

^a Intermediate groundwater (GW) BVs are from LANL (LANL 2007, 096665).

^b na = Not available.

^c NMGSF, NM Groundwater Standards (dissolved fraction, filtered sample), NMAC 20.6.2.3103 (<http://www.nmcp.state.nm.us/nmac/parts/title20/20.006.0004.htm>).

^d — = Not a COPC at that location (not detected if no BV, not detected above BV, or not analyzed).

Table 6.4-13
General Inorganic COPCs in Nonfiltered Intermediate Groundwater from the Sandia Canyon Watershed

Location	Calcium	Cyanide (Total)	Hardness	Magnesium	Potassium	Sodium	Total Kjeldahl Nitrogen
LANL Intermediate GW BV ^a	na ^b	na	na	na	na	na	na
Comparison Value	na	0.2	na	na	na	na	na
Comparison Source	na	MCL ^c	na	na	na	na	na
LADP-3	15.4	— ^d	58.1	4.77	6.83	27.9 (J+)	—
LAOI(a)-1.1	8.99	—	32.6	2.47	9.91	10.5	0.04 (J)
LAOI-3.2	19.7	0.00306 (J)	70.4	5.18	7.19	19.8	0.04 (J)
LAOI-3.2a	25.2	—	85.2	5.43	10.5	16.4	0.0631 (J)
LAOI-7	18.1	—	77.4	7.82	5.6	12.4	—
MCOI-4	29.5	0.00704	92.2	4.54	0.746	20	0.14 (J-)
MCOI-5	21.8	—	71.3	4.12	0.592	14.6	0.106 (J-)
MCOI-6	73.3	0.0029 (J)	244	15.1	1.25	28.1	0.165 (J-)
R-12 S1	31.9	—	106	6.41	3.67	14.7	0.402 (J-)
R-12 S2	18.8	—	63.6	4.07	2.58	11.1	0.0898 (J)
R-3i	59.2	—	215	16.4	6.15	20.1	0.129
R-9i S1	22	0.00202 (J)	86.8	7.89 (J)	4.64	25	0.103
R-9i S2	19.9	—	72.3	5.85 (J)	4.26	10.9	0.077 (J-)
SCI-1	76.6	0.00234 (J)	237	11.2	1.99	62.9	0.166
SCI-2	69.2	0.304	238	15.9	3.91	24.6 (J)	0.151 (J+)
TA-53i	37.9	—	127	7.95	5.67	17.3	0.132

Notes: Values are in mg/L. Values are maximum values greater than the intermediate groundwater BV for analytes with a BV, and the maximum detected value for analytes without a BV. Grey shading indicates a comparison value was exceeded. All standards adjusted to a target risk of 10⁻⁶. Data qualifiers are defined in Appendix A.

^a Intermediate groundwater (GW) BVs are from LANL (LANL 2007, 096665).

^b na = Not available.

^c MCL = EPA maximum contaminant level.

^d — = Not a COPC at that location (not detected if no BV, not detected above BV, or not analyzed).

Table 6.4-14
Inorganic COPCs in Filtered Regional Groundwater and Springs from the Sandia Canyon Watershed

Location	Aluminum	Antimony	Barium	Beryllium	Boron	Chromium	Cobalt	Copper	Iron	Manganese	Mercury	Molybdenum	Nickel	Perchlorate	Tin	Uranium	Vanadium	Zinc
LANL Regional GW BV ^a	68	1	56.83	1	38.77	5.75	0.5	3	21	2.94	0.07	2	3.09	0.46	3.26	1.9	13.41	3.89
Comparison Value	5000	6	1000	4	750	50	50	1000	1000	200	2	1000	200	25.6	9300	30	183	10000
Comparison Source	NMGSF ^b	MCL ^c	NMGSF	MCL	NMGSF	NMGSF	NMGSF	NMGSF	NMGSF	NMGSF	NMGSF	NMGSF	NMGSF	tapNMED ^d	tapRSL ^e	NMGSF	tapNMED	NMGSF
Sandia Canyon Wells																		
R-10 S1	— ^f	—	—	—	—	8.22 (J)	—	—	—	—	—	—	—	0.84	—	—	—	37.6
R-10 S2	—	—	—	—	—	7.38 (J)	—	—	49.2 (J)	17.7	—	—	—	0.53	—	—	—	48.7
R-10a	475	—	85.3	—	—	8.56 (J)	—	8.18	—	4.59 (J)	—	—	—	0.887	5.01 (J)	2.59	—	16.4
R-11	—	—	—	—	—	22.7	1.03 (J)	—	37.5 (J)	—	—	—	—	1.55	—	—	14.8 (J)	52.9
R-35a	—	—	380	—	43.6 (J)	9.78 (J)	—	—	38.4 (J)	3.78 (J)	—	—	22.2	-	—	—	18.7	12.4
R-35b	—	—	—	—	—	7.4 (J)	—	—	66.2 (J)	3.64 (J)	—	—	—	0.653	—	—	15.3	36.2
R-36	—	—	—	—	—	8.48 (J)	—	—	527	6.6 (J)	—	2.63 (J)	—	1.74	—	—	15.7	73.6
R-43 S1	—	—	—	—	—	37.4	—	—	88.3 (J)	—	—	—	—	0.988	—	—	—	15.9
R-43 S2	—	—	—	—	40.3 (J)	7.39 (J)	—	—	69.6	3.23 (J)	—	6.52	3.71	0.756	—	—	—	—
R-62	—	—	—	—	—	198 (J-)	—	—	—	—	—	2.14	—	0.777	—	—	—	37.5
Sandia Spring	—	—	81.5	—	—	—	—	—	—	16.7	—	—	—	0.482	—	2.28	—	—
Los Alamos Canyon Wells																		
R-9	—	—	192	—	50.2	—	—	3.34 (J)	—	—	—	—	—	1.25	—	—	—	—
Mortadad Canyon Wells																		
R-1	—	1.11 (J)	—	—	—	8.7	—	3.51 (J)	—	3.89 (J)	—	—	17.7	—	—	—	—	22.7
R-13	—	—	—	—	—	8.54 (J)	—	—	—	—	—	—	—	—	—	—	—	5.58 (J)
R-15	—	—	—	—	—	18.2 (J)	—	—	53.1 (J)	—	—	—	—	8.14	—	—	—	7.34 (J)
R-28	—	—	73.7	1.18 (J)	—	472	1.19 (J)	4.77 (J)	39.3 (J)	7.69 (J)	—	—	34	1.12	—	—	—	29.4
R-33 S1	—	—	—	—	—	8.8 (J)	—	8.62 (J)	55.8 (J)	7.75 (J)	—	—	—	—	—	—	—	50.5
R-33 S2	—	—	—	—	—	8.73 (J)	—	—	—	—	—	—	—	—	—	—	—	—
R-42	—	1.54 (J)	99.8	—	—	1240	1.22 (J)	5.19 (J)	39.3 (J)	3.46 (J)	0.078 (J-)	—	29.6	1.46	—	—	—	23.3
R-44 S1	—	—	—	—	—	17.5	—	—	35.5 (J)	4.67 (J)	—	—	—	—	—	—	—	15.1
R-44 S2	—	—	—	—	—	16.8 (J)	—	—	88.8 (J)	4.38 (J)	—	—	—	—	—	—	—	16.4
R-45 S1	2380	—	63.1	1.8 (J)	—	21.4 (J)	1.11 (J)	—	—	3.51 (J)	—	—	—	0.591	—	—	—	40.8
R-45 S2	208	—	—	—	—	11.5	—	—	—	4.76 (J)	—	—	—	—	—	—	—	15.4
R-50 S1	—	—	—	—	—	99.8	—	—	48.7 (J)	90.6	—	6.39	5.41	0.582	—	—	—	200
R-50 S2	818 (J+)	—	—	—	—	7.27 (J)	1.53 (J)	—	462	29.9	—	4.32 (J)	—	—	—	—	—	103
R-61 S1	—	—	61.6	—	—	16.8	2.85 (J)	—	2550	1100	—	14.6	4.02	6.54	—	—	—	18.3
R-61 S2	—	—	—	—	—	—	2.45 (J)	—	5590	908	—	10.9	—	—	—	—	—	5.43 (J)

Table 6.4-14 (continued)

Location	Aluminum	Antimony	Barium	Beryllium	Boron	Chromium	Cobalt	Copper	Iron	Manganese	Mercury	Molybdenum	Nickel	Perchlorate	Tin	Uranium	Vanadium	Zinc
Water-Supply Wells																		
O-4	—	—	—	—	—	6.61 (J)	—	—	—	—	—	—	—	—	—	—	—	—
PM-1	—	—	—	—	—	6.47 (J)	—	—	—	—	—	—	—	—	—	—	—	—
PM-3	—	—	—	—	—	6.9 (J)	—	—	—	—	—	—	—	—	—	—	—	—
PM-5	—	—	—	—	—	6.95 (J)	—	—	—	—	—	—	—	—	—	—	—	—

Notes: Values are in µg/L. Values are the maximum detected value. Grey shading indicates a comparison value was exceeded. All standards adjusted to a target risk of 10⁻⁵. Data qualifiers are defined in Appendix A.

- ^a Regional groundwater (GW) BVs are from LANL (LANL 2007, 096665).
- ^b NMGSF, NM Groundwater Standards (filtered sample), NMAC 20.6.2.3103 (<http://www.nmcpr.state.nm.us/nmac/parts/title20/20.006.0002.htm>).
- ^c MCL = EPA maximum contaminant level.
- ^d tapNMED = NMED tap water from NMED Risk Assessment Guidance for Investigations and Remediation, Volume I, February 2012 (updated June 2012) (NMED 2012, 219971).
- ^e tapRSL= EPA tap water from the EPA regional screening level publication (http://www.epa.gov/earth1r6/6pd/rcra_c/pd-n/screen.htm).
- ^f — = Not a COPC at that location (not detected if no BV, not detected above BV, or not analyzed).

Table 6.4-15
Inorganic COPCs in Nonfiltered Regional Groundwater and Springs from the Sandia Canyon Watershed

Location	Aluminum	Antimony	Arsenic	Barium	Boron	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Manganese	Molybdenum	Nickel	Perchlorate	Strontium	Thallium	Tin	Uranium	Vanadium	Zinc
LANL Regional GW BV ^a	na ^b	na	na	na	na	na	na	na	na	na	na	na	na	na	0.05	na	na	na	na	na	na
Comparison Value	36500	6	10	7300	7300	5	100	4.7	1460	25600	15	876	183	730	25.6	21900	2	9300	30	183	11000
Comparison Source	tapNMED ^c	MCL ^d	MCL	tapNMED	tapNMED	MCL	MCL	tapRSL	tapNMED	tapNMED	MCL	tapNMED	tapNMED	tapNMED	tapNMED	tapNMED	MCL	tapRSL ^e	MCL	tapNMED	tapNMED
Sandia Canyon Wells																					
R-10 S1	219	— ^f	3.64 (J)	50	26.1 (J)	—	7.69 (J)	—	—	34.5 (J)	—	6.1 (J)	1.31	1.07 (J)	—	111	—	—	1.4	12.1 (J)	35.9
R-10 S2	—	—	4.1 (J)	49.1	30.2 (J)	—	7.46 (J)	—	—	71.3 (J)	—	17.3	1.28	1.22 (J)	—	112	—	—	1.55	12.3 (J)	52.6
R-10a	—	—	3.93 (J)	85.4	22.1 (J)	—	9.76 (J)	—	—	47.8 (J)	—	—	1.43	1.43 (J)	—	206	0.545 (J)	4.15 (J)	2.63	7.95	19.5
R-11	—	—	7.41	39.3	33.1 (J)	—	22.4	—	4.8 (J)	—	—	—	2.52 (J)	1.03 (J)	—	93.2	—	—	0.858	8.16	12.2
R-35a	—	—	2.95 (J)	372	43.7 (J)	—	29.2	—	—	125	0.56 (J)	3.6 (J)	2.72 (J)	22.9	—	186	—	—	0.712 (J)	18.2	26.8
R-35b	—	—	2.16 (J)	40.8	27.9 (J)	—	7.29 (J)	—	—	114	0.799 (J)	3.4 (J)	1.43 (J)	1.54 (J)	—	71.7 (J)	—	—	0.418	15	41.3
R-36	220	—	1.6 (J)	40.5 (J)	30.7 (J)	—	10.4	—	—	65.7 (J)	0.729 (J)	3.21 (J)	2.73 (J)	2.25	—	92.2	—	—	0.386	15.6	82.9
R-43 S1	85	—	2.54 (J)	22.9	18.5	—	33	—	—	123	—	2.66 (J)	1.59	4.64	—	71.1	0.656 (J)	—	0.123 (J)	8.56	20
R-43 S2	—	0.614 (J)	3.43 (J)	16.4	40.6 (J)	—	5.8 (J)	—	—	226	—	3.15 (J)	6.59	3.2	—	100	—	—	1.32	8.28	4.92 (J)
R-62	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Sandia Spring	—	—	2.32 (J)	79.6	19.4 (J)	—	6.63 (J)	—	—	36.4 (J)	—	17	1.07	0.781 (J)	—	350	—	—	2.26	11.2	—
Los Alamos Canyon Wells																					
R-9	—	—	—	197	50.4	—	5.4 (J)	—	3.23 (J)	—	—	2.62 (J)	1.43	0.913 (J)	—	190	—	—	1.78	12.2	3.55 (J)

Table 6.4-15 (continued)

Location	Aluminum	Antimony	Arsenic	Barium	Boron	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Manganese	Molybdenum	Nickel	Perchlorate	Strontium	Thallium	Tin	Uranium	Vanadium	Zinc
Mortandad Canyon Wells																					
R-1	—	1.45 (J)	2.74 (J)	15.6	15.8 (J)	—	7.66 (J)	—	8.61 (J)	62.1 (J)	1.34 (J)	4.44 (J)	1.44	17.3	—	55.1	0.549	—	1.09	9.25	26.8
R-13	—	—	3.95 (J)	26.1	16.9 (J)	—	7.98 (J)	—	6.29 (J)	35.3 (J)	—	—	1.24	0.929 (J)	—	53.2	—	2.53 (J)	0.5	5.6	6.57 (J)
R-15	250	—	3.2 (J)	35.5	15.7 (J)	—	17.2	—	3.53 (J)	2440	39.5	23.7	0.991	2.79	—	72.6	—	—	0.508	7.7	8.18 (J)
R-28	—	—	—	71.9	28.5 (J)	0.113 (J)	539	—	6.18 (J)	85.8 (J)	—	2.31 (J)	0.845	35.3	—	185	—	—	1.42 (J)	5.99	10.9
R-33 S1	68.1 (J)	—	3.08 (J)	35.1	16.3 (J)	—	8.4 (J)	—	—	147	—	6.56 (J)	1.29 (J)	6.56	—	54.5 (J)	0.383 (J)	—	0.956	6.44	52.4
R-33 S2	—	—	4.02 (J)	37.6	—	—	8.9 (J)	—	11.4	36.8 (J)	0.668 (J)	—	1.36	1.19 (J)	—	51.9 (J)	—	—	1.16	6.39	—
R-42	—	1.62 (J)	—	96.1	23.6 (J)	—	1270	1.14 (J)	6.75 (J)	221	1.64 (J)	3.56 (J)	0.605	30.3	—	206	—	—	0.736	5.77	26
R-44 S1	—	—	4 (J)	23	17.2 (J)	—	15	—	—	358	—	—	1.12	2.57	—	62.7	—	—	0.553	5.37	30
R-44 S2	—	—	4.45 (J)	25.5	18.8 (J)	—	11.5	—	—	335	—	4.72 (J)	1.09	1.16	—	66.4	—	—	0.704	6.58	27.8
R-45 S1	74.2 (J)	—	3.06 (J)	30.9	18.4 (J)	—	22.2	—	5.08 (J)	40.4 (J)	0.616 (J)	—	1	4.79	—	80.6	—	—	1.03	5.92	45.4
R-45 S2	81.6 (J)	—	4.63	33.6	24 (J)	—	10.9	—	—	52.4	—	3.61 (J)	1.11	1.78 (J)	—	81.7	—	—	0.985	7.41	10.5
R-50 S1	311	0.787 (J)	1.9 (J)	24.5	59.2	—	95.1	—	—	111	0.783 (J)	89.5	6.4	3.5	—	60.3	—	—	0.846 (J)	5.67	191
R-50 S2	1620	—	2.32 (J)	34.1	25.8 (J)	—	7.2 (J)	—	—	671	2.63	29.2	4.01 (J)	2.86	—	58.1	—	—	2.48 (J)	7.72	99.7
R-61 S1	200	—	3.17 (J)	62.4	28.8 (J)	—	18.2	2.44 (J)	3.58 (J)	3070	—	1090	13.4	4.33	—	91.1	—	—	0.985	3.74 (J)	20.2
R-61 S2	75.8 (J)	—	—	41.8	33 (J)	—	2.59 (J)	2.16 (J)	—	5680	—	882	10.7	1.62 (J)	—	79.2	0.521 (J)	—	0.827	5.21	5.46 (J)
Water-Supply Wells																					
O-4	198 (J)	—	—	45.2	55	—	6.89 (J)	—	22.1	—	5.91	—	1.24	0.929 (J)	0.446	118	—	—	0.858	16	30.5
PM-1	—	—	—	76.3	53.1	—	5.28 (J)	—	52.8	—	4.05	—	1.05	0.714 (J)	0.491	144	—	—	1.97	12.4	70
PM-3	—	—	—	52.3	52.3	—	7.54 (J)	—	12.8	—	0.731 (J)	—	0.951	0.644 (J)	0.458	137	—	—	1.1	15.4	16.3
PM-5	—	—	—	28.5	16.4 (J)	—	8.79 (J)	—	11	—	1.16 (J)	—	1.17	—	0.383	48	—	—	0.562	9.78	6.22 (J)

Notes: Values are in µg/L. Values are the maximum detected value. Grey shading indicates a comparison value was exceeded. All standards adjusted to a target risk of 10⁻⁵. Data qualifiers are defined in Appendix A.

^a Regional groundwater (GW) BVs are from LANL (LANL 2007, 096665).

^b na = Not available.

^c tapNMED = NMED tap water from NMED Risk Assessment Guidance for Investigations and Remediation, Volume I, February 2012 (updated June 2012) (NMED 2012, 219971).

^d MCL = EPA maximum contaminant level.

^e tapRSL = EPA tap water from the EPA regional screening level publication (http://www.epa.gov/earth1r6/6pd/rcra_c/pd-n/screen.htm).

^f — = Not a COPC at that location (not detected if no BV, not detected above BV, or not analyzed).

Table 6.4-16
Organic COPCs in Nonfiltered Regional Groundwater and Springs from the Sandia Canyon Watershed

Location	Acetone	Acrolein	Aroclor-1254	BHC[beta-]	Benzoic Acid	Bis(2-ethylhexyl)phthalate	Butanone[2-]	Chloromethane	Dibenz(a,h)anthracene	Diethyl Ether	Diethylphthalate	Endosulfan I	Heptachlor	Heptachlorodibenzodioxin[1,2,3,4,6,7,8-]	Heptachlorodibenzodioxins (Total)	Heptachlorodibenzofuran[1,2,3,4,6,7,8-]	Heptachlorodibenzofurans (Total)	Methyl-2-pentanone[4-]	Methylphenol[4-]	Naphthalene
Comparison Value	21800	0.0416	0.5	0.373	58000	6	7060	188	0.0295	7300	29200	219	0.4	na ^a	na	na	na	1990	72	30
Source Value	tapNMED ^b	tapNMED	MCL ^c	tapNMED	tapRSL ^d	MCL	tapNMED	tapNMED	tapNMED	tapNMED	tapNMED	tapNMED	MCL	na	na	na	na	tapNMED	tapRSL	NMGSU ^e
R-10 S1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
R-10 S2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
R-10a	—	—	—	—	—	—	—	—	—	—	17.3	—	—	—	—	—	—	—	—	—
R-11	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
R-35a	—	—	—	—	—	—	—	—	—	—	—	0.00741 (J)	—	—	—	—	—	—	—	—
R-35b	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
R-36	—	—	—	—	—	10.7 (J)	—	—	—	—	—	—	—	—	—	—	—	—	—	—
R-43 S1	300 (J)	—	—	—	—	4.82 (J)	—	0.23 (J)	—	—	—	—	—	—	—	—	—	—	—	—
R-43 S2	—	—	—	—	—	—	—	—	—	—	—	—	—	1.23e-006 (J)	1.23E-06	5.22e-007 (J)	5.22E-07	—	—	—
R-62	5.72 (J)	—	—	—	228	10.2	5.52 (J)	—	—	—	—	—	—	—	—	—	—	—	—	—
Sandia Spring	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
R-9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
R-1	—	1.95 (J-)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
R-13	—	—	—	—	—	3.6 (J)	—	—	—	—	—	—	—	—	—	—	—	—	—	—
R-15	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
R-28	—	—	—	—	—	—	—	0.34 (J)	—	—	—	—	—	—	—	—	—	—	—	—
R-33 S1	—	—	—	—	—	—	—	0.36 (J)	—	—	—	—	—	—	—	—	—	—	—	—
R-33 S2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
R-42	—	—	—	—	—	0.984 (J)	—	—	—	—	40.3	—	0.0122 (J)	1.1e-006 (J)	1.63E-06	—	—	—	—	—
R-44 S1	—	—	—	—	—	—	—	—	—	—	—	—	—	4.86e-007 (J)	1.39E-06	—	—	—	—	—
R-44 S2	21.6 (J)	—	—	—	—	—	—	—	—	—	—	—	—	—	1.01E-06	—	—	—	—	—
R-45 S1	3.53 (J)	—	—	—	—	—	—	—	—	—	41.7	—	—	—	1.40E-06	—	—	—	—	—
R-45 S2	—	—	—	—	—	—	—	—	—	—	3.74 (J)	—	—	—	—	—	—	—	—	—
R-50 S1	—	—	0.057 (J)	—	13 (J)	—	—	—	—	—	432 (J)	—	—	—	—	—	—	—	—	—
R-50 S2	—	—	—	—	—	—	—	—	—	—	14.2	—	—	—	—	—	—	—	—	0.353 (J)
R-61 S1	78.1 (J)	—	—	—	—	—	—	0.36 (J)	—	—	—	—	—	—	—	—	—	1.52 (J)	—	—
R-61 S2	6.62 (J)	—	—	0.0117 (J)	—	—	2.15 (J)	—	—	—	—	—	—	—	—	—	—	—	4.58 (J)	—
O-4	—	—	—	—	—	—	—	0.33 (J)	—	—	—	—	—	—	—	—	—	—	—	—
PM-1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
PM-3	—	—	—	—	—	—	—	0.414 (J)	—	—	—	—	—	—	—	—	—	—	—	—
PM-5	—	—	—	—	—	—	—	0.32 (J)	—	—	—	—	—	—	—	—	—	—	—	—

Table 6.4-16 (continued)

Location	Octachlorodibenzodioxin[1,2,3,4,6,7,8,9-]	Octachlorodibenzofuran [1,2,3,4,6,7,8,9-]	Oil and Grease	Toluene	Trichloroethene	TPH-DRO
Comparison Value	na	na	na	750	5	na
Source Value	na	na	na	NMGSU	MCL	na
R-10 S1	—	—	—	—	—	—
R-10 S2	—	—	—	—	—	—
R-10a	—	—	—	—	—	—
R-11	—	—	—	—	—	—
R-35a	—	—	—	—	—	—
R-35b	3.03e-006 (J)	—	—	—	—	—
R-36	2.56e-006 (J)	—	—	0.476 (J)	—	—
R-43 S1	—	—	—	—	—	—
R-43 S2	1.03e-005 (J)	9.13e-007 (J)	—	—	0.35 (J)	—
R-62	—	—	—	0.26 (J-)	—	—
Sandia Spring	—	—	—	—	—	—
R-9	—	—	—	—	—	—
R-1	—	—	—	—	—	—
R-13	—	—	—	—	—	—
R-15	—	—	—	—	—	—
R-28	—	—	—	—	—	—
R-33 S1	3.52e-006 (J)	—	—	—	—	—
R-33 S2	—	—	—	—	—	—
R-42	2.98e-006 (J)	—	—	—	—	—
R-44 S1	3.17e-006 (J)	—	—	—	—	—
R-44 S2	3.32e-006 (J)	—	—	—	0.36 (J)	—
R-45 S1	2.26e-006 (J)	—	—	—	—	—
R-45 S2	2.66e-006 (J)	—	—	—	—	—
R-50 S1	—	—	—	—	—	—
R-50 S2	—	—	—	—	—	—
R-61 S1	—	—	2.08 (J)	33.2	—	90.2 (J)
R-61 S2	—	—	1.63 (J-)	2.29	—	89 (J)

Table 6.4-16 (continued)

Location	Octachlorodibenzodioxin[1,2,3,4,6,7,8,9-]	Octachlorodibenzofuran [1,2,3,4,6,7,8,9-]	Oil and Grease	Toluene	Trichloroethene	TPH-DRO
Comparison Value	na	na	na	750	5	na
Source Value	na	na	na	NMGSU	MCL	na
O-4	—	—	—	—	—	—
PM-1	—	—	—	—	—	—
PM-3	—	—	—	—	—	—
PM-5	—	—	—	—	—	—

Notes: Values are in µg/L. Values are the maximum detected value. Grey shading indicates a comparison value was exceeded. All standards adjusted to a target risk of 10⁻⁵. Data qualifiers are defined in Appendix A.

- ^a na = Not available.
- ^b tapNMED = NMED tap water from NMED Risk Assessment Guidance for Investigations and Remediation, Volume I, February 2012 (updated June 2012) (NMED 2012, 219971).
- ^c MCL = EPA maximum contaminant level.
- ^d tapRDL = EPA tap water from the EPA regional screening level publication (http://www.epa.gov/earth1r6/6pd/rcra_c/pd-n/screen.htm).
- ^e NMGSU, NM Groundwater Standards (nonfiltered sample), NMAC 20.6.2.3103 (<http://www.nmcpr.state.nm.us/nmac/parts/title20/20.006.0004.htm>).
- ^f — = Not a COPC at that location (not detected if no BV, not detected above BV, or not analyzed).

Table 6.4-17
Radionuclide COPCs in Nonfiltered Regional Groundwater and Springs from the Sandia Canyon Watershed

Location	Bismuth-214	Gross alpha	Gross beta	Gross gamma	Radium-226	Radium-228	Thorium-230	Tritium	Uranium-234	Uranium-235/236	Uranium-238
LANL Regional GW BV ^a	na ^b	na	na	na	na	na	na	0.32	na	na	na
Comparison Value	na	15	50	na	5	5	12	20000	20	24	24
Comparison Source	na	MCL ^c	SMCL ^d	na	MCL	MCL	DCG ^e	MCL	DCG	DCG	DCG
Sandia Canyon Wells											
R-10 S1	— ^f	—	7.14	—	0.847	—	—	—	0.801	0.0377	0.422
R-10 S2	23	—	8.37	—	—	—	—	2.3828	0.983	0.0334	0.447
R-10a	—	—	4.13	—	—	—	—	—	1.19	0.0342	0.71
R-11	—	1.71	5.09	—	—	0.862	—	6.7942	0.589	—	0.276
R-35a	—	—	5.44	—	0.523	—	—	—	0.504	—	0.203
R-35b	—	—	5.23	32	0.472	—	—	—	0.329	—	0.121
R-36	—	—	8.59	—	—	—	—	21.381	0.556	—	0.206
R-43 S1	—	6.9	2.48	70	0.883	—	—	1.4168	0.106	—	0.0398
R-43 S2	—	—	1.07	94	0.756	1.3	—	—	1.17	0.0756	0.446
R-62	—	—	3.17	—	—	0.825	—	6.638	0.8 (J)	—	0.341 (J)
Sandia Spring	—	3.6	7.15	—	—	—	—	—	0.707	—	0.322
Los Alamos Canyon Wells											
R-9	—	—	4.56	—	0.446	2.24	—	9.3058	1.13	—	0.593

Table 6.4-17 (continued)

Location	Bismuth-214	Gross alpha	Gross beta	Gross gamma	Radium-226	Radium-228	Thorium-230	Tritium	Uranium-234	Uranium-235/236	Uranium-238
Mortandad Canyon Wells											
R-1	—	2.18	—	—	—	0.879	—	—	0.768	—	0.333
R-13	—	11.1	14.5	—	—	—	—	4.991	0.291	—	0.136
R-15	—	5.36	4.38	—	—	—	—	34.1	0.285	—	0.178
R-28	—	3.18	2.42	97	—	—	—	220.38	0.954	0.059	0.407
R-33 S1	—	—	3.4	22	0.777	—	—	—	0.525	0.0342	0.287
R-33 S2	—	—	3.44	101	1.53	—	—	—	0.627	—	0.329
R-42	—	1.62	22.2	—	—	—	0.168	329.75	0.56	—	0.217
R-44 S1	—	—	—	143	0.404	1.03	—	1.2236	0.386	—	0.197
R-44 S2	—	1.53	26.5	128	—	—	—	—	0.481	—	0.258
R-45 S1	—	—	3.73	27	0.785	1.56	—	11.173	0.921	0.0472	0.242
R-45 S2	—	—	9.32	—	0.416	—	—	1.288	0.588	—	0.233
R-50 S1	—	—	2.68	107	—	—	—	29.463	0.549	—	0.267
R-50 S2	—	5.78	4.47	—	—	—	—	23.15	1.28	0.0716	0.76
R-61 S1	—	4.25	—	—	0.529	—	—	33.63	0.65	—	0.32
R-61 S2	—	—	2.81	—	—	—	—	—	0.552	—	0.349

Table 6.4-17 (continued)

Location	Bismuth-214	Gross alpha	Gross beta	Gross gamma	Radium-226	Radium-228	Thorium-230	Tritium	Uranium-234	Uranium-235/236	Uranium-238
Water-Supply Wells											
O-4	—	4.64	5.14	—	0.683	11.8	—	—	0.586	—	0.311
PM-1	—	—	4.69	—	—	—	—	3.28	1.36	—	0.627
PM-3	—	1.05	4.91	3.2	—	—	—	—	0.972	—	0.351
PM-5	—	3.67	3.52	83	0.882	6.58	0.0664 (J)	—	0.295	—	0.176 (J)

Notes: Values are in pCi/L. Values are maximum values greater than the LANL BV; if no BV, value is maximum detected value. Data qualifiers are defined in Appendix A.

^a Regional Groundwater BVs are from LANL (2007, 096665).

^b na = Not available.

^c MCL = EPA maximum contaminant level.

^d SMCL = EPA Secondary maximum contaminant level.

^e DCG = DOE DCGs based on 4 mrem/yr.

^f — = Not a COPC at that location (not detected if no BV, not detected above BV, or not analyzed).

Table 6.4-18
General Inorganic COPCs in Filtered Regional Groundwater and Springs from the Sandia Canyon Watershed

Location	Alkalinity-CO ₃	Ammonia as Nitrogen	Bromide	Calcium	Chlorate	Chloride	Fluoride	Hardness	Magnesium	Nitrate-Nitrite as Nitrogen	Potassium	Silicon Dioxide	Sulfate	Total Phosphate as Phosphorus
LANL Regional GW BV ^a	na ^b	0.05	0.1	24.88	na	3.57	0.57	na	4.15	0.89	2.63	88.5	7.2	0.16
Comparison Value	na	na	na	na	na	250	1.6	na	na	10	na	na	600	na
Comparison Source	na	na	na	na	na	NMGSF ^c	NMGSF	na	na	NMGSF	na	na	NMGSF	na
Sandia Canyon Wells														
R-10 S1	— ^d	—	—	—	—	—	—	72	4.5	—	2.8	—	—	—
R-10 S2	—	—	—	—	—	—	—	75	4.8	1.24	3	—	—	—
R-10a	—	—	0.148 (J)	28.8	-	6.43 (J+)	—	89	—	1.64	3.3	—	10.6	—
R-11	—	—	0.125 (J)	—	—	5.62	0.58	83	6.2	6.11	—	—	12.2	—
R-35a	—	0.052 (J-)	—	—	—	6.58	0.625	87	6.2	—	4.4	84100	—	—
R-35b	—	0.296 (J)	—	—	—	—	0.786	64	5.3	1.4 (J)	—	—	—	—
R-36	—	0.0608	0.115 (J)	—	—	5.97	0.803	66	4.5	2.71	—	—	9.82	—
R-43 S1	—	0.068	0.127 (J)	—	—	6.16	—	63	4.6	5.71 (J)	—	—	11.7	—
R-43 S2	10	0.08 (J-)	—	—	—	3.97	—	62	4.9	5.4	—	—	8.92	—
R-62	4	0.0629	—	—	—	8.26	—	65	4.9	1.39	—	—	13.8	—
Sandia Spring	—	—	—	29.2	—	—	0.644 (J-)	81	—	—	2.7	—	22.7	—
Los Alamos Canyon Wells														
R-9	—	—	—	—	—	6.3	—	87	7.1	—	4	—	—	—

Table 6.4-18 (continued)

Location	Alkalinity-CO3	Ammonia as Nitrogen	Bromide	Calcium	Chlorate	Chloride	Fluoride	Hardness	Magnesium	Nitrate-Nitrite as Nitrogen	Potassium	Silicon Dioxide	Sulfate	Total Phosphate as Phosphorus
Mortandad Canyon Wells														
R-1	—	—	—	—	—	—	—	48	4.2	—	—	—	—	0.257 (J)
R-13	—	0.104 (J-)	—	—	—	—	—	51	—	—	—	—	—	0.171 (J)
R-15	1.1	—	0.114 (J)	—	—	4.47	—	54	—	2.78	—	—	—	—
R-28	—	—	0.33	48.1	0.005 (J)	35.3 (J+)	—	170	12	4.72 (J)	—	—	50.7	—
R-33 S1	—	—	—	—	—	—	—	48	—	—	—	—	—	0.293 (J)
R-33 S2	—	0.055	—	—	—	—	—	47	4.3	—	—	—	—	0.313 (J)
R-42	—	0.176	0.244	56.5	0.0047 (J)	40.3	—	206	16	6.56	2.7	—	80.6	0.28 (J)
R-44 S1	—	—	—	—	—	—	—	53	4.2	1.35	—	—	11.3	—
R-44 S2	—	0.083	—	—	—	—	—	52	4.2	0.98	—	—	—	—
R-45 S1	—	—	—	—	—	3.88	—	67	5.1	2.61	—	—	—	—
R-45 S2	—	—	—	—	—	—	—	65	5	—	—	—	—	—
R-50 S1	—	—	—	—	—	7.79	—	58	4.8	1.72	—	—	12	—
R-50 S2	—	0.0723	—	—	—	—	—	47	4.2	—	—	—	—	—
R-61 S1	—	—	—	—	—	3.59	—	60	4.7	1.55	—	—	—	0.253 (J)
R-61 S2	—	—	—	—	—	—	—	53	4.5	—	—	—	—	—

Table 6.4-18 (continued)

Location	Alkalinity-CO3	Ammonia as Nitrogen	Bromide	Calcium	Chlorate	Chloride	Fluoride	Hardness	Magnesium	Nitrate-Nitrite as Nitrogen	Potassium	Silicon Dioxide	Sulfate	Total Phosphate as Phosphorus
Water-Supply Wells														
O-4	—	—	—	—	—	—	—	—	—	—	—	—	—	—
PM-1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
PM-3	—	—	—	—	—	—	—	—	—	—	—	—	—	—
PM-5	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Notes: Values are in µg/L. Values are the maximum detected value. No comparison value was exceeded. All standards adjusted to a target risk of 10^{-5} . Data qualifiers are defined in Appendix A.

^a Regional Groundwater BVs are from LANL (2007, 096665).

^b na = Not available.

^c NMGSF = NM Groundwater Standards (filtered sample), NMAC 20.6.2.3103 (<http://www.nmcpr.state.nm.us/nmac/parts/title20/20.006.0002.htm>).

^d — = Not a COPC at that location (not detected if no BV, not detected above BV, or not analyzed).

Table 6.4-19

General Inorganic COPCs in Nonfiltered Regional Groundwater and Springs from the Sandia Canyon Watershed

Location	Alkalinity-CO ₃ +HCO ₃	Ammonia as Nitrogen	Bromide	Calcium	Chloride	Cyanide (Total)	Fluoride	Hardness	Magnesium	Nitrate-Nitrite as Nitrogen	Potassium	Silicon Dioxide	Sodium	Sulfate	Total Kjeldahl Nitrogen	Total Phosphate as Phosphorus
Comparison Value	na ^a	na	na	na	na	0.2	1460	na	na	10	na	na	na	na	na	na
Comparison Source	na	na	na	na	na	MCL ^b	tapNMED ^c	na	na	MCL	na	na	na	na	na	na
Sandia Canyon Wells																
R-10 S1	— ^d	—	—	21.3	—	—	—	71	4.37	—	2.75	—	12.7	—	0.06 (J)	—
R-10 S2	—	—	—	22	—	—	—	74	4.73	—	3.03	—	13.4	—	0.0642 (J)	—
R-10a	—	—	—	29	—	—	—	88	3.96 (J)	—	3.29	—	15.2	—	0.117 (J-)	—
R-11	—	—	—	23.2	—	—	—	84	6.29	—	1.62	—	13.4	—	0.092 (J)	—
R-35a	—	—	—	24	—	—	—	85	6.14	—	4.63	—	20	—	0.331 (J-)	—
R-35b	—	—	—	16.6	—	—	—	62	5.12	—	2.16	—	12.4 (J)	—	0.16	—
R-36	—	—	—	23.7	—	—	—	85	6.29	—	2.23	—	15.8	—	0.271 (J-)	—
R-43 S1	—	—	—	18.2	—	—	—	62	3.95	—	1.42	—	11.1	—	0.0807 (J-)	—
R-43 S2	—	—	—	17	—	—	—	61	4.56	—	1.62	—	18.8	—	—	—
R-62	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Sandia Spring	—	—	—	28.5	—	—	—	79	1.95	—	2.66	—	15.4	—	—	—
Los Alamos Canyon Wells																
R-9	—	—	—	23.7	—	—	—	88	7.21	—	4.03	—	18.8	—	—	—

Table 6.4-19 (continued)

Location	Alkalinity-CO3+HCO3	Ammonia as Nitrogen	Bromide	Calcium	Chloride	Cyanide (Total)	Fluoride	Hardness	Magnesium	Nitrate-Nitrite as Nitrogen	Potassium	Silicon Dioxide	Sodium	Sulfate	Total Kjeldahl Nitrogen	Total Phosphate as Phosphorus
Mortandad Canyon Wells																
R-1	—	—	—	12.2	—	0.00402 (J)	—	48	4.31	—	1.86	—	12.9	—	—	—
R-13	—	—	—	14.4	—	—	—	51	3.57	—	1.46	—	10.8	—	0.053 (J-)	—
R-15	—	—	—	15.4	—	—	—	55	4.17	—	1.99	—	11.7	—	0.098 (J-)	—
R-28	—	—	—	48.3	—	0.00623	—	170	12.3	—	1.98	—	17	—	1.4 (J-)	—
R-33 S1	—	—	—	12.8	—	—	—	49	4.14	—	1.71	—	14.6	—	0.068 (J-)	—
R-33 S2	—	—	—	11.7	—	—	—	47	4.27	—	2.6	—	12.4	—	0.054 (J)	—
R-42	—	—	—	54.6	—	0.00504	—	198	15.1	—	2.74	—	17.9	—	0.345 (J-)	—
R-44 S1	—	—	—	13.9	—	0.00406 (J)	—	49	3.66	—	1.43 (J)	—	11	—	—	—
R-44 S2	—	—	—	13.9	—	—	—	52	4.11	—	1.56	—	11.1	—	—	—
R-45 S1	—	—	—	18.3	—	—	—	66	5.02	—	1.34	—	11.1	—	0.109	—
R-45 S2	—	—	—	17.6	—	—	—	64	4.96	—	1.41	—	13.8	—	0.158	—
R-50 S1	—	—	—	15.7	—	—	—	59	4.71	—	1.5 (J)	—	17.7	—	0.0765 (J)	—
R-50 S2	—	—	—	12.1	—	—	—	48	4.2	—	1.61 (J)	—	19	—	0.0354 (J)	—
R-61 S1	—	—	—	16.3	—	—	—	60	4.65	—	1.83	—	22.5	—	—	—
R-61 S2	—	—	—	13.6	—	—	—	52	4.39	—	2.33	—	23.7	—	—	—

Table 6.4-19 (continued)

Location	Alkalinity-CO ₃ +HCO ₃	Ammonia as Nitrogen	Bromide	Calcium	Chloride	Cyanide (Total)	Fluoride	Hardness	Magnesium	Nitrate-Nitrite as Nitrogen	Potassium	Silicon Dioxide	Sodium	Sulfate	Total Kjeldahl Nitrogen	Total Phosphate as Phosphorus
Water-Supply Wells																
O-4	118	0.039 (J-)	0.109 (J)	20.9	7.8	—	0.301	87	8.46	0.885	3.7	96	21.6	5.6	—	—
PM-1	122	—	0.092 (J)	26.2	6.1	—	0.258	93	6.75	0.89	3.72	80	21	5.4	—	—
PM-3	116	0.0272 (J)	0.0778 (J)	23.8	6.5	—	0.486	92	8.02	0.83	3.6	91	20.1	5.4	0.098 (J-)	0.32
PM-5	65	0.0542	0.0817 (J)	10.2	2.1	—	0.269	42	3.9	0.95	2.06	89	12.5	2.3	0.073 (J-)	0.12

Notes: Values are in mg/L. Values are the maximum detected value. No comparison value was exceeded. All standards adjusted to a target risk of 10^{-5} . Data qualifiers are defined in Appendix A.

^a na = Not available.

^b tapNMED = NMED tap water from NMED Risk Assessment Guidance for Investigations and Remediation, Volume I, February 2012 (updated June 2012) (NMED 2012, 219971).

^c MCL = EPA maximum contaminant level.

^d — = Not a COPC at that location (not detected if no BV, not detected above BV, or not analyzed).

**Table 6.5-1
Sandia Canyon Watershed COPC Summary**

Analyte	Sediment		Stormwater ^a		Nonstorm-Related Surface Water ^b		Alluvial Groundwater		Intermediate Groundwater		Regional Groundwater ^b	
	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
Metals												
Aluminum	X ^c	— ^d	X	X	X	X	X	X	—	X	X	X
Antimony	—	X	X	X	X	X	—	X	X	X	—	X
Arsenic	X	—	X	X	X	X	X	X	—	X	—	X
Barium	X	—	X	X	X	X	X	X	—	X	X	X
Beryllium	X	—	X	X	X	X	X	—	—	X	—	X
Boron	—	—	X	X	X	X	X	X	X	X	X	X
Cadmium	X	X	X	X	X	—	—	—	—	—	—	X
Calcium	X	—	X	X	X	X	X	X	X	X	X	X
Chromium	X	X	X	X	X	X	X	X	X	X	X	X
Chromium Hexavalent Ion	X	—	—	—	X	—	—	—	X	—	X	—
Cobalt	X	—	X	X	X	X	X	—	—	X	—	X
Copper	X	X	X	X	X	X	X	X	X	X	X	X
Iron	X	—	X	X	X	X	X	X	X	X	X	X
Lead	X	X	X	X	X	X	X	X	X	X	X	X
Magnesium	X	—	X	X	X	X	X	X	X	X	X	X
Manganese	X	—	X	X	X	X	X	X	X	X	—	X
Mercury	X	—	X	X	X	—	X	—	—	—	—	X
Molybdenum	X	X	X	—	X	X	X	X	X	X	X	X
Nickel	X	—	X	X	X	X	X	X	—	X	X	X
Potassium	X	—	X	X	X	X	X	X	—	X	X	X

Table 6.5-1 (continued)

Analyte	Sediment		Stormwater ^a		Nonstorm-Related Surface Water ^b		Alluvial Groundwater		Intermediate Groundwater		Regional Groundwater ^b	
	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
Selenium	X	X	X	X	X	X	—	X	—	—	X	—
Silver	X	X	X	X	X	X	—	X	—	—	—	—
Sodium	—	—	X	X	X	X	X	X	X	X	X	X
Strontium	—	—	X	—	X	X	X	X	X	X	—	X
Thallium	X	—	X	X	X	X	—	—	—	X	—	X
Tin	—	—	X	—	—	—	—	—	X	—	X	X
Uranium	X	—	X	X	X	X	X	X	X	X	X	X
Vanadium	X	—	X	X	X	X	X	X	—	X	X	X
Zinc	X	X	X	X	X	X	X	X	X	X	X	X
Other Inorganic Chemicals												
Ammonia as Nitrogen	—	—	X	—	X	X	X	X	X	—	X	X
Bromide	—	—	—	—	X	X	X	X	X	X	X	X
Chlorate	—	—	—	—	—	—	—	—	—	X	—	X
Chloride	X	—	X	—	X	X	X	X	X	X	X	X
Cyanide [Total]	X	—	X	X	X	X	X	—	X	X	X	X
Cyanide, Amenable to Chlorination	—	—	X	X	X	—	—	—	—	—	—	—
Fluoride	X	—	X	—	X	X	X	X	X	X	X	X
Nitrate	X	—	—	—	—	—	—	—	—	—	—	—
Nitrate-Nitrite as Nitrogen	—	—	X	X	X	X	X	X	X	X	X	X
Perchlorate	X	X	—	—	X	X	—	X	X	X	X	X
Phosphorus, Orthophosphate [Expressed as PO ₄]	—	—	—	—	X	—	—	—	—	—	—	—

Table 6.5-1 (continued)

Analyte	Sediment		Stormwater ^a		Nonstorm-Related Surface Water ^b		Alluvial Groundwater		Intermediate Groundwater		Regional Groundwater ^b	
	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
Silicon Dioxide	—	—	X	—	X	X	X	X	X	X	X	X
Sulfate	X	—	X	—	X	X	X	—	X	X	X	X
Sulfide, Extractable	X	—	—	—	—	—	—	—	—	—	—	—
Sulfide, Total	—	—	—	—	—	—	—	—	X	—	X	—
Total Kjeldahl Nitrogen	—	—	X	—	X	X	X	X	X	X	—	—
Total Phosphate as Phosphorus	—	—	X	—	X	X	X	X	X	X	X	X
Dioxins and Furans												
Heptachlorodibenzodioxin[1,2,3,4,6,7,8-]	—	—	—	—	—	—	—	—	—	X	—	X
Heptachlorodibenzodioxins (Total)	—	—	—	—	—	—	—	—	—	X	—	X
Heptachlorodibenzofuran[1,2,3,4,6,7,8-]	—	—	—	—	—	—	—	—	—	—	—	X
Heptachlorodibenzofurans (Total)	—	—	—	—	—	—	—	—	—	—	—	X
Hexachlorodibenzodioxins (Total)	—	—	—	—	—	—	—	—	—	X	—	—
Octachlorodibenzodioxin[1,2,3,4,6,7,8,9-]	—	—	—	—	—	—	—	—	—	X	X	X
Octachlorodibenzofuran[1,2,3,4,6,7,8,9-]	—	—	—	—	—	—	—	—	—	—	—	X
High Explosives												
2,4-Diamino-6-nitrotoluene	—	—	—	—	X	—	—	—	—	—	—	—
2,6-Diamino-4-nitrotoluene	—	—	—	—	X	—	—	—	—	—	—	—
Amino-2,6-dinitrotoluene[4-]	—	—	X	—	—	—	—	—	—	—	—	—
Amino-4,6-dinitrotoluene[2-]	—	—	X	—	—	—	—	—	—	—	—	—
Dinitrobenzene[1,3-]	—	—	—	—	—	—	—	—	—	—	X	—
Dinitrotoluene[2,6-]	—	—	X	—	—	—	—	—	—	—	—	—
DNX	—	—	—	—	—	—	—	—	—	—	X	—

Table 6.5-1 (continued)

Analyte	Sediment		Stormwater ^a		Nonstorm-Related Surface Water ^b		Alluvial Groundwater		Intermediate Groundwater		Regional Groundwater ^b	
	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
HMX	—	—	X	—	—	—	—	—	—	—	—	—
Nitrotoluene[3-]	—	—	—	—	—	—	—	—	—	—	X	—
Nitrotoluene[4-]	—	—	X	—	—	—	—	—	—	—	—	—
RDX	—	—	X	—	—	—	—	—	—	—	—	—
Tetryl	—	—	X	—	—	—	—	—	—	—	—	—
Pesticides and PCBs												
Aldrin	—	—	—	—	—	—	—	—	X	—	—	—
Aroclor-1016	X	—	—	—	—	—	—	—	—	—	X	—
Aroclor-1242	X	—	X	—	—	—	—	—	—	—	—	—
Aroclor-1248	X	—	—	—	—	—	—	—	—	—	—	—
Aroclor-1254	X	X	X	—	X	—	X	—	—	—	X	X
Aroclor-1260	X	X	X	—	X	—	X	—	—	X	X	—
Total PCBs	—	—	—	X	—	X	—	—	—	—	—	—
BHC[beta-]	—	—	—	—	—	—	—	—	—	—	—	X
BHC[delta-]	X	—	—	—	X	—	—	—	—	—	—	—
Chlordane[gamma-]	X	—	—	—	—	—	—	—	—	—	—	—
DDD[4,4'-]	X	X	—	—	—	—	—	—	X	—	X	—
DDE[4,4'-]	—	X	—	—	—	—	—	—	X	—	X	—
DDT[4,4'-]	—	X	—	—	—	—	—	—	X	—	X	—
Dieldrin	X	—	—	—	—	—	—	—	X	—	X	—
Endosulfan I	—	—	—	—	—	—	—	—	—	—	—	X
Endosulfan II	—	—	—	—	—	—	—	—	X	—	—	—

Table 6.5-1 (continued)

Analyte	Sediment		Stormwater ^a		Nonstorm-Related Surface Water ^b		Alluvial Groundwater		Intermediate Groundwater		Regional Groundwater ^b	
	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
Endosulfan Sulfate	—	—	—	—	—	—	—	—	X	—	—	—
Endrin	—	—	—	—	—	—	—	—	X	—	X	—
Heptachlor	—	—	—	—	—	—	—	—	X	—	X	X
Heptachlor Epoxide	—	—	—	—	—	—	—	—	X	—	X	—
Methoxychlor[4,4']	X	—	—	—	—	—	—	—	—	—	—	—
SVOCs												
Acenaphthene	X	X	X	—	—	—	—	—	—	—	—	—
Acenaphthylene	X	—	X	—	—	—	—	—	—	—	—	—
Acrolein	—	—	—	—	—	—	—	—	—	—	—	X
Anthracene	X	—	X	—	—	—	—	—	—	—	—	—
Benzo[a]anthracene	X	X	X	—	—	—	—	—	—	X	—	—
Benzo[a]pyrene	X	X	X	—	—	—	—	—	—	X	—	—
Benzo[b]fluoranthene	X	X	X	—	—	—	—	—	—	X	—	—
Benzo[g,h,i]perylene	X	X	—	—	—	—	—	—	—	—	—	—
Benzo[k]fluoranthene	X	X	—	—	—	—	—	—	—	X	—	—
Benzoic Acid	X	—	—	—	X	X	—	—	X	X	X	X
Bis[2-chloroethoxy]methane	—	—	X	—	—	—	—	—	—	—	—	—
Bis[2-ethylhexyl]phthalate	X	—	X	—	—	—	X	—	X	X	X	X
Butylbenzylphthalate	X	—	X	—	—	—	—	—	—	—	—	—
Chloroaniline[4-]	X	—	—	—	—	—	—	—	—	—	—	—
Chloronaphthalene[2-]	—	—	X	—	—	—	—	—	—	—	—	—
Chrysene	X	X	X	—	—	—	—	—	—	—	—	—

Table 6.5-1 (continued)

Analyte	Sediment		Stormwater ^a		Nonstorm-Related Surface Water ^b		Alluvial Groundwater		Intermediate Groundwater		Regional Groundwater ^b	
	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
Dibenzofuran	X	—	X	—	—	—	—	—	—	—	—	—
Dibenz(a,h)anthracene	—	—	—	—	—	—	—	—	—	—	—	X
Dichlorophenol[2,4-]	—	—	—	—	X	—	—	—	—	—	X	—
Diethylphthalate	—	—	X	—	—	—	—	—	—	X	X	X
Diphenylamine	—	X	—	—	—	—	—	—	—	—	—	—
Di-n-butylphthalate	X	—	X	—	—	—	—	—	—	—	—	—
Di-n-octylphthalate	X	—	—	—	—	—	—	—	—	—	—	—
Fluoranthene	X	X	X	—	—	—	—	—	—	—	—	—
Fluorene	X	X	X	—	—	—	—	—	—	—	—	—
Indeno[1,2,3-cd]pyrene	X	X	—	—	—	—	—	—	—	—	—	—
Isophorone	—	—	X	—	—	—	—	—	—	—	—	—
Methylnaphthalene[2-]	X	—	X	—	—	—	—	—	—	—	—	—
Methylphenol[4-]	—	—	—	—	—	—	—	—	—	—	—	X
Naphthalene	—	—	—	—	—	—	—	—	—	—	—	X
Nitroso-di-n-propylamine[N-]	—	—	X	—	—	—	—	—	—	—	—	—
Phenanthrene	X	X	X	—	—	—	—	—	—	—	X	—
Phenol	—	—	—	—	—	—	—	—	—	—	X	—
Pyrene	X	X	X	—	—	—	—	—	—	—	—	—
Trichlorophenol[2,4,5-]	—	—	—	—	X	—	—	—	—	—	X	—
Trichlorophenol[2,4,6-]	—	—	X	—	X	—	—	—	—	—	X	—

Table 6.5-1 (continued)

Analyte	Sediment		Stormwater ^a		Nonstorm-Related Surface Water ^b		Alluvial Groundwater		Intermediate Groundwater		Regional Groundwater ^b	
	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
TPHs												
Diesel Range Organics	X	X	X	—	—	—	—	—	X	—	X	X
Oil and Grease	—	—	—	—	—	—	—	—	—	—	—	X
VOCs												
Acetone	X	X	—	—	X	X	X	—	X	—	X	X
Benzene	X	—	—	—	—	X	—	—	—	—	X	—
Bromodichloromethane	—	—	—	—	X	X	—	—	—	—	—	—
Bromoform	—	—	—	—	X	X	—	—	—	—	—	—
Bromomethane	—	—	—	—	—	—	—	—	—	—	X	—
Butanone[2-]	X	X	—	—	—	—	X	—	—	—	X	X
Butylbenzene[n-]	X	—	—	—	—	—	—	—	—	—	—	—
Butylbenzene[sec-]	X	—	—	—	—	—	—	—	—	—	—	—
Carbon Disulfide	X	—	—	—	—	—	—	—	—	—	X	—
Chlorodibromomethane	—	—	—	—	X	X	—	—	—	—	—	—
Chloroform	X	—	—	—	X	X	X	X	X	X	—	—
Chloromethane	—	—	—	—	—	X	—	—	X	X	X	X
Dichlorobenzene[1,3-]	—	—	—	—	X	—	X	—	—	—	X	—
Diethyl Ether	—	—	—	—	—	—	—	—	—	X	—	X
Dioxane[1,4-]	—	—	—	—	X	—	X	—	—	X	—	—
Ethylbenzene	X	—	—	—	—	—	—	—	—	—	—	—
Hexachlorobenzene	—	—	X	—	—	—	—	—	—	—	—	—
Isopropyltoluene[4-]	X	X	—	—	—	—	—	—	—	—	—	—

Table 6.5-1 (continued)

Analyte	Sediment		Stormwater ^a		Nonstorm-Related Surface Water ^b		Alluvial Groundwater		Intermediate Groundwater		Regional Groundwater ^b	
	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
Methyl-2-pentanone[4-]	—	—	—	—	—	—	—	—	—	—	X	X
Methylene Chloride	—	X	—	—	—	—	—	—	—	X	X	—
Naphthalene	X	—	X	—	—	—	—	—	X	—	—	—
Styrene	X	—	—	—	—	—	X	—	—	—	—	—
Toluene	X	—	—	—	—	—	X	—	X	X	X	X
Tetrachloroethene	—	X	—	—	—	—	—	—	—	—	—	—
Trichloroethene	—	—	—	—	—	—	—	—	—	—	—	X
Trimethylbenzene[1,2,4-]	X	—	—	—	—	—	—	—	—	—	—	—
Xylene [Total]	X	—	—	—	—	—	—	—	—	—	—	—
Xylene[1,2-]	X	—	—	—	—	—	—	—	—	—	—	—
Xylene[1,3-]+Xylene[1,4-]	X	—	—	—	—	—	—	—	—	—	X	—
Other												
Methyl Mercury	X	—	—	—	—	—	—	—	—	—	—	—
Radionuclides												
Americium-241	X	—	X	X	X	—	—	—	—	—	X	—
Bismuth-214	—	—	—	—	—	—	—	—	—	—	—	X
Cesium-137	X	—	X	—	—	—	—	—	—	—	—	—
Gross alpha	—	—	X	X	X	X	X	X	X	X	X	X
Gross alpha/beta	—	—	—	—	—	—	—	—	X	—	X	—
Gross beta	—	—	X	X	X	X	X	X	X	X	X	X
Gross gamma	—	—	—	—	—	—	—	—	X	X	X	X
Lead-210	—	—	X	—	—	—	—	—	—	—	—	—

Table 6.5-1 (continued)

Analyte	Sediment		Stormwater ^a		Nonstorm-Related Surface Water ^b		Alluvial Groundwater		Intermediate Groundwater		Regional Groundwater ^b	
	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
Plutonium-238	X	—	X	—	X	—	—	—	—	—	X	—
Plutonium-239/240	X	—	X	X	X	—	—	—	—	—	—	—
Polonium-210	—	—	X	—	—	—	—	—	—	—	—	—
Potassium-40	—	—	X	—	X	—	X	—	X	—	X	—
Radium-226	—	—	X	X	X	—	X	—	X	X	X	X
Radium-228	—	—	X	X	—	—	X	X	X	X	X	X
Strontium-90	X	—	X	—	X	—	X	—	—	X	X	—
Thorium-228	X	—	X	X	—	—	—	—	—	—	—	—
Thorium-230	—	—	X	X	—	—	—	—	—	—	X	X
Thorium-232	X	—	X	X	—	—	—	—	—	—	—	—
Tritium	X	—	X	—	X	—	X	X	X	X	X	X
Uranium-234	X	—	X	X	X	X	X	X	X	X	X	X
Uranium-235/236	X	—	X	X	X	X	X	—	X	X	X	X
Uranium-238	X	—	X	X	X	X	X	X	X	X	X	X

Note: Light grey shading indicates analyte was not a Phase I sediment COPC. Dark grey shading indicates analyte exceeded a comparison value for water.

^a For stormwater, an analyte is marked with "X" if it was detected and is shaded gray if it exceeded a comparison value.

^b Sandia spring is screened both as surface water and regional groundwater.

^c X = Analyte is a COPC for given medium.

^d — = Analyte is not a COPC for a given medium or not detected in stormwater.

Table 6.5-2
Summary of Water COPCs Greater than Comparison Values

Group	Analyte	Field Prep	Number Exceeding	Total	Number Exceeding	Total	Number Exceeding	Total	Number Exceeding	Total	Number Exceeding	Total
INORGANIC	Arsenic	F	—*	—	1	25	—	—	—	—	—	—
INORGANIC	Chromium	F	—	—	—	—	—	—	34	120	44	357
INORGANIC	Chromium	UF	—	—	—	—	—	—	14	104	20	267
INORGANIC	Copper	F	2	9	3	25	—	—	—	—	—	—
INORGANIC	Iron	F	—	—	—	—	—	—	1	113	3	274
INORGANIC	Lead	UF	—	—	—	—	—	—	—	—	1	265
INORGANIC	Manganese	F	—	—	—	—	—	—	1	111	5	273
INORGANIC	Manganese	UF	—	—	—	—	—	—	—	—	4	264
INORGANIC	Selenium	UF	—	—	1	25	—	—	—	—	—	—
INORGANIC	Thallium	F	—	—	2	25	—	—	—	—	—	—
ORGANIC	Acrolein	UF	—	—	—	—	—	—	—	—	1	130
ORGANIC	Benzo(a)pyrene	UF	—	—	—	—	—	—	1	83	—	—
ORGANIC	Bis(2-ethylhexyl)phthalate	UF	—	—	—	—	—	—	—	—	4	196
ORGANIC	Dibenz(a,h)anthracene	UF	—	—	—	—	—	—	—	—	1	196
ORGANIC	Dioxane[1,4-]	UF	—	—	—	—	—	—	20	83	—	—
ORGANIC	Methylene Chloride	UF	—	—	—	—	—	—	1	90	—	—
ORGANIC	Total PCB	UF	3	3	8	8	—	—	—	—	—	—
OTHER	Cyanide (Total)	UF	—	—	—	—	—	—	1	106	—	—
OTHER	Nitrate-Nitrite as Nitrogen	F	—	—	—	—	—	—	8	115	—	—
OTHER	Perchlorate	F	—	—	—	—	—	—	35	116	—	—
RAD	Gross alpha	UF	3	9	—	—	—	—	—	—	—	—
RAD	Radium-228	UF	—	—	—	—	—	—	—	—	2	63

Notes: F = Filtered; UF = unfiltered.

* — = Not greater than comparison value.

Table 7.2-1
Reductive Capacity of the Sandia Canyon Wetland and the Rock Units within the Chromium Area

Rock	Setting	Reductive Capacity	Groundwater flow / Chromium migration velocity	Chromium migration mechanism	Notes
Wetland	Surface and saturated groundwater flow	High	Predominantly lateral flow; limited vertical migration plausible. Surface water flows across wetland in a few hours; shallow groundwater flow rate is unknown.	Surface water interaction with solid organic matter and olive green sandy sediments.	Wetland may contain ~30% of the original Cr mass as Cr(III). Stabilization of wetland is planned to retain this Cr source.
Bandelier Tuff plus Cerro Toledo sediments	Unsaturated zone	Low to potentially moderate	1–6 m/yr Darcy velocity predicted; predominantly vertical flow; the effective travel times through the vadose zone is predicted to be 10–40 yr.	Unsaturated porous and possible fracture flow through variably welded ash-flow tuffs and stratified pumiceous sedimentary deposits; good interaction with matrix having moderate iron content (2–3%). Uncertain if attenuation is predominantly adsorption or reduction.	Not considered to currently be an active area for reducing additional Cr(VI) because source stopped in 1972. Pore water concentrations are low indicating that Cr(VI)-bearing water has probably passed through main infiltration zone. Evidence for attenuation of chromium on core samples.
Puye Formation above Cerros del Rio basalt	Unsaturated zone with some evidence of perching	Moderate to high	Predominantly vertical flow with potential lateral flow along interface with basalt	Unsaturated porous flow through reddish brown siltstone, sandstone, and fine- to coarse-conglomeratic sandstone with potentially high iron content.	Evidence for reduction of chromium on core samples.
Cerros del Rio basalt	Unsaturated zone with perched zones	Low to high	Presumed fracture flow with some longer residence times in rubble zones. Lateral flow toward south in perched zones.	Massive and fractured basalt flows separated by porous rubble zones; high iron content (4–7%); reduction along fracture surfaces and in rubble zones; potential low residence time in fractured zones; reductive capacity along the active flow zones may be exhausted.	Some indication that basalt may have reached its reductive capacity along the main flowpaths in the infiltration zone. Evidence for reduction of chromium on core samples.

Table 7.2-1 (continued)

Rock	Setting	Reductive Capacity	Groundwater flow / Chromium migration velocity	Chromium migration mechanism	Notes
Puye Formation below Cerros del Rio basalt	Unsaturated zone extending into the regional aquifer	Uncertain	10–40 m/yr; Predominantly lateral flow in the regional aquifer.	Unsaturated and saturated porous flow through coarse conglomerate with variable amounts of silt and fine-grained sand in the matrix; silt and clay less abundant than in upper Puye zone.	Highest Cr(VI) concentrations occur in the regional aquifer in this formation (R-42 and R-28). Single core sample from unsaturated zone did not indicate above-background concentration of chromium.
Miocene sands and gravels (Miocene pumiceous sediments)	Thin segments in unsaturated zone extending predominantly into regional aquifer	Likely low	10–40 m/yr; Predominantly lateral flow in the regional aquifer.	Porous flow through poorly indurated silty sand, sand, and pumiceous conglomerate with relatively low iron content	Single core sample from unsaturated zone did not indicate above-background concentration of chromium.

Table 8.4-1
Maximum Phase II Sediment COPC Concentrations
Compared with Screening Levels

Additional Phase II COPCs	Maximum Detect	Residential SSL	SSL Source ^a	Soil ESL ^b
DDE[4,4'-]	0.000393	14.3	NMED	0.11
DDT[4,4'-]	0.00119	17.2	NMED	0.044
Diphenylamine	0.121	1500	EPA	10
Methylene Chloride	0.00413	409	NMED	2.6
Tetrachloroethene	0.000633	7.02	NMED	0.18

Note: Values are in mg/kg.

^a NMED Risk Assessment Guidance for Investigations and Remediation, Volume I, February 2012. (updated June 2012) (NMED 2012, 219971) or EPA regional screening level (May 2012).

^b ESLs are from the ECORISK Database, Version 3 (LANL 2011, 206473).

Appendix A

*Acronyms and Abbreviations,
Metric Conversion Table, and Data Qualifier Definitions*

A-1.0 ACRONYMS AND ABBREVIATIONS

2-D	two-dimensional
3-D	three-dimensional
‰	per mil
AE	assessment endpoint
amsl	above mean sea level
AOC	area of concern
AQA	Analytical Quality Associates
asl	above sea level
ASTM	American Society for Testing and Materials
BCG	Biota Concentration Guide (DOE)
BEHP	bis(2-ethylhexyl)phthalate
bgs	below ground surface
BMP	best management practice
BV	background value
CFR	Code of Federal Regulations
csf	cubic foot per second
CM	conceptual model
Consent Order	Compliance Order on Consent
COPC	chemical of potential concern
COPEC	chemical of potential ecological concern
CWA	Clean Water Act
DC	direct current
DDE	dichlorodiphenyldichloroethylene
DDT	dichlorophenyltrichloroethylene
DOE	Department of Energy (U.S.)
DRI	Desert Research Institute
DRO	diesel range organics
EES	Earth and Environmental Sciences
Eh	oxidation-reduction potential
EPA	Environmental Protection Agency (U.S.)
ESL	ecological screening level
FEHM	Finite Element Heat and Mass Transfer code

FR	Federal Register
GEL	General Engineering Laboratory
gpd	gallons per day
gpm	gallons per minute
HE	high explosives
HI	hazard index
HQ	hazard quotient
ID	identification
IAEA	International Atomic Energy Agency
IP	Individual Permit
IR	investigation report
LANL	Los Alamos National Laboratory
LCS	laboratory control sample
MADS	Model Analyses for Decision Support
MCIR	Mortandad Canyon investigation report
MCL	maximum contaminant levels (EPA)
MS	matrix spike
NEPA	National Environmental Policy Act
NIST	National Institute of Standards and Technology
NMAC	New Mexico Administrative Code
NMED	New Mexico Environment Department
NMWQCC	New Mexico Water Quality Control Commission
NPDES	National Pollutant Discharge Elimination System
OB	Oversight Bureau (NMED)
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PCE	perchloroethylene
QA	quality assurance
QC	quality control
RF	radio frequency
RLWTF	Radioactive Liquid Waste Treatment Facility
RME	reasonable maximum exposure
RPF	Records Processing Facility
SAL	screening action level

SCIR	Sandia Canyon investigation report
SERF	Sanitary Effluent Reclamation Facility
SL	screening level
SOP	standard operating procedure
SOW	statement of work
SSL	soil screening level
SVOC	semivolatile organic compound
SWMU	solid waste management unit
SWSC	Sanitary Wastewater Systems Consolidation (plant)
T&E	threatened and endangered
TA	technical area
TCE	trichloroethene
TCDD-2,3,7,8	Tetrachlorodibenzodioxin(2,3,7,8-)
TD	total depth
TDS	total dissolved solids
TEC	TCDD-equivalent concentration
TKN	total Kjeldahl nitrogen
TOC	total organic compound
TPH	total petroleum hydrocarbon
UIUC	University of Illinois–Urbana Champaign
USGS	U.S. Geological Survey
VOC	volatile organic compound
VSMOW	Vienna Standard Mean Ocean Water
WOE	weight of evidence
WQC	water-quality criteria
WWTP	waste water treatment plant

A-2.0 METRIC CONVERSION TABLE

Multiply SI (Metric) Unit	by	To Obtain U.S. Customary Unit
kilometers (km)	0.622	miles (mi)
kilometers (km)	3281	feet (ft)
meters (m)	3.281	feet (ft)
meters (m)	39.37	inches (in.)
centimeters (cm)	0.03281	feet (ft)
centimeters (cm)	0.394	inches (in.)
millimeters (mm)	0.0394	inches (in.)
micrometers or microns (μm)	0.0000394	inches (in.)
square kilometers (km^2)	0.3861	square miles (mi^2)
hectares (ha)	2.5	acres
square meters (m^2)	10.764	square feet (ft^2)
cubic meters (m^3)	35.31	cubic feet (ft^3)
kilograms (kg)	2.2046	pounds (lb)
grams (g)	0.0353	ounces (oz)
grams per cubic centimeter (g/cm^3)	62.422	pounds per cubic foot (lb/ft^3)
milligrams per kilogram (mg/kg)	1	parts per million (ppm)
micrograms per gram ($\mu\text{g/g}$)	1	parts per million (ppm)
liters (L)	0.26	gallons (gal.)
milligrams per liter (mg/L)	1	parts per million (ppm)
degrees Celsius ($^{\circ}\text{C}$)	$9/5 + 32$	degrees Fahrenheit ($^{\circ}\text{F}$)

A-3.0 DATA QUALIFIER DEFINITIONS

Data Qualifier	Definition
U	The analyte was analyzed for but not detected.
J	The analyte was positively identified, and the associated numerical value is estimated to be more uncertain than would normally be expected for that analysis.
J+	The analyte was positively identified, and the result is likely to be biased high.
J-	The analyte was positively identified, and the result is likely to be biased low.
UJ	The analyte was not positively identified in the sample, and the associated value is an estimate of the sample-specific detection or quantitation limit.
R	The data are rejected as a result of major problems with quality assurance/quality control (QA/QC) parameters.

Appendix B

Field Investigation Methods and Results

B-1.0 SEDIMENT INVESTIGATIONS

This appendix summarizes results from field investigations of potentially contaminated sediment deposits in reach 5-EC within Sandia Canyon that were conducted in 2011 and 2012 as part of implementation of the Phase II investigation work plan for Sandia Canyon (LANL 2011, 206234).

Geomorphic mapping at a scale of 1:200 occurred in this reach and focused on delineating geomorphic units with differences in physical characteristics and/or contaminant levels within a poorly characterized area between two reaches previously investigated in the 2009 Sandia Phase I investigation report (LANL 2009, 107453). The map of reach S-5EC is shown on Plate 2. Unit designations followed those used in previous reports on canyons in and near the Los Alamos National Laboratory (LANL or the Laboratory) (e.g., LANL 2004, 087390; LANL 2006, 094161; LANL 2009, 106506; LANL 2009, 106939; LANL 2009, 106790), with “c” designating post-1942 channel units and “f” designating post-1942 floodplain units. A summary of the physical characteristics of post-1942 geomorphic units in this Sandia Canyon investigation reach is presented in Table B-1.0-1.

Sediment thickness measurements distinguished between fine facies sediment, with typical median particle size of silt to very fine sand (0.0625 to 0.125 mm) in the less than 2-mm fraction, and coarse facies sediment, with typical median particle size of coarse sand (0.5 to 1mm) in the less than 2-mm fraction. One sample with median particle size of medium sand (0.25 to 0.5 mm) was classified as fine facies because of its stratigraphic context and the particle size of adjacent layers. Coarse facies sediment is characteristic of material transported along the streambeds as bed load, and fine facies sediment is characteristic of material transported in suspension (Malmon 2002, 076038, pp. 94–97; Malmon et al. 2004, 093018). Several methods were used to identify the bottom of post-1942 sediment deposits, including determining the depth of buried trees and associated buried soils and noting the presence or absence of materials imported to the watershed after 1942 (e.g., quartzite gravel, plastic). Sediment thickness measurements from reach S-5EC are presented in Table B-1.0-2.

Average facies thickness in each unit was combined with unit area, as determined from digitized geomorphic maps, to obtain an estimated volume. These volume estimates were combined with estimates of contaminant levels, where available, to allocate samples using a stratified sample allocation process (Gilbert 1987, 056179, pp. 45–57) designed to reduce uncertainties in the contaminant inventory in each reach. In this process, samples were preferentially allocated to units and sediment facies with a large portion of the total inventory (e.g., Rytí et al. 2005, 093019). One result of this sample allocation process is a high bias in sampling results because of a disproportionately large number of samples collected from the more contaminated geomorphic units and sediment facies. Weighted averages are used in this investigation in calculations of contaminant inventory to remove the bias introduced during sample collection. In contrast, in the human health risk assessment weighted averages are not used for simplicity in calculation, which results in systematic overestimates of average chemical of potential concern (COPC) concentrations.

Particle-size analyses of sediment samples were obtained at an off-site laboratory at the Desert Research Institute (DRI) following the procedures described in Janitzky (1986, 057674) to examine the effect of particle-size distribution on contaminant concentrations. Organic-matter content was determined for some of the samples at DRI using the loss-on-ignition method to provide additional information about the physical characteristics of potentially contaminated sediment deposits, and pH data were obtained from some samples because ecological screening levels (ESLs) are pH-dependant for some analytes. Particle size, organic matter, and pH from the Sandia Canyon investigation reach in this study are presented in Table B-1.0-3.

Dendrochronological analyses (tree-ring dating) were obtained in reach S-5EC to provide supplemental information on the age of sampled sediment deposits in this portion of Sandia Canyon. Sediments burying trees of known age are constrained to be younger than the trees, and sediments beneath the base of trees are constrained to be older. In some cases, nearby trees of different ages can provide more precise determination of the ages of sediment deposits. For example, two adjacent trees of different ages can be buried by different thicknesses of sediment, recording a variable number of floods since the germination of each tree and approximate ages for such floods, or different age trees can be buried by the same thickness of sediment, recording the absence of deposition during specific time periods. Cores were collected from two individual trees in reach S-5EC using a 5-mm-diameter increment borer. Each tree was assigned a unique four-letter two-number identifier following the general convention used by the Laboratory of Tree-Ring Research at the University of Arizona, with the designation "SAN" chosen to indicate trees cored in Sandia Canyon. These trees are located at or near sediment sampling sites, and data on the tree diameter and the thickness of sediment burying each tree were recorded. These analyses followed the methodology described in Stokes and Smiley (1996, 057644) and Phipps (1985, 058477), and the process is discussed further in Reneau et al. (Reneau et al. 1998, 065407, Appendix B, Section B-1.0). Dendrochronology data are presented in Table B-1.0-4.

Cross-section profiles were surveyed using a Geodimeter 620 theodolite total station.

B-2.0 WATER INVESTIGATIONS

The methods used during groundwater investigations in Sandia Canyon and adjacent canyons are described in the well completion reports for well R-50 (LANL 2010, 109980), R-61 (LANL 2011, 206492), and R-62 (LANL 2012, 215008). The well completion reports provide information about drilling methodologies, use of drilling fluids and additives, sample collection methods, well construction, borehole geophysical logs, well development, and waste management. The regional aquifer boreholes were drilled using fluid-assisted rotary air-drilling methods.

B-3.0 REFERENCES

The following list includes all documents cited in this appendix. Parenthetical information following each reference provides the author(s), publication date, and ER ID. This information is also included in text citations. ER IDs are assigned by the Environmental Programs Directorate's Records Processing Facility (RPF) and are used to locate the document at the RPF and, where applicable, in the master reference set.

Copies of the master reference set are maintained at the New Mexico Environment Department Hazardous Waste Bureau and the Directorate. The set was developed to ensure that the administrative authority has all material needed to review this document, and it is updated with every document submitted to the administrative authority. Documents previously submitted to the administrative authority are not included.

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Table B-1.0-1
Physical Characteristics of Post-1942
Geomorphic Units in the Sandia Canyon Investigation Reach S-5EC

Reach	Geomorphic Unit	Average Unit Width (m) ^a	Sediment Facies	Estimated Average Sediment Thickness (m)	Typical Median Particle-Size Class (<2-mm fraction)	Notes
S-5EC	c1	2.9	Fine	0.07	Very fine sand ^b	Active channel
			Coarse	0.5	Coarse sand	
	c2	16.3	Fine	0.27	Coarse silt	Low abandoned post-1942 channel
			Coarse	0.21	Coarse sand	
	c2f	4.4	Fine	0.12	Fine sand ^c	Post-1975 fan inset into and overlying c2
			Coarse	0.62	coarse sand	
	c3	0.8	Fine	0.17	Very fine sand ^c	High abandoned post-1942 channel
			Coarse	0.26	Coarse sand	
	f1	11.1	Fine	0.23	Coarse silt	Post-1942 floodplain
			Coarse	0.02	Medium sand ^c	
	f2	7.0	Fine	0.07	Fine sand	Possible post-1942 floodplain
			Coarse	0.0	n/a ^d	

^a Average unit width is total area of unit in reach divided by reach length.

^b No particle-size data from unit; median particle size inferred based on data from other units and field descriptions.

^c Single particle-size analysis from unit f2 was medium sand; typical median particle size of fine sand based on multiple field descriptions and data from other units.

^d n/a = Not applicable.

Table B-1.0-2
Sediment Thickness Measurements from Reach S-5EC

Stratigraphic Description Location	Location ID	Reach Distance (m)	Side of Channel	Geomorphic Unit	Fine Facies Thickness (cm)	Coarse Facies Thickness (cm)
S5EC-s1	—*	7	S	c3	15	30
S5EC-s2	—	9	S	f1	16	10
S5EC-s3	SA-614443	15	—	c1	15	95
S5EC-s4	—	16	N	f1	10	—
S5EC-s5	—	17	S	c2	64	18
S5EC-s6	—	24	S	c3	0	4
S5EC-s7	SA-614444	27	N	c2	72	10
S5EC-s8	SA-614445	38	S	c3	35	45
S5EC-s9	—	39	S	f1	15	—
S5EC-s10	—	40	—	c1	0	95
S5EC-s11	—	39	N	f1	71	10
S5EC-s12	—	49	S	c2	26	14
S5EC-s13	—	49	S	f2	10	0
S5EC-s14	—	63	—	c1	0	97
S5EC-s15	—	60	S	c2	17	11
S5EC-s16	—	61	S	f1	22	0
S5EC-s17	—	62	S	c2	30	7
S5EC-s18	SA-614446	68	N	f1	13	0
S5EC-s19	SA-614447	79	—	c1	0	120
S5EC-s20	—	85	S	f1	39	10
S5EC-s21	—	82	N	f1	17	0
S5EC-s22	—	82	N	f2	13	0
S5EC-s23	SA-614448	96	S	f1	82	0
S5EC-s24	—	104	—	c1	0	110
S5EC-s25	SA-614450	109	N	f2	9	0
S5EC-s26	—	111	S	c2	14	56
S5EC-s27	—	116	N	c2	12	21
S5EC-s28	—	133	—	c1	12	13
S5EC-s29	—	140	N	f1	24	0
S5EC-s30	—	138	Island	c2	22	13
S5EC-s31	—	144	N	f2	4	0
S5EC-s32	—	129 S	—	c1S	10	84
S5EC-s33	SA-614451	132 S	S	c2	19	51
S5EC-s34	—	135 S	S	f1	37	0
S5EC-s35	—	149 S	Island	c2	41	10
S5EC-s36	—	152 S	—	c1S	15	80

Table B-1.0-2 (continued)

Stratigraphic Description Location	Location ID	Reach Distance (m)	Side of Channel	Geomorphic Unit	Fine Facies Thickness (cm)	Coarse Facies Thickness (cm)
S5EC-s37	SA-614453	155 S	S	f1	27	6
S5EC-s38	SA-614455	156 S	Island	c2	42	0
S5EC-s39	—	160	N	c2	4	62
S5EC-s40	—	161	—	c1	0	20
S5EC-s41	—	164	N	f2	2	0
S5EC-s42	—	169	Island	c2	0	20
S5EC-s43	—	171 S	—	c2f	15	40
S5EC-s44	—	173	N	f1	8	0
S5EC-s45	—	173 S	S	f1	22	0
S5EC-s46	—	193 S	—	c1S	29	19
S5EC-s47	—	185 S	S	f1	8	0
S5EC-s48	—	191 S	Island	c2	43	19
S5EC-s49	—	196 S	Island	f1	18	0
S5EC-s50	—	207 S	S	f1	11	10
S5EC-s51	—	220 S	—	c1S	4	32
S5EC-s52	—	217 S	—	c2f	21	8
S5EC-s53	—	203 S	—	c2f	45	60
S5EC-s54	—	189	—	c1	8	36
S5EC-s55	—	190	Island	c2	20	25
S5EC-s56	—	195	N	f1	17	0
S5EC-s57	—	198	Island	c2	84	24
S5EC-s58	—	208	N	f1	12	0
S5EC-s59	SA-614457	217	—	c2f	0	96
S5EC-s60	—	219	N	c2	11	23
S5EC-s61	—	237	—	c1	4	17
S5EC-s62	—	244	Island	c2	13	31
S5EC-s63	SA-614459	245	N	f1	20	0
S5EC-s64	—	237 S	—	c1S	11	13
S5EC-s65	—	241 S	Island	c2	7	34
S5EC-s66	—	246 S	S	f1	5	0
S5EC-s67	—	250 S	—	c2f	0	92
S5EC-s68	—	262	—	c1	0	30
S5EC-s69	—	268	Island	c2	46	0
S5EC-s70	—	268	N	f1	27	0
S5EC-s71	SA-614460	272	—	c2f	0	103
S5EC-s72	—	263 S	—	c1S	0	43
S5EC-s73	—	266 S	Island	c2	15	17

Table B-1.0-2 (continued)

Stratigraphic Description Location	Location ID	Reach Distance (m)	Side of Channel	Geomorphic Unit	Fine Facies Thickness (cm)	Coarse Facies Thickness (cm)
S5EC-s74	—	270 S	S	f1	15	0
S5EC-s75	—	287	—	c1	24	10
S5EC-s76	—	289	N	f1	21	0
S5EC-s77	SA-614461	289	Island	c2	37	14
S5EC-s78	—	289 S	—	c2f	6	34
S5EC-s79	—	287 S	—	c1S	7	35
S5EC-s80	—	288 S	Island	c2	16	0
S5EC-s81	—	292	S	c2	7	13
S5EC-s82	—	297 S	S	f1	7	0
S5EC-s83	—	306 S	S	c2	3	2
S5EC-s84	—	309 S	S	f2	6	0
S5EC-s85	—	312 S	—	c1S	9	29
S5EC-s86	—	318 S	S	f2	4	0
S5EC-s87	—	313	—	c1	0	29
S5EC-s88	—	316	N	c2	34	12
S5EC-s89	—	315	N	f1	27	0
S5EC-s90	SA-614462	321	S	c2	22	81
S5EC-s91	—	310	S	c2	37	13

* — indicates not applicable (no Location ID or no relation to channel or swale)

Table B-1.0-3
PSDA Results for Sandia Canyon Reach S-5EC Sediment Samples

Reach	Sample ID	Unit	Facies	% wt. Gravel	Very Coarse Sand; 2.0-1.0 mm %wt.	Coarse Sand; 1.0- 0.5 mm %wt.	Medium Sand; 0.5- 0.25 mm %wt.	Fine Sand; 0.25- 0.125 mm %wt.	Very Fine Sand; 0.125-0.0625 mm %wt.	Coarse Silt %wt.	Fine Silt %wt.	Clay %wt.	median particle size class	% Silt + Clay	OM (% LOI)	pH
S-5EC	CASA-11-22339	c1	coarse	3.7	31.4	35.9	17.8	7.0	2.6	2.9	0.6	1.6	cs	5.0	0.22	6.98
S-5EC	CASA-11-22340	c2	fine	0.3	2.1	4.6	10.0	16.8	16.7	34.2	9.2	6.3	vfs	49.7	1.52	7.05
S-5EC	CASA-11-22341	c3	coarse	5.4	33.3	38.1	14.0	4.5	2.5	3.9	1.4	2.4	cs	7.7	0.25	7.37
S-5EC	CASA-11-22342	f1	fine	0.5	7.8	12.5	10.8	10.0	16.3	30.0	6.4	6.1	vfs	42.5	1.31	6.41
S-5EC	CASA-11-22343	c1	coarse	3.5	23.0	34.7	23.5	10.7	3.8	3.1	0.4	1.0	cs	4.4	0.16	6.79
S-5EC	CASA-11-22344	f1	fine	3.8	11.8	12.8	7.9	8.0	11.3	31.0	8.2	9.1	vfs	48.3	2.03	6.41
S-5EC	CASA-11-22345	f1	fine	0.3	1.4	3.6	7.6	11.8	15.5	42.0	9.8	8.4	csi	60.2	1.77	6.53
S-5EC	CASA-11-22346	f2	fine	1.0	10.7	25.1	26.8	14.5	5.9	9.7	3.3	4.0	ms	17.0	1.64	5.23
S-5EC	CASA-11-22347	c2	fine	0.3	3.3	5.5	3.4	6.3	19.9	48.7	7.5	5.4	csi	61.6	1.69	6.64
S-5EC	CASA-11-22348	c2	coarse	1.7	24.4	43.8	18.3	7.0	2.9	2.3	0.4	1.1	cs	3.7	0.25	6.48
S-5EC	CASA-11-22349	f1	fine	2.8	1.1	2.6	2.1	7.3	19.4	49.7	10.8	7.2	csi	67.7	2.07	6.62
S-5EC	CASA-11-22350	f1	fine	3.4	7.9	15.0	13.6	13.1	10.6	22.2	9.0	8.7	vfs	39.9	2.14	6.81
S-5EC	CASA-11-22351	c2	fine	0.2	1.4	3.0	2.9	6.1	10.1	44.0	22.1	10.6	csi	76.7	2.69	6.55
S-5EC	CASA-11-22352	c2	fine	0.1	0.8	1.7	4.2	21.6	22.6	35.6	7.6	5.7	vfs	49.0	1.90	6.41
S-5EC	CASA-11-22353	c2f	coarse	5.1	33.9	46.2	12.1	3.4	1.3	1.8	0.5	0.9	cs	3.2	0.20	6.41
S-5EC	CASA-11-22354	c2f	coarse	0.8	17.3	47.8	20.3	6.6	2.6	1.7	2.2	1.6	cs	5.5	0.27	6.32
S-5EC	CASA-11-22355	f1	fine	0.1	0.4	1.0	1.0	4.6	24.0	49.0	11.5	8.6	csi	69.1	2.22	6.57
S-5EC	CASA-11-22356	c2f	coarse	3.8	29.0	43.2	16.9	3.9	1.9	2.8	0.8	1.5	cs	5.2	0.24	6.38
S-5EC	CASA-11-22357	c2	fine	0.4	5.9	11.4	13.5	12.0	14.4	28.8	7.4	6.8	vfs	42.9	1.78	6.44
S-5EC	CASA-11-22358	c2	fine	0.9	2.9	6.2	6.7	15.9	15.0	38.8	8.4	6.2	csi	53.4	1.79	6.55

Table B-1.0-4
Dendrochronological Analyses from Sandia Canyon Investigation Reach S-5EC

Core ID	Reach	Channel Distance (m)	Geomorphic Unit	Depth of Burial (cm)	Stratigraphic Description Location	Location ID	Species	Date of Pith Ring
SAN-021A	S-5EC	156	c2	42	S5EC-s38	SA-614455	Douglas fir	1981 ^a
SAN-021B								1981 ^a
SAN-022A	S-5EC	109	f2	9	S3E-s25	SA-614450	Ponderosa pine	1940 ^b
SAN-022B								1940 ^b

^a Estimate 6 yr missing based on buried whorls; therefore, estimated date of pith ring = 1975.

^b Poor match with chronology; field count = 73 yr.

Appendix C

Analytical Data

C-1.0 ANALYTICAL RESULTS

All available sediment data and analytical data packages from both the Phase I and Phase II Sandia Canyon investigations are included as Attachment C-1 on DVD. The following sediment data are provided: analytical data (Sandia Biota.xlsx, Sandia Sediment.xlsx), field quality control (QC) data (Sandia Biota Field QC.xlsx, Sandia Sediment Field QC.xlsx), and rejected data (Sandia Sediment Rejected). A data validation summary (Sandia Sediment Validation Summary.xlsx) and the samples taken tables (STT) for the Phase II sediment reach, S-5EC, (STT Sed.xlsx) are also provided.

All available water data and analytical data packages from both the Phase I and Phase II Sandia Canyon investigations are included as Attachment C-2 on DVD. The following water data are provided: analytical data (Sandia Water.xlsx), field QC data (Sandia Water Field QC.xlsx), and rejected data (Sandia Water Rejected.xlsx). A data validation summary (Sandia Water Validation Summary.xlsx) and the STT for the Phase II water data (STT Water.xlsx) are also provided.

C-1.1 Analytical Data

The following files containing sediment data are included as Attachment C-1 on DVD:

- Biota data—Sandia Biota.xlsx
- Sediment Data—Sandia Sediment.xlsx
- Biota field QC data—Sandia Biota Field QC.xlsx
- Sediment Field QC—Sandia Sediment Field QC.xlsx
- Rejected data (Sandia Sediment Rejected)
- Data Validation Summary (Sandia Sediment Validation Summary.xlsx)
- STT for the Phase II Sediment Reach S-5EC (STT Sed.xlsx)

The following files containing water data are included as Attachment C-2 on DVD:

- Water data (Sandia Water.xlsx)
- Water field QC data Sandia Water Field QC.xlsx
- Rejected data (Sandia Water Rejected.xlsx)
- Data Validation Summary (Sandia Sediment Validation Summary.xlsx)
- STT for the Phase II Water Data (STT Water.xlsx)

C-1.2 Data Obtained from Other Sources

Select analytical data collected by the New Mexico Environment Department (NMED) from groundwater monitoring wells are used in the development of the conceptual model. The data are not included in separate tables in this report but will be available at the intellusnm.com website.

C-2.0 SAMPLE COLLECTION METHODS

Historical groundwater samples have been collected using a variety of sampling methods: automated pump sampler, bailer, bladder pump, direct container grab sampling, discharge pipe/faucet, gear-driven submersible pump, peristaltic pump, transfer device for grab samples, weighted bottle, or Westbay sampler. Historical storm water samples have been collected using an automated pump sampler, direct container grab sampling, or single-stage samplers.

Current Los Alamos National Laboratory (LANL or Laboratory) standard operating procedures (SOPs) for water sampling methods are as follows:

- SOP-5213, Revision 0, Collecting Storm Water Runoff Samples and Inspecting Samplers
- SOP-5224, Revision 0, Spring and Surface Water Sampling
- SOP-5226, Revision 0, Groundwater Sampling Using Pressure Probes Using Westbay System
- SOP-5232, Revision 0, Groundwater Sampling.

Historical sediment samples have been collected using a spade and scoop. The current Laboratory SOP for this sediment sampling method is

- SOP-06.09, Spade and Scoop Method for Collection of Soil Samples.

C-3.0 ANALYTICAL PROGRAM

After the Laboratory receives the analytical laboratory data packages, the packages receive secondary validation. For data collected before March 2012, validation was done by an independent contractor, Analytical Quality Associates, Inc. (AQA). After that date, validation is done by an automated process after data are loaded.

Data validation determines the quality of an analytical data set. Data validation focuses on specific quality assurance (QA) samples, such as matrix spikes (MS), duplicates, surrogates, method blanks, laboratory control samples (LCSs), and holding times, which indicate the accuracy and precision of the analyses. Based on the results, data qualifiers are applied to indicate data-quality issues as well as the usability of results. This process also includes a description of the reasons for any failure to meet method, procedural, or contractual requirements and an evaluation of the impact of such failure on the overall data set.

AQA's reviews follow the guidelines set in the U.S. Department of Energy model SOP for data validation, which includes reviewing the data-quality and the documentation's correctness and completeness, verifying holding times were met and ensuring analytical laboratory QC measures were applied, documented, and kept within contract requirements. As a result of secondary validation, a second set of qualifiers was assigned to the analytical results.

Auto validation (1) ensures that the electronic data deliverable contains all the required fields, (2) verifies that results of all QC checks and procedures are within valid criteria limits, and (3) applies specific qualifiers and reason codes per the U.S. Environmental Protection Agency's National Functional Guidelines for data review (EPA 1994, 048639; EPA 1999, 066649) as well as the Laboratory's SOPs. Once auto validation is complete, the data are uploaded into the Laboratory's database system and the public database (<http://intellusnm.com/>).

The Laboratory assigns detection status to the analytical result based on the analytical laboratory and secondary validation qualifiers. A detect flag of "N" indicates that, based on the qualifiers, the result was not detected.

C-4.0 ANALYSIS METHODS

The analytical methods used for all target analytes are provided in the data tables of Attachment C-1 and C-2.

QA, QC, and data validation procedures were implemented in accordance with the Quality Assurance Project Plan Requirements for Sampling and Analysis (LANL 1996, 054609) and the Laboratory's statements of work (SOWs) for analytical laboratories (LANL 1995, 049738; LANL 2008, 109962). The results of the QA/QC procedures were used to estimate the accuracy, bias, and precision of the analytical measurements. Samples for QC include method blanks, MSs, LCSs, IS, initial calibration verifications and continuing calibration verifications, surrogates, and tracers.

The type and frequency of laboratory QC analyses are described in the SOWs for analytical laboratories (LANL 1995, 049738; LANL 2008, 109962). Other QC factors, such as sample preservation and holding times, were also assessed in accordance with the requirements outlined in SOP-5056, Sample Containers and Preservation.

C-5.0 DATA QUALITY

A sediment data validation summary (Sandia Sediment Validation Summary.xlsx) is provided in Attachment C-1 on DVD.

A water data validation summary (Sandia Water Validation Summary.xlsx) is provided in Attachment C-2 on DVD.

C-6.0 REFERENCES

The following list includes all documents cited in this appendix. Parenthetical information following each reference provides the author(s), publication date, and ER ID. This information is also included in text citations. ER IDs are assigned by the Environmental Programs Directorate's Records Processing Facility (RPF) and are used to locate the document at the RPF and, where applicable, in the master reference set.

Copies of the master reference set are maintained at the NMED Hazardous Waste Bureau and the Directorate. The set was developed to ensure that the administrative authority has all material needed to review this document, and it is updated with every document submitted to the administrative authority. Documents previously submitted to the administrative authority are not included.

EPA (U.S. Environmental Protection Agency), February 1994. "USEPA Contract Laboratory Program National Functional Guidelines for Inorganic Data Review," EPA-540/R-94/013, Office of Emergency and Remedial Response, Washington, D.C. (EPA 1994, 048639)

EPA (U.S. Environmental Protection Agency), October 1999. "USEPA Contract Laboratory Program National Functional Guidelines for Organic Data Review," EPA540/R-99/008, Office of Emergency and Remedial Response, Washington, D.C. (EPA 1999, 066649)

LANL (Los Alamos National Laboratory), July 1995. "Statement of Work (Formerly Called "Requirements Document") - Analytical Support, (RFP number 9-XS1-Q4257), (Revision 2 - July, 1995)," Los Alamos National Laboratory, Los Alamos, New Mexico. (LANL 1995, 049738)

LANL (Los Alamos National Laboratory), March 1996. "Quality Assurance Project Plan Requirements for Sampling and Analysis," Los Alamos National Laboratory document LA-UR-96-441, Los Alamos, New Mexico. (LANL 1996, 054609)

LANL (Los Alamos National Laboratory), June 30, 2008. "Exhibit 'D' Scope of Work and Technical Specifications, Analytical Laboratory Services for General Inorganic, Organic, Radiochemical, Asbestos, Low-Level Tritium, Particle Analysis, Bioassay, Dissolved Organic Carbon Fractionation, and PCB Congeners," Los Alamos National Laboratory document RFP No. 63639-RFP-08, Los Alamos, New Mexico. (LANL 2008, 109962)

Attachment C-1

*Sediment Analytical Data, Data Packages,
and Data Validation Summary
(on DVD included with this document)*

Attachment C-2

*Water Analytical Data, Data Packages,
and Data Validation Summary
(on DVD included with this document)*

Appendix D

Contaminant Trends and Inventory

D-1.0 INTRODUCTION

This appendix presents new data and plots that help further define the nature and extent of contaminants in the Chromium Investigation monitoring group area, including both Sandia Canyon itself and groundwater locations within Mortandad Canyon. These data and plots help refine the hydrogeologic conceptual models for alluvial sediments (section D-2) and perched-intermediate and regional groundwater (section D-3). The appendix focuses on newer data and on those key constituents that help elucidate the conceptual models described in section 7 of the investigation report. More comprehensive information on contaminant trends and inventories are provided in Appendix D of the Sandia Canyon investigation report (hereafter, the Phase I SCIR) (LANL 2009, 107453).

D-2.0 SEDIMENT

This section presents information on contaminants in sediments in Sandia Canyon that supports the physical system conceptual model delineated in section 7 of the investigation report. It includes updated information on spatial and temporal variations in the concentrations of chemicals of potential concern (COPCs) that helps refine the evaluation of contaminant sources and provides additional data to understand the effects of sediment redistribution by floods on contaminant concentrations and potential exposure to receptors. Calculations of the inventory (amount) of key sediment COPCs are refined based on results of the Reach S-5EC investigation. These new results are consistent with the conclusions of the Phase I SCIR (LANL 2009, 107453) that support a conceptual understanding of the current distribution of contaminants.

D-2.1 Spatial Variations in Sample Results for Sediment COPCs

Several COPCs were identified in the Phase I SCIR (LANL 2009, 107453) that have clearly defined source areas, with concentrations decreasing downstream from these sources. For example, chromium, mercury, silver, and the polychlorinated biphenyls (PCBs) Aroclor-1254 and Aroclor-1260 primarily had releases into the south fork of Sandia Canyon and decreasing concentrations downstream in Sandia Canyon. Some COPCs have no clearly defined source areas or spatial trends, indicating the sample results primarily represent variations in background concentrations and/or variability in detection limits. Examples include cobalt and perchlorate.

For the supplemental Reach S-5EC investigation, concentrations of key constituents are compared with concentrations upstream (Reach S-5C) and downstream (Reach S-5E). Key constituents evaluated in Reach S-5EC include arsenic, chromium, lead, zinc, PCBs (Aroclor-1254 and Aroclor-1260), benzo(a)pyrene, and total petroleum hydrocarbon (TPH) diesel range organics (DRO). Figure D-2.1-1 presents the spatial trends for all 10 inorganic Phase II COPCs, and Figure D-2.1-2 shows the spatial trends for all 24 organic Phase II COPCs. Radionuclide COPCs were not analyzed in the Phase II sediment investigation.

D-2.2 Spatial Variations in Average Concentrations of Select Sediment COPCs

This section presents information on the average concentrations of sediment COPCs in Sandia Canyon Reach S-5EC that are important for assessing potential human health risk in section 8.2 or potential ecological risk in section 8.1 of the Phase I SCIR (LANL 2009, 107453). This supplemental information supports the identification of sources for the COPCs and refines the understanding of how concentrations change with distance from sources and how they vary with sediment facies. Averages were calculated

separately for fine facies sediment samples and coarse facies samples to highlight differences between concentrations in these facies. All samples in each reach that were assigned to discrete sediment facies were weighted equally in these calculations, excluding samples of specific sediment layers collected a second time. For inorganic and organic COPCs that include nondetected results in a reach, upper and lower bounds on average concentrations in this section are calculated by replacing the sample result for nondetects with either the detection limit (upper bound) or zero (lower bound). The midpoint or median of this range is also calculated by substituting one-half of the detection limit for nondetects. Tables D-2.2-1 through D-2.2-4 present the average concentrations for COPCs discussed in sections 7.1.1 through 7.1.3.

D-2.3 Contaminant Inventory

This section presents inventory estimates for key sediment COPCs in Sandia Canyon that were updated based on contaminant concentrations from the Reach S-5EC investigation. The estimates for chromium and PCBs have been updated from estimates presented in the Phase I SCIR (LANL 2009, 107453). The term “inventory” refers to the total amount of a COPC in a geomorphic unit, in a reach, or in a canyon. Inventory estimates provide basic information for understanding how contaminants have been redistributed in the environment and hence for understanding the processes of contaminant transport. Inventory estimates are also useful when considering corrective action alternatives and as input into fate and transport models that predict future contaminant redistribution (e.g., Malmon 2002, 076038; Malmon et al. 2002, 082604; Malmon et al. 2003, 082603; Malmon et al. 2005, 093540).

Inventory estimates in this report are focused on chromium and PCBs because they have both well-documented sources and are potentially important in considering possible remedial options. In general, other COPCs released into the upper part of the Sandia Canyon watershed and associated with sediment particles are expected to share the same trends in inventory as chromium and PCBs.

Inventory estimates presented here are based on the same process used in previous reports (Reneau et al. 1998, 059159; Reneau et al. 1998, 065407; Reneau et al. 1998, 059667; LANL 1999, 063915; LANL 2004, 087390; LANL 2006, 094161) as modified as discussed in the Phase I SCIR (LANL 2009, 107453). In these calculations, estimates of the average COPC concentration in each sediment facies and each geomorphic unit in most reaches are combined with estimates of sediment volume, sediment density, and gravel content. Sediment volume is calculated as unit area, as determined from digitized geomorphic maps, multiplied by average sediment thickness as determined from field measurements (as discussed in section B-1.0 of Appendix B of this report). Sediment density utilizes measurements made previously in Los Alamos and Pueblo Canyons (Reneau et al. 1998, 059159, Appendix B-4.0). Gravel content, as determined from particle-size analyses (section B-1.0), is used to adjust the effective volume of each unit because of the predominant association of contaminants with fine-grained particles (clay, silt, and sand). Samples from the same sediment facies but different geomorphic units are grouped together for calculating averages where no apparent difference exists between units.

For chromium, the average concentration from the background sediment data set (5.6 mg/kg) (McDonald et al. 2003, 076084, Table 10, p. 47) is subtracted from the average concentration in each unit. Background levels of chromium are subtracted because some of the unit averages are close to the background average, and background, therefore, dominates the inventory in some downcanyon reaches. The inventory is considered to be zero for units and facies where the average concentration is less than the background average.

For PCBs, a value of one-half the detection limit is used for nondetected sample results. The resulting uncertainty in average PCB concentrations in units and facies with nondetects is relatively small where the frequency of nondetects is relatively small and PCB concentrations are relatively high (e.g.,

Reach S-2 from the Phase I SCIR (LANL 2009, 107453), and the uncertainty increases in downcanyon reaches (including Reach S-5EC) where the detection frequency and concentrations are relatively low. However, these uncertainties do not affect the identification of the general spatial distributions in PCB inventory (i.e., highest in Reach S-2 and lower in upcanyon and downcanyon reaches).

Table D-2.3-1 presents detailed estimates of the inventory of chromium and the PCBs Aroclor-1254 and Aroclor-1260 in Reach S-5EC. Estimates of the inventory of chromium and PCBs in all other Sandia Canyon reaches, along with the underlying data used in these calculations are presented in the Phase I SCIR (LANL 2009, 107453). Table D-2.3-2 uses the estimates provided in Table D-2.3-1 to estimate inventories of these COPCs along the length of Sandia Canyon. The inventory in reaches not sampled uses the average of normalized inventories in bounding reaches (in units of kg/km), except for the area between Reaches S-2 and S-3W, where the inventory in Reach S-3W is extrapolated through the area not sampled. In Table D-2.3-2, the relative coarse versus fine facies inventory in Reach S-2 assumes the same percentages of the total reach inventory as estimated downcanyon in Reach S-3W (35% in coarse facies sediment and 65% in fine facies sediment for chromium). These estimates are applicable to the period when geomorphic mapping, characterization, and sediment sampling was conducted in each reach (2007 to 2008 for Phase I reaches, and the 2011 characterization of Reach S-5EC), and the distribution of the inventory will change over time because of subsequent flooding.

As discussed in section 7.1.4, the total inventory of anthropogenic chromium in post-1942 sediment deposits in Sandia Canyon is estimated at approximately 18,000 kg (25% to 58% of the released chromium). The Reach S-5EC investigation resulted in lowering chromium inventory in the watershed by approximately 1% (total estimated inventory was reduced from 17,974 kg to 17,814 kg) because total chromium was overestimated when projecting normalized chromium concentrations between Reaches S-5C and S-5E (LANL 2009, 107453). An estimated 85% of the total is contained within Reach S-2, where concentrations are highest and where a large volume of post-1942 sediment exists. Over 99.9% of the chromium in Reach S-2 is stabilized as insoluble chromium(III). Approximately 5% of the chromium in sediment is contained along the next 4 km of channel, between Reach S-2 and the east end of Reach S-4W, where stormwater runoff is confined to a relatively narrow band along the channel. Approximately 10% occurs in the next 5 km, on Los Alamos National Laboratory (the Laboratory) land east of NM 4, and less than 0.5% farther downcanyon.

D-3.0 GROUNDWATER DATA FOR THE CHROMIUM INVESTIGATION MONITORING GROUP AND GEOCHEMICAL CONCEPTUAL MODEL

This section presents information related to trends in distributions of contaminants and other key constituents in perched-intermediate groundwater and regional groundwater within the Chromium Investigation monitoring group, including wells located in Mortandad and Sandia Canyons. Additional information on surface water, springs, alluvial groundwater, perched-intermediate groundwater, and regional groundwater is provided in Appendix D of the Phase I SCIR (LANL 2009, 107453). Together, these data support the physical system conceptual model presented in section 7.2 and the risk and standard evaluations in section 8. It includes information on spatial and temporal variations in the concentrations of key constituents that help identify contaminant sources and pathways.

Plots provided in this section relevant to updating the geochemical conceptual model include:

- Trilinear (Piper) diagrams showing major cation and anion concentrations in wells within the Chromium Investigation monitoring group and in nearby background wells (Figures D-3.0-1a and D-3.0-1b). (See also section D-2.3.2 and Figures D-2.3-4, D-2.3-5, and D-2.3-6 of the Phase I SCIR [LANL 2009, 107453].)

- Stiff diagrams showing major cations (on the left y axis) and anions (on the right y axis) for wells within the Chromium Investigation monitoring group plotted on a regional (Figure 3.0-2) base map of the Sandia and Mortandad Canyon areas. Additional Stiff diagrams relevant to the Chromium Investigation monitoring group are provided in Figures 7.2-1 and 7.2-2 in the main text of this document. These Stiff diagrams are color-coded by geologic unit because interactions with local geologic formations can modify the major element, particularly the cation, compositions of associated groundwater. (See also Figures 7.2-1, 7.2-2, and 7.2-3 of the Phase I SCIR [LANL 2009, 107453].)
- Time-series plots for the key constituents chloride, chromium, perchlorate, molybdenum, nitrate, sulfate, and tritium for intermediate-perched and regional groundwater in wells within the Chromium Investigation monitoring group (Figure D-3.0-3). (See also Figure D-2.1-2 of the Phase I SCIR [LANL 2009, 107453].)
- Element-element log plots for chromium and chloride versus a series of conservative constituents including bromide, chloride, chromium, 1,4-dioxane, fluoride, molybdenum, nitrate, total phosphorus, sulfate, and tritium (unfiltered). These plots are subdivided into wells containing contamination (Figures D-3.0-4 and D-3.0-5) and those with little or no contamination (Figures D-3.0-6 and D-3.0-7, primarily to improve readability). Detected data are shown as filled symbols, and data with at least one of the two analytes as nondetected are shown with unfilled symbols.
- Histograms showing concentrations of constituents (chlorate, rhenium, ^{36}Cl ratio) based on New Mexico Environment (NMED) data, which enhance understanding of the conceptual model (Figure D-3.0-8).

For most of the inorganic constituent plots described above, filtered data are plotted because such data are typically more useful for constraining conceptual models than are unfiltered data. The major element plots are most useful for identifying distinct geochemical groups of wells; the conservative constituent element-element plots are more useful for identifying transport pathways and delineating potential source mixing because conservative constituents are minimally affected by interactions with host formations. Both contaminant sources and background well characteristics are frequently more clearly identified using conservative element ratios than absolute element concentrations. Two-component mixing lines on the element-element log plots are slightly curved lines between the mixing end members. Time-series plots are provided to help evaluate sources and the dynamics of plume mixing.

The section is organized by conceptual model elements. A brief summary of aspects of the conceptual model for surface and alluvial groundwater provides context for more detailed discussions of perched intermediate groundwater and regional groundwater. The focus is on the behavior of key constituents, which inform the hydrologic conceptual model. Detailed discussions of additional COPCs are provided in the Phase I SCIR (LANL 2009, 107453).

D-3.1 Surface/Alluvial Groundwater

Little new data modifying the geochemical conceptual model for surface and alluvial groundwater have been collected since the Phase I SCIR (LANL 2009, 107453). Five alluvial groundwater wells (SCA-1, SCA-1-DP, SCA-2, SCA-4 and SCA-5) in Sandia Canyon (Figure D-2.3-2 of the Phase I SCIR), were extensively sampled between 2006 and the present. Sandia Canyon surface water stations SCS-1 through SCS-3 were sampled from the 1970s to the present, providing insights into the evolution of the Sandia Canyon alluvial groundwater source. Surface and alluvial groundwater represent the initial compositions of water entering the infiltration window near wells SCA-2 and SCA-4. Mortandad Canyon

surface and alluvial groundwater was also sampled for many years as described in the Mortandad Canyon Investigation Report (MCIR) (LANL 2006, 094161). Key aspects of the geochemistry of surface and alluvial water in Mortandad and Sandia Canyons relevant to interpreting deeper groundwater conceptual models include the following.

- Constituents such as chloride (up to ~130 mg/L), chromium (up to ~100 µg/L), sulfate (up to ~150 mg/L), molybdenum (up to ~300 µg/L), and tritium (up to several 1000 pCi/L) were elevated in Sandia Canyon alluvial groundwaters.
- Thirty years of surface water monitoring at stations SCS-1 through SCS-3 show significant heterogeneities in major element composition and contaminant concentrations, particularly in chromium, molybdenum, and sulfate concentrations and in tritium activities (Figure D-2.3-7 of Phase I SCIR, LANL 2009, 107453).
- Recent alluvial groundwaters in Sandia Canyon contain significant chlorate (Figure D-2.3-9 of the Phase I SCIR [LANL 2009, 107453]), which is likely a by-product of the mixed-oxidants process that was introduced at the Sanitary Wastewater Systems Consolidation treatment plant in 2000 (LANL 2009, 107453).
- Sulfate and chromium concentrations and tritium activities in surface water were at a maximum during the period from 1980 to 1985 (Figure D-2.3-7 of Phase I SCIR, LANL 2009, 107453).
- Molybdenum concentrations in surface water were at a maximum during the period 1990–1995 (Figure D-2.3-7 of Phase I SCIR [LANL 2009, 107453]).
- Nitrate concentrations in alluvial groundwater in Mortandad Canyon were extremely high (approaching 500 mg/L), with concentrations remaining above 100 mg/L through 1995 (section 7.2.2.1 and Figure 7.2-17 of the MCIR [LANL 2006, 094161]).
- Perchlorate concentration in the Technical Area (TA-50) outfall (NPDES Outfall 051) and in the Mortandad Canyon alluvial system were also elevated (section 7.2.2 and Figure 7.2-25 of the MCIR [LANL 2006, 094161]), although perchlorate concentrations were not measured in TA-50 outfall discharge for most of the presumed discharge history, which began in approximately 1963.
- Molybdenum was elevated in the Mortandad Canyon alluvial system (Table 6.3-1 of the MCIR [LANL 2006, 094161]).
- Chromium concentrations were elevated in both filtered and unfiltered alluvial groundwater samples within the upgradient reaches of the Mortandad Canyon alluvial system (section 7.2.2.1 and Figures D-2.1-7 through D-2.1-9 of the MCIR [LANL 2006, 094161]). The predominance of chromium in unfiltered samples indicates much of this is chromium(III).

These conservative geochemical signatures in surface and alluvial groundwaters represent key indicators of sources and pathways, which can be traced through the deeper hydrologic systems in the Chromium Investigation monitoring group. In some cases, the temporally constrained discharge histories manifest in surface and alluvial groundwaters (e.g., molybdenum in Sandia Canyon) allow estimates of the time frame of contaminant transport through deep groundwater conceptual model components.

D-3.2 Perched-Intermediate Groundwater

Perched-intermediate groundwater in wells SCI-1 and SCI-2 is characterized by high ionic strength waters (Figures 7.2-2, 7.2-3, and D-3.0-2), consistent with rapid transport from the Sandia Canyon alluvial system. These well waters are typically calcium-rich and contain high concentrations of chloride and sulfate relative to bicarbonate (Figures 7.2-2, 7.2-3, and D-3.0-2), consistent with similar high major

element abundances in historic alluvial waters. Chloride/sulfate ratios are reasonably constant (Figure D-3.0-5). Major ions in Mortandad Canyon perched-intermediate waters are also elevated, particularly in well MCOI-6 (Figure 7.2-2) and have similar chloride/sulfate ratios to the SCI wells (Figure D-3.0-5).

Deep-perched intermediate well SCI-1 is the shallowest perched-intermediate well within Sandia Canyon. It is geochemically distinct from groundwater in the other perched intermediate wells within either Sandia Canyon (well SCI-2) or Mortandad Canyon (wells MCOI-4, MCOI-5, MCOI-6) being characterized by (1) higher boron, bromide, chloride, lithium, molybdenum, and phosphate (Figures D-3.0-4 and D-3.0-5; NMED data in Appendix C) than the other intermediate-perched groundwater wells and any of the regional groundwater wells in the Chromium Investigation monitoring group; (2) lower chromium, nitrate, and tritium than the more highly chromium-contaminated wells (SCI-2, R-28, and R-42); and (3) higher chlorate than all of the regional groundwater wells and the other intermediate-perched groundwater wells except MCOI-6 (Figure D-3.0-8). These characteristics, particularly the high molybdenum and chlorate, are consistent with derivation from later-vintage (post-1990) discharge waters within Sandia Canyon than the deeper contaminated wells. The high chloride and bromide may be from increased road salt components in more recent years.

Deep perched-intermediate well SCI-2 strongly exhibits the key geochemical and contaminant characteristics of regional groundwater at wells R-28 and R-42, which have high ($> 500 \mu\text{g/L}$) chromium concentrations (Figures D-3.0-3 and D-3.0-4); high calcium and sulfate concentrations (Figures 7.2-1, 7.2-2, D-3.0-2, D-3.0-3, D-3.0-4, D-3.0-5); low molybdenum concentrations (Figures D-3.0-4 and D-3.0-5); and moderately elevated chloride, chlorate, bromide, nitrate, and rhenium concentrations and tritium activities and a low bromide/chloride ratio (Figures D-3.0-3, D-3.0-4, D-3.0-5, D-3.0-8). Together, these observations are consistent with derivation from moderately old (pre-1990s) surface and alluvial groundwaters in the Sandia Canyon system.

The Mortandad Canyon perched-intermediate groundwater wells (MCOI-4, MCOI-5, and MCOI-6) are geochemically distinct from the Sandia Canyon perched-intermediate wells. They have much higher tritium activities than the other perched-intermediate wells (Figures D-3.0-4 and D-3.0-5) and are consistently contaminated with 1,4-dioxane (Figures D-3.0-4 and D-3.0-5), which is a stabilizer for chlorinated solvents, including trichloroethene (TCE), which is used in the processing of plutonium at TA-55 (LANL 2009, 107453). Wells MCOI-4 and MCOI-6 are higher in nitrate and perchlorate, which are known contaminants released into Mortandad Canyon from the TA-50 outfall, than in other wells in the Chromium Investigation monitoring group (Figures D-3.0-4 and D-3.0-5). They also tend to have higher rhenium, 36-chlorine, and perchlorate/chloride and nitrate/chloride ratios (Figures D-3.0-5 and D-3.0-8). Wells MCOI-4 and MCOI-6 appear to be similar to each other but distinct from well MCOI-5 in several conservative constituents and conservative-constituent ratios (Figures D-3.0-4 and D-3.0-5) such as low molybdenum, moderately elevated chloride and bromide, and highly elevated nitrate (Figure D-3.0-4). Well MCOI-6 geochemistry indicates mixing with groundwater migrating from Sandia Canyon because it (1) shows the highest chromium of the Mortandad Canyon perched-intermediate groundwater wells (Figures D-3.0-4, D-3.0-5); (2) shows increasing chromium with decreasing perchlorate, nitrate, and tritium and decreasing perchlorate/chloride and nitrate/chloride ratios (Figures D-3.0-3, D-3.0-4, and D-3.0-5) during the past several years; and (3) is the Mortandad Canyon perched-intermediate groundwater well that contains the most chlorate (Figures D-3.0-4, D-3.0-5, and D-3.0-8; Figure D-2.3-9 of Phase I SCIR [LANL 2009, 107453]). The decreasing concentration time-series for tritium, perchlorate, and nitrate in wells MCOI-4, MCOI-5, and MCOI-6 (Figure D-3.0-3) may reflect the significantly reduced concentrations of these contaminants in effluent water since about 2000 and the reduced flow volumes from National Pollutant Discharge Elimination System (NPDES) Outfall 051 during the past several years and may indicate the alluvial groundwater signal propagates rapidly (within a decade or less) to the

perched-intermediate zone(s) manifest in wells MCOI-4, MCOI-5, and MCOI-6. Overall, the geochemical characteristics of the Mortandad Canyon intermediate groundwater wells thus suggest derivation of most of their water (and contaminants) from infiltration in Mortandad Canyon, with subsidiary inmixing of Sandia Canyon–derived water, particularly in well MCOI-6.

D-3.3 Regional Groundwater

Chromium Plume Centroid. Regional wells R-28, R-42, R-50, and R-62 are located in the centroid of the chromium plume as defined by the 50 µg/L–contour interval (Figure 7.2-1), with the highest concentrations detected at wells R-42 and R-28.

Groundwater in regional wells R-28 and R-42 are geochemically distinct among regional groundwater wells within the Chromium Investigation monitoring group; as importantly, they share many geochemical characteristics with groundwater in perched-intermediate aquifer well SCI-2. These characteristics include high (>800 µg/L) chromium concentrations (Figures D-3.0-3, D-3.0-4, D-3.0-5); high ionic strengths with elevated sulfate and calcium (Figures 7.2-2, 7.2-3, and D-3.0-2); moderately elevated bromide, chloride, and nitrate concentrations and tritium activities (Figures D-3.0-4 and D-3.0-5); and low but detectable chlorate and rhenium concentrations (Figure D-3.0-8). Together, these geochemical indicators are consistent with the core of the centroid of the chromium plume reflecting primarily moderately old (1970s–1980s) discharge water from the Sandia Canyon outfall (NPDES Outfall 001).

Wells R-50 and R-62 also are at concentrations above the 50 µg/L New Mexico groundwater standard in their upper screens. They are distal from the core of the plume centroid located in wells R-28 and R-42. Temporal trends and element–element relations for conservative constituent concentrations are somewhat equivocal for identifying mixing trends (Figures D-3.0-3, D-3.0-4, and D-3.0-5) in these wells. Well R-50 waters appear to represent a mixing trend between lightly contaminated groundwater and an R-28/R-42 end-member when considering plots of chromium versus chloride, tritium, nitrate and sulfate; however, the chromium versus molybdenum trend is inconsistent with such a mixing model (Figures D-3.0-3, D-3.0-4, and D-3.0-5). Wells R-62 has too few data points to establish robust temporal mixing trends. Some low concentrations of chloride and sulfate in well R-62 are anomalous.

Key implications for the geochemical conceptual model of these observations include the following:

- (1) A high likelihood that the principal “drip point” for the chromium plume centroid is located near well R-42.
- (2) Constituents that were largely discharged in the early 1990s or later (most notably molybdenum and chlorate—although chlorate is beginning to be detected in SCI-2, R-28 and R-42) have not yet reached the regional aquifer at high levels, suggesting a travel time from the surface to the regional aquifer of at least 20 yr.

Perchlorate Plume Centroid. Wells R-15 and R-61 both have distinctly elevated perchlorate (>4 µg/L) at relatively low chromium abundances (Figures D-3.0-3, D-3.0-4, and D-3.0-5), high perchlorate/chloride ratios, and moderately elevated tritium activities (Figures D-3.0-3, D-3.0-4, and D-3.0-5). Nitrate is variable with moderately elevated levels in well R-15 and low or variable levels in well R-61. Together, these data support a geochemical conceptual model where much of the contamination at these wells is derived from a Mortandad Canyon source. The lack of 1,4-dioxane, also identified as geochemically diagnostic of a Mortandad Canyon source, is puzzling, although the relatively low concentrations of 1,4-dioxane (<50 µg/L) in the MCOI perched-intermediate groundwater wells may mean waters in wells R-15 and R-61 are below the detection limits (~10 µg/L) for 1,4-dioxane at these regional groundwater locations.

Chromium Plume Margins. Regional groundwater wells R-11, R-43, R-44, R-45, and R-61 all contain chromium at levels greater than regional background values (~6 µg/L to 10 µg/L) and are therefore within the chromium plume. In cases where these wells have multiple screens, only the uppermost screen typically contains elevated chromium (Figures D-3.0-4 and D-3.0-6). All these wells have relatively low ionic strengths and major element compositions similar to background regional groundwater wells (Figures 7.2-2, 7.2-3, and D-3.0-2). Well R-43 has distinctly different mixing curve slopes on plots of chromium versus chloride and sulfate compared with wells such as R-50 (above) and contains essentially no tritium (Figures D-3.0-3, D-3.0-4, and D-3.0-5), indicating a different mode of mixing and perhaps a different “drip point” than the chromium plume centroid wells. Wells R-11, R-44 and R-45 have low concentrations of most key constituents; the chromium versus sulfate and chromium versus nitrate plots for the latter may indicate mixing with a plume centroid source. Wells R-61 has too few data points to establish robust temporal mixing trends.

Key implications for the geochemical conceptual model of these data include the following:

- Two geochemically distinct regional groundwater plumes are present within the Chromium Investigation monitoring group, one clearly derived from a Sandia Canyon source (with elevated chromium concentrations as a key indicator) and one derived from a Mortandad Canyon source (with elevated perchlorate concentrations as a key indicator).
- The zone of contamination is confined to the upper portions of the regional aquifer.
- Wells R-50 and R-43 have distinct mixing modes, with the former exhibiting more geochemical similarities to the plume centroid wells than the latter.
- Well R-61 shows both elevated chromium and elevated perchlorate, indicating mixing between the two plumes, although the data set for this well is too limited to draw robust conclusions.

D-4.0 REFERENCES

The following list includes all documents cited in this appendix. Parenthetical information following each reference provides the author(s), publication date, and ER ID. This information is also included in text citations. ER IDs are assigned by the Environmental Programs Directorate's Records Processing Facility (RPF) and are used to locate the document at the RPF and, where applicable, in the master reference set.

Copies of the master reference set are maintained at the New Mexico Environment Department Hazardous Waste Bureau and the Directorate. The set was developed to ensure that the administrative authority has all material needed to review this document, and it is updated with every document submitted to the administrative authority. Documents previously submitted to the administrative authority are not included.

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D-11

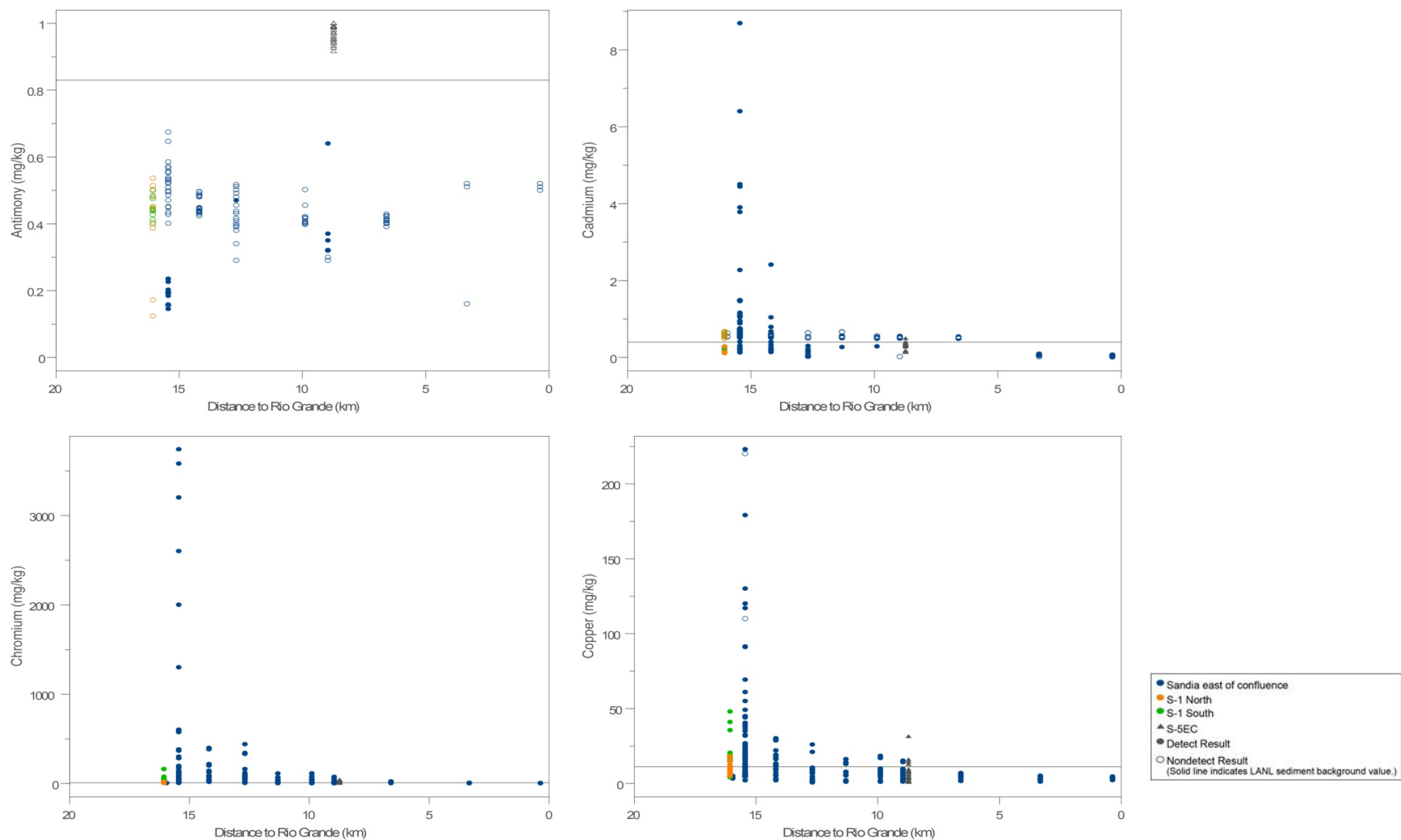


Figure D-2.1-1 Plots of sample results versus distance from the Rio Grande for all inorganic Phase II COPCs identified in sediment in the Sandia watershed

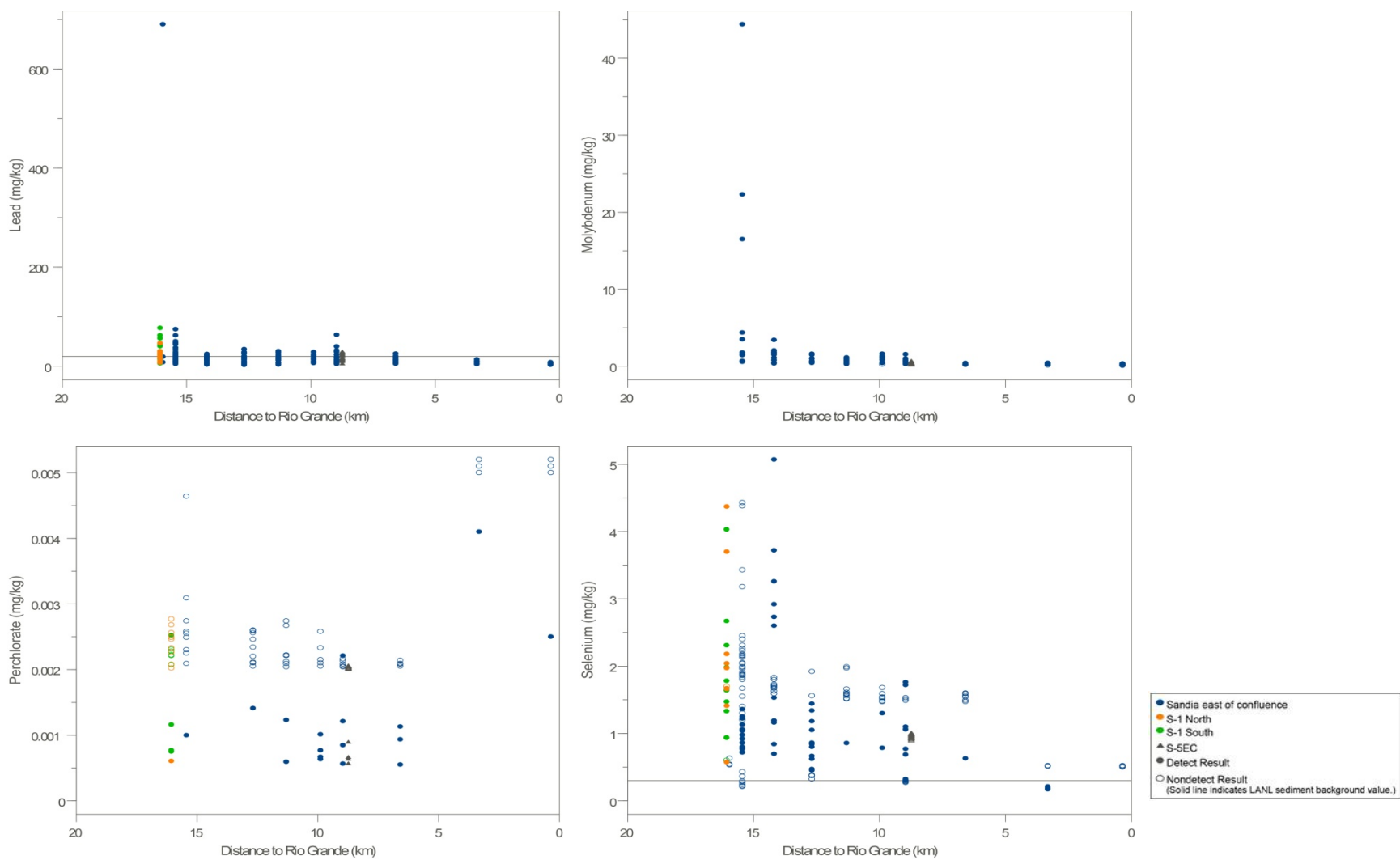


Figure D-2.1-1 (continued) Plots of sample results versus distance from the Rio Grande for all inorganic Phase II COPCs identified in sediment in the Sandia watershed

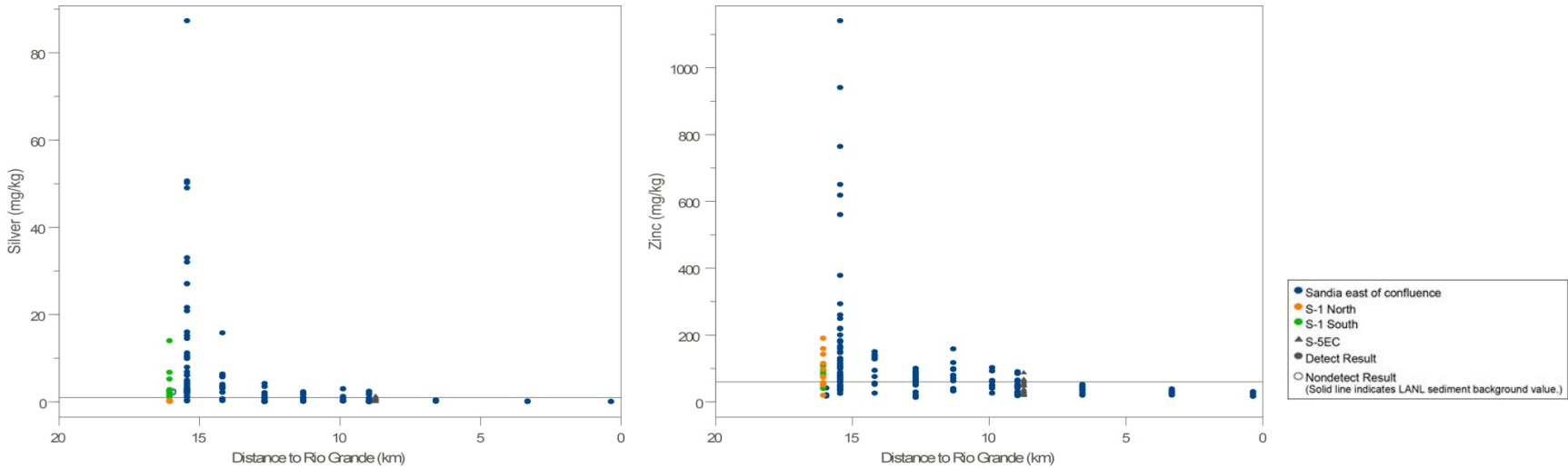


Figure D-2.1-1 (continued) Plots of sample results versus distance from the Rio Grande for all inorganic Phase II COPCs identified in sediment in the Sandia watershed

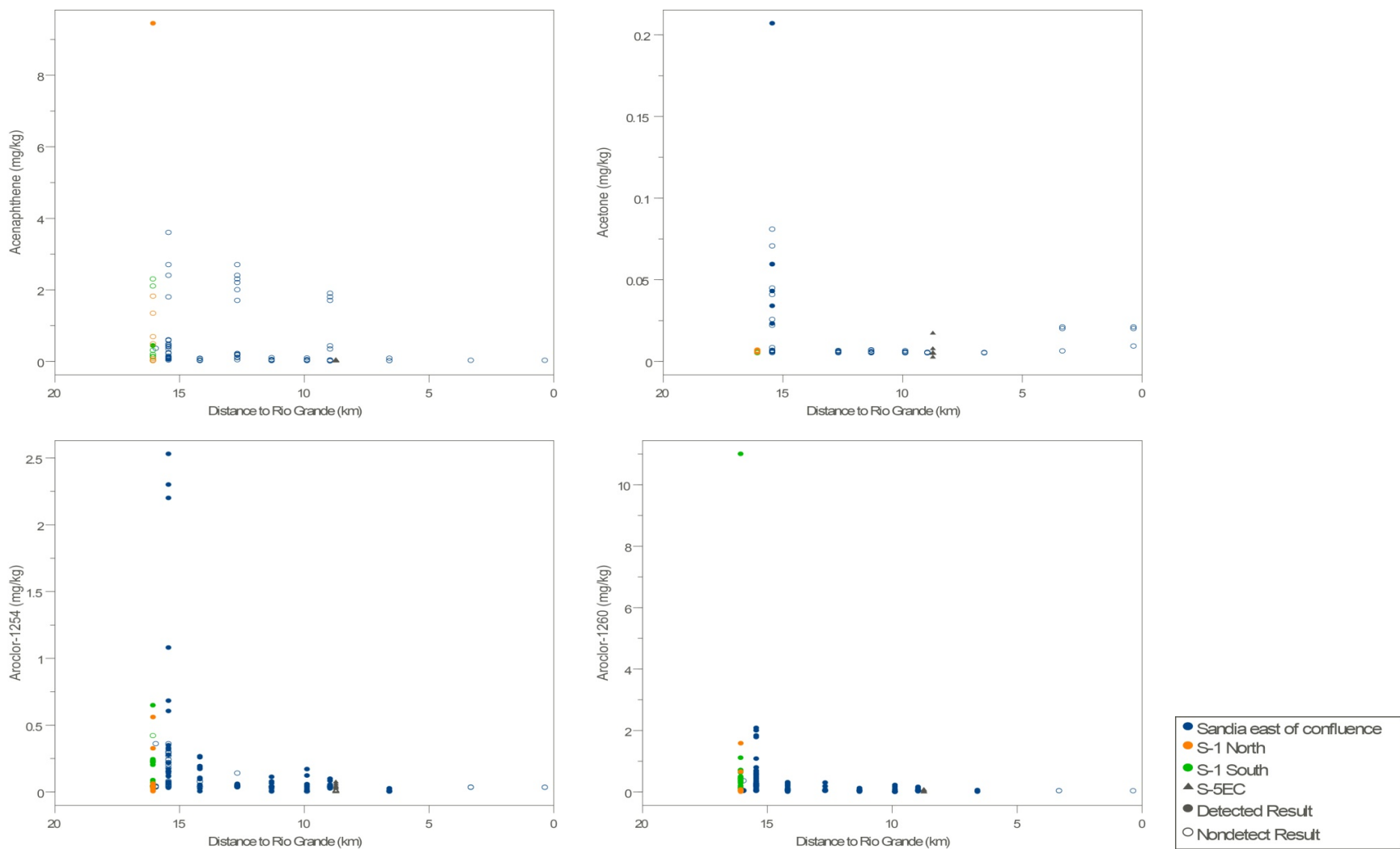


Figure D-2.1-2 Plots of sample results versus distance from the Rio Grande for all organic Phase II COPCs identified in sediment in the Sandia watershed

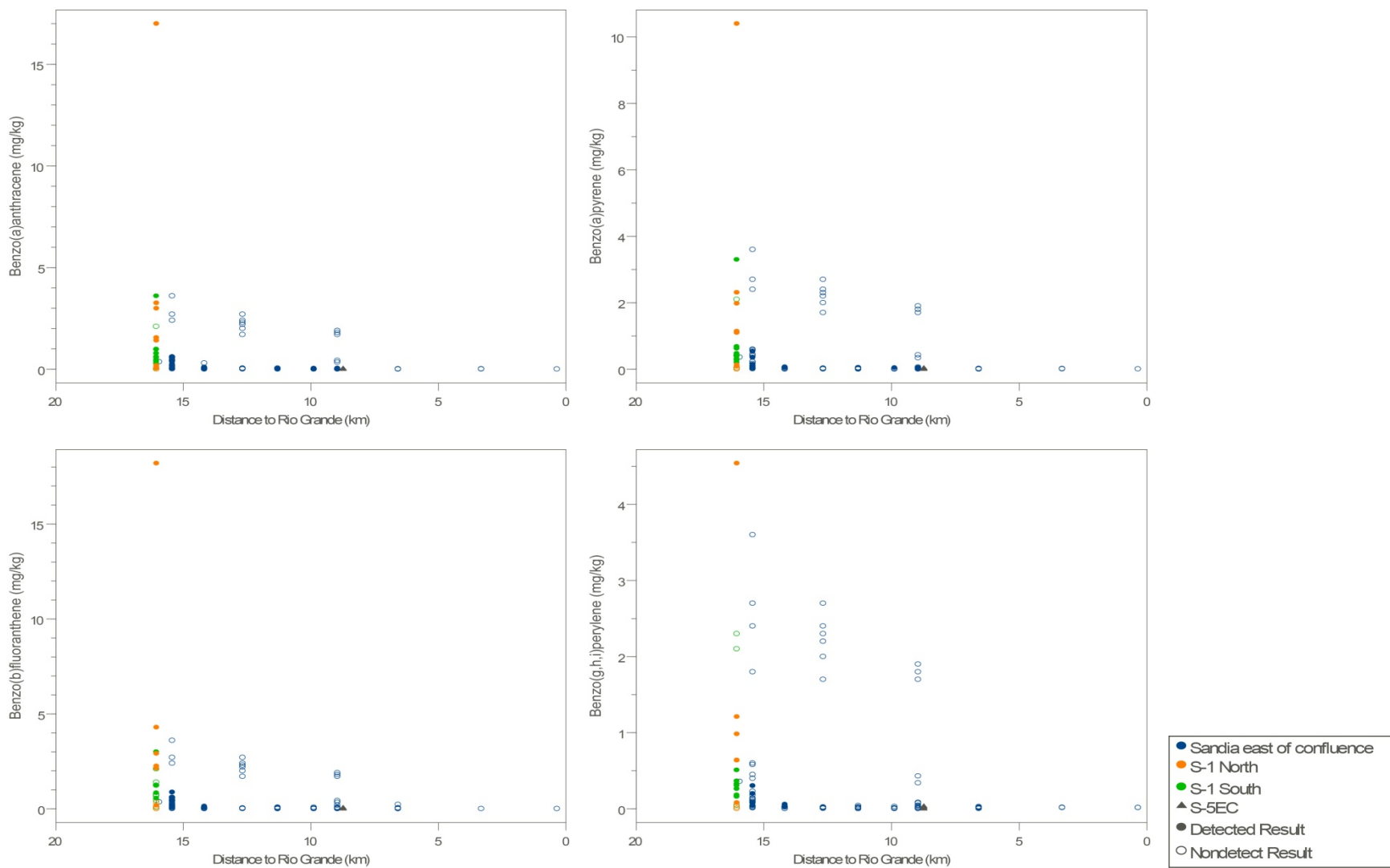


Figure D-2.1-2 (continued) Plots of sample results versus distance from the Rio Grande for all organic Phase II COPCs identified in sediment in the Sandia watershed

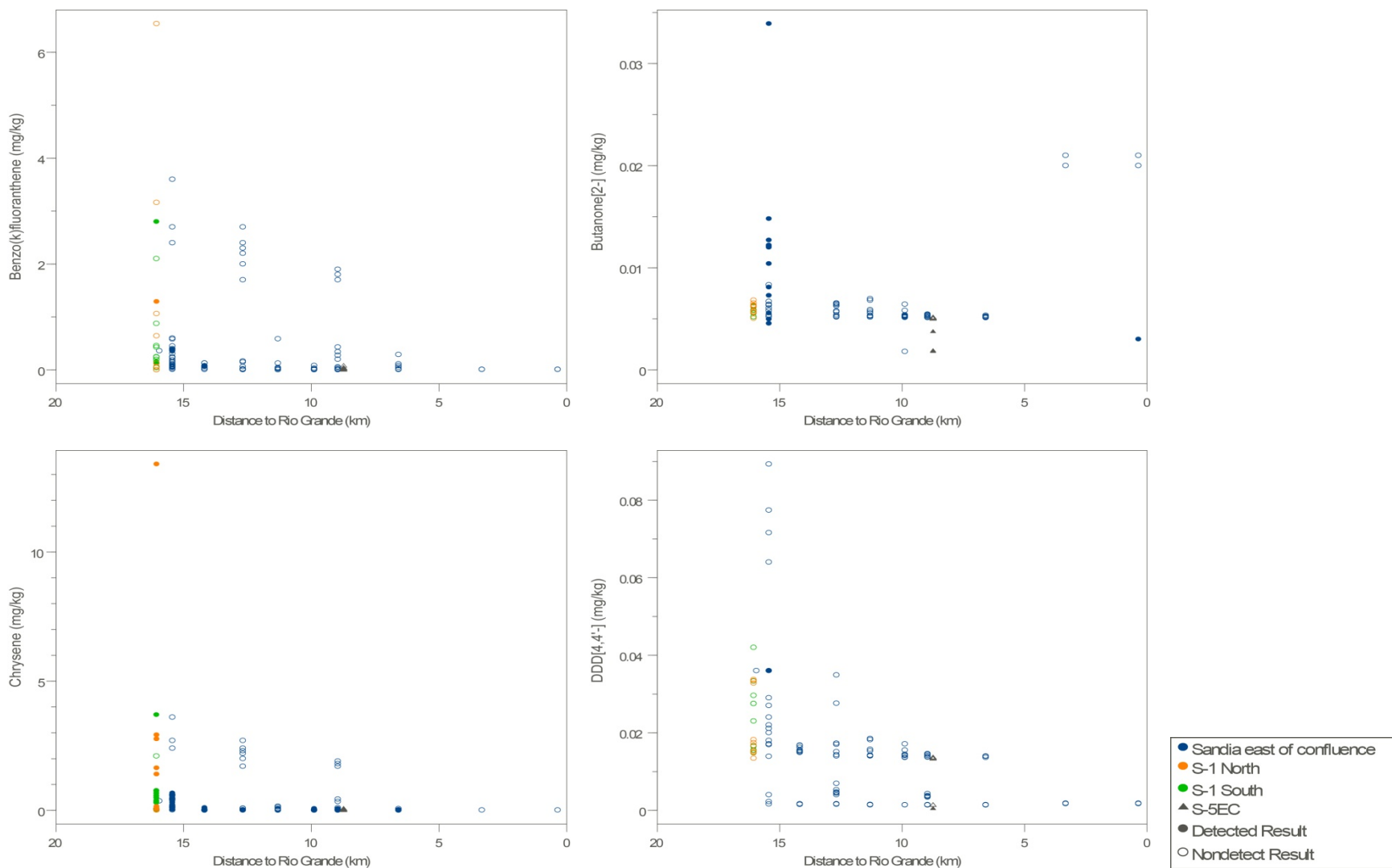


Figure D-2.1-2 (continued) Plots of sample results versus distance from the Rio Grande for all organic Phase II COPCs identified in sediment in the Sandia watershed

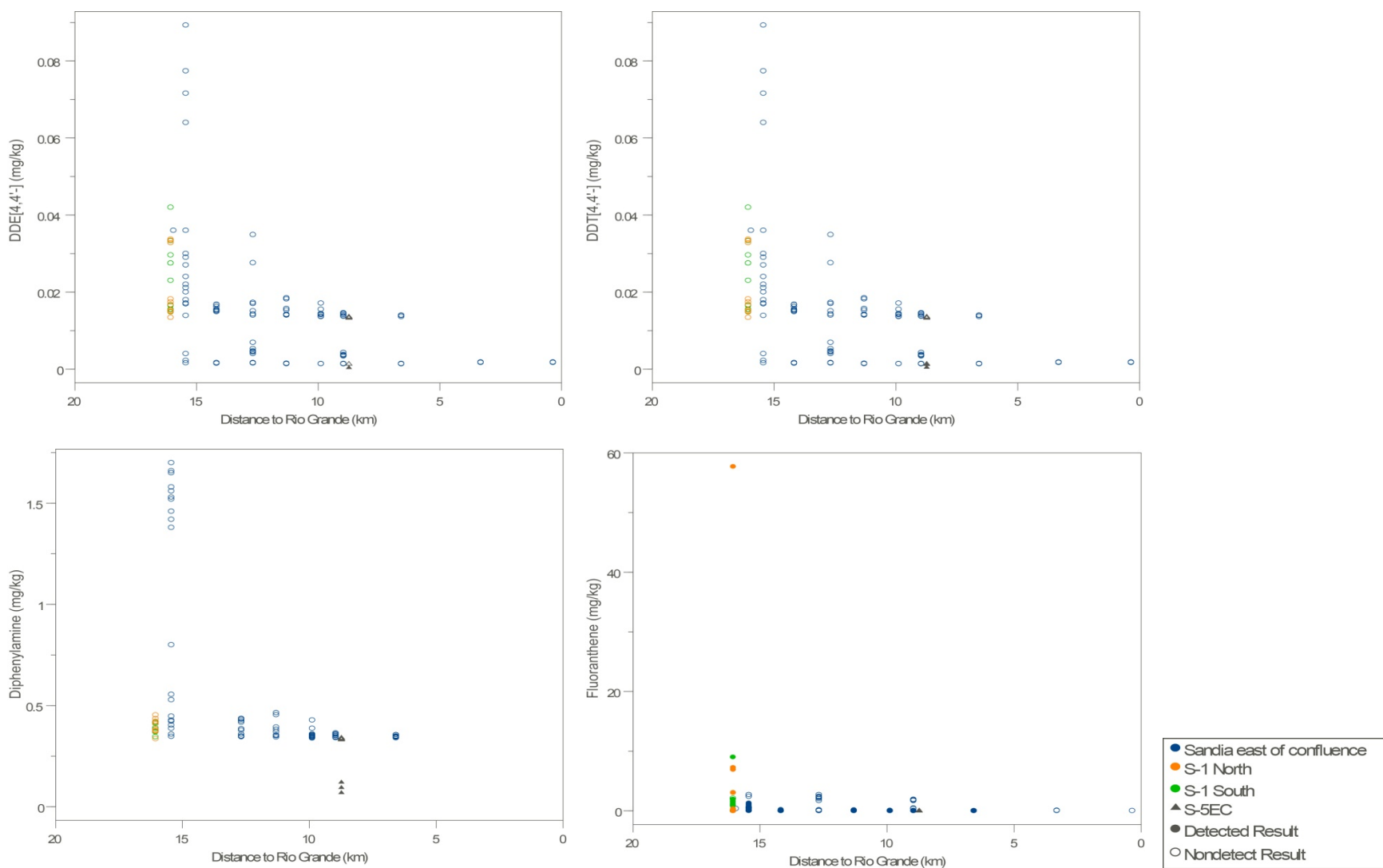


Figure D-2.1-2 (continued) Plots of sample results versus distance from the Rio Grande for all organic Phase II COPCs identified in sediment in the Sandia watershed

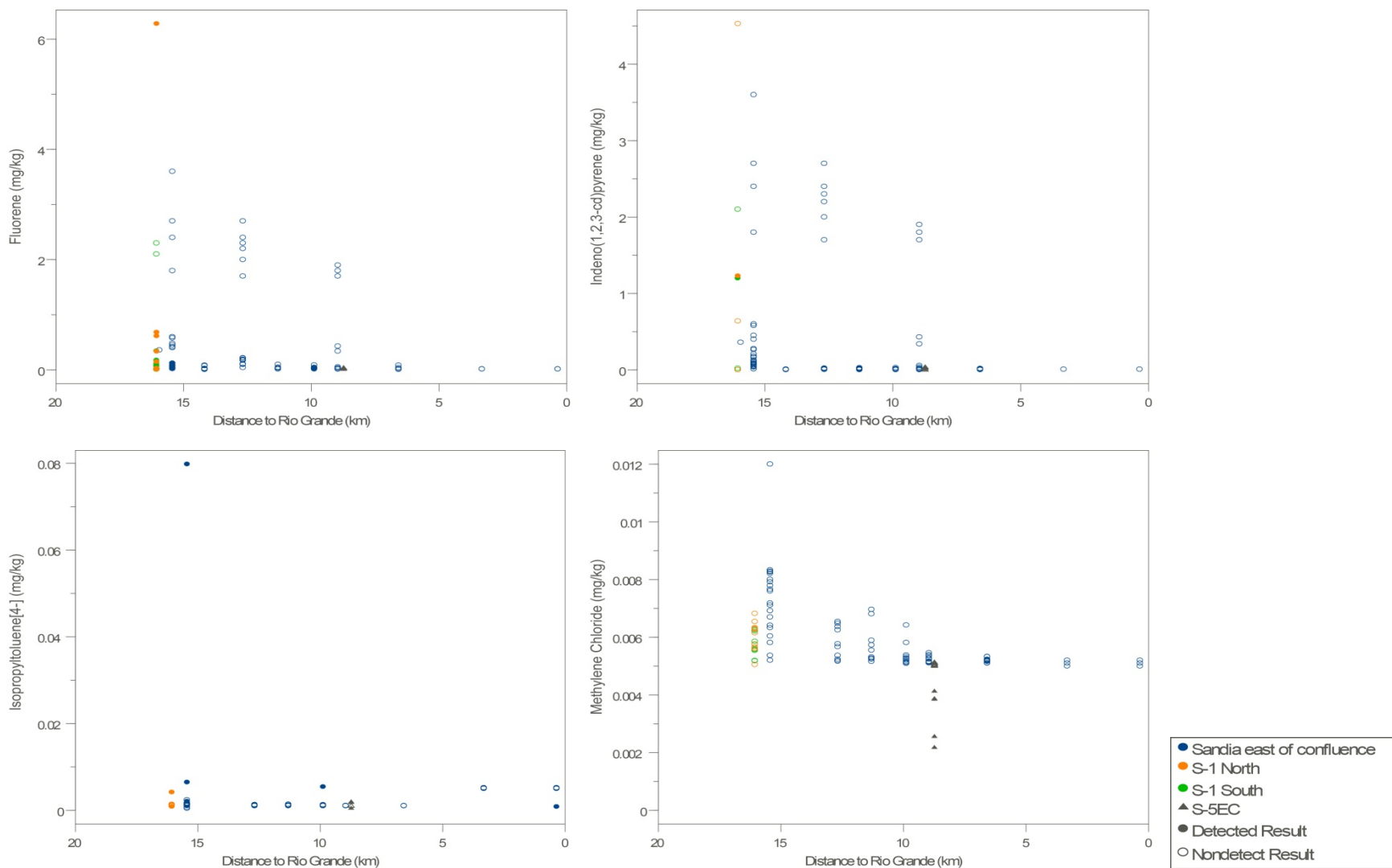


Figure D-2.1-2 (continued) Plots of sample results versus distance from the Rio Grande for all organic Phase II COPCs identified in sediment in the Sandia watershed

D-19

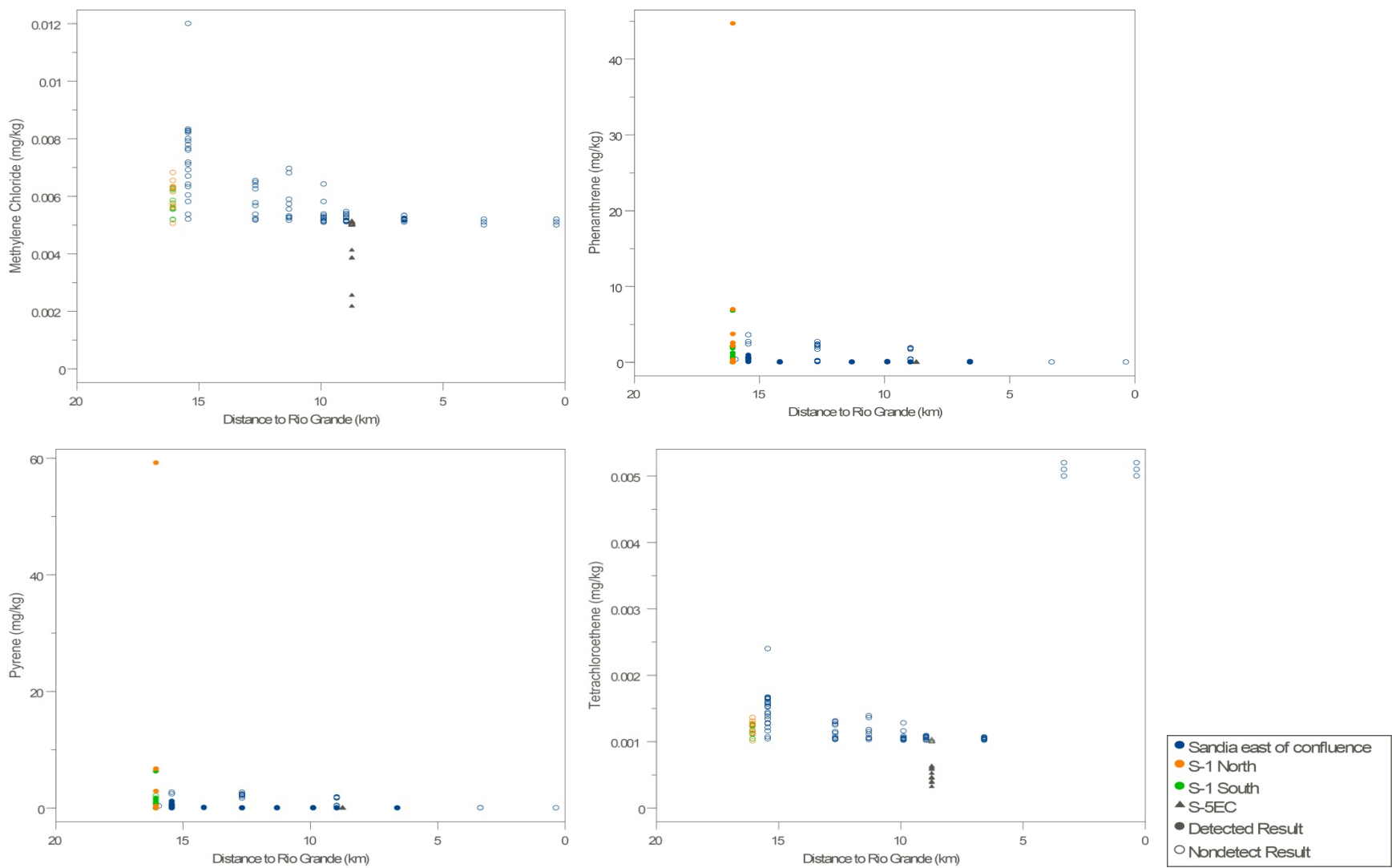


Figure D-2.1-2 (continued) Plots of sample results versus distance from the Rio Grande for all organic Phase II COPCs identified in sediment in the Sandia watershed

Trilinear Plot of Chromium Monitoring Group

Regional and Intermediate Groundwater Wells*

Cr > 50 µg/L

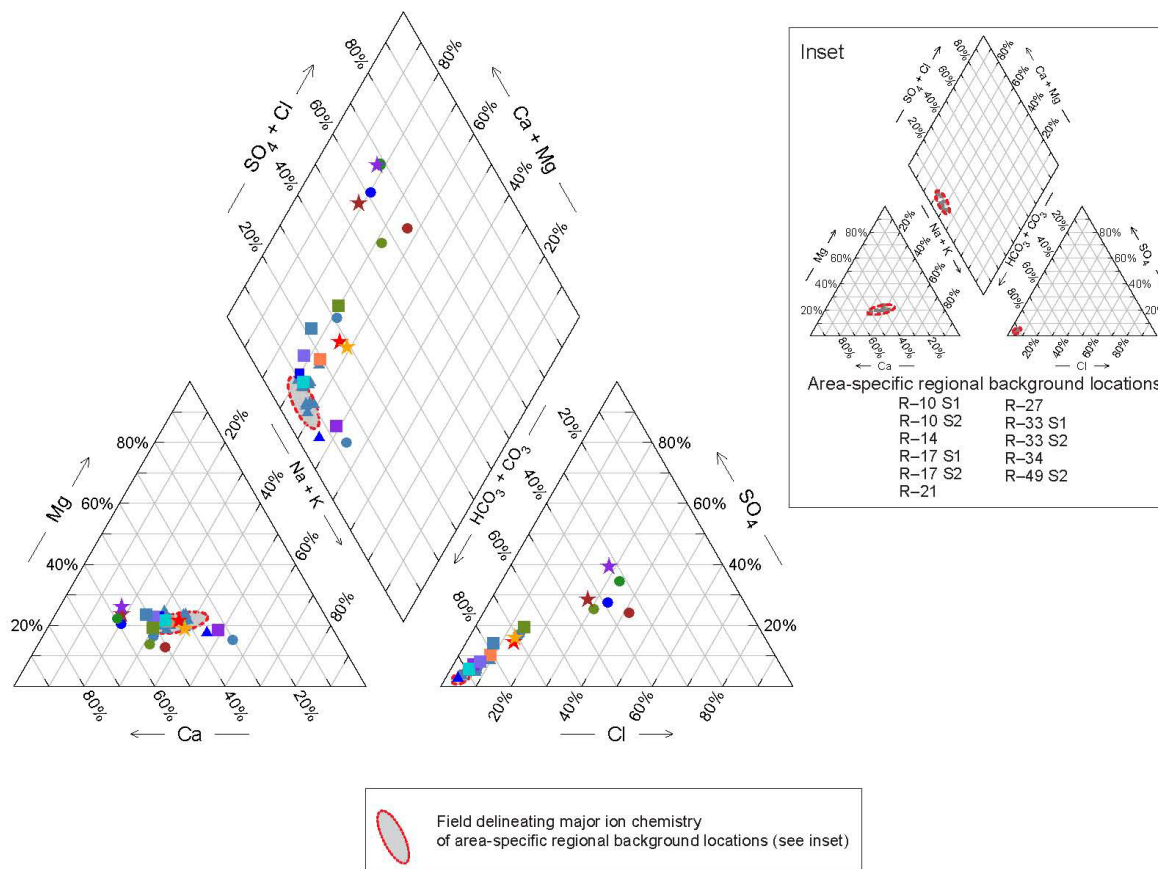
- ★ R-42
- SCI-2
- ★ R-28
- ★ R-62
- ★ R-50 S1
- MCOI-6

Cr = 10 - 50 µg/L

- R-43 S1
- R-11
- R-45 S1
- R-44 S1
- MCOI-4
- R-15
- R-45 S2
- SCI-1
- R-61 S1

Cr ≤ 10 µg/L

- LADP-3
- ▲ R-33 S2
- ▲ R-44 S2
- ▲ R-36
- MCOI-5
- ▲ R-33 S1
- ▲ R-1
- ▲ R-35b
- ▲ R-35a
- ▲ R-43 S2
- ▲ R-13
- ▲ R-9
- ▲ R-50 S2



*Most current data with the exception of R-61 data which are from May 2011 (aquifer test)

8/28/2012

Figure D-3.0-1a Piper diagrams for Sandia, Mortandad and Los Alamos Canyon watershed groundwaters

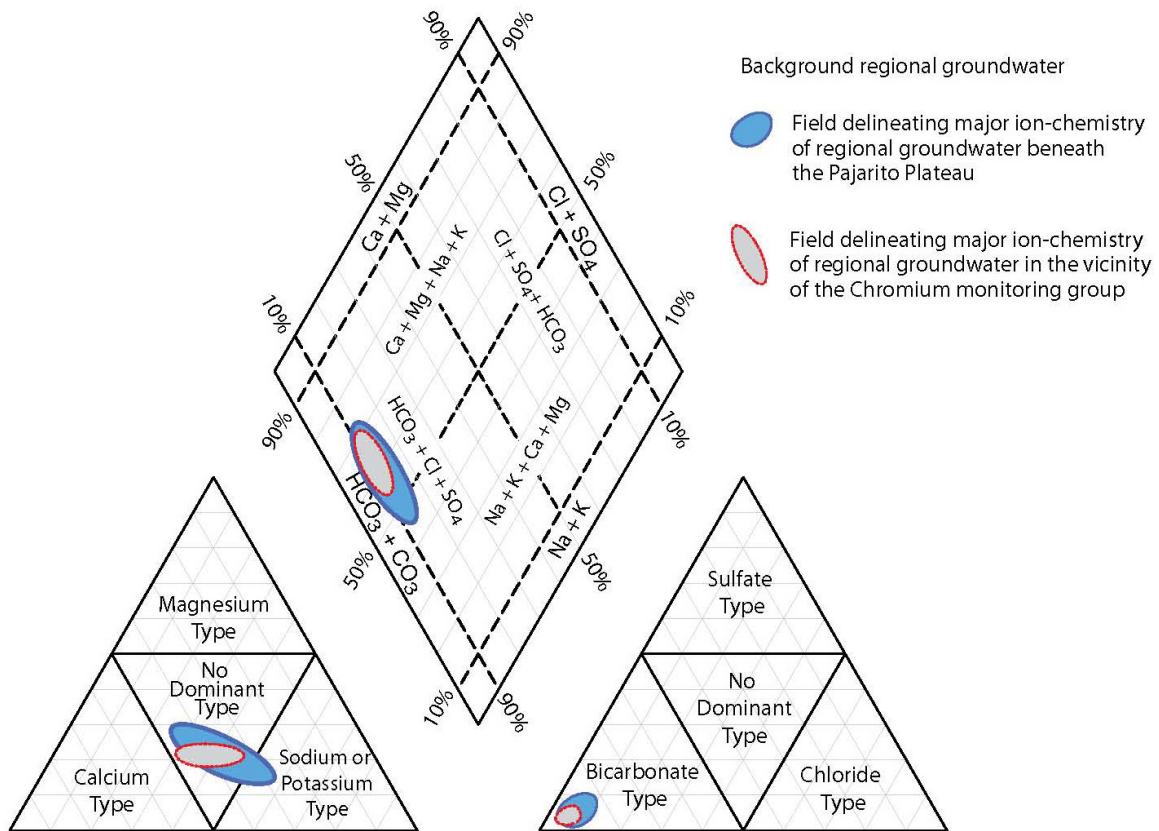
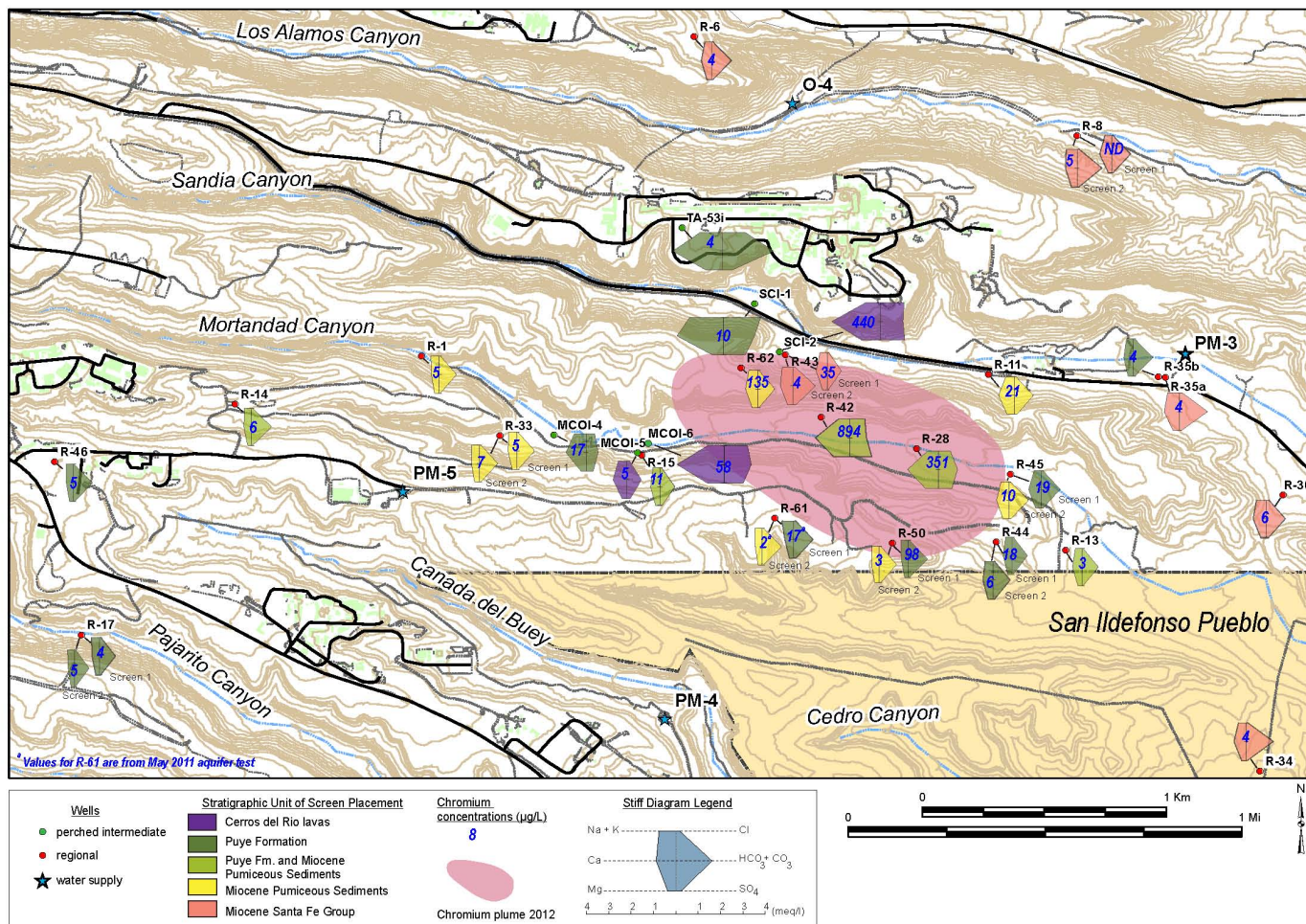


Figure D-3.0-1b Piper diagrams for Sandia, Mortandad, and Los Alamos Canyon watershed groundwaters compared to background groundwaters



Stiff diagrams for monitoring wells in the vicinity of the chromium plume. Concentrations of Chromium are overlain in blue type. Latest data used for the period 1/1/2011 - 7/15/2012 9/28/2012

Figure D-3.0-2 Map showing Stiff diagrams for Sandia, Mortandad and Los Alamos Canyon watershed groundwaters

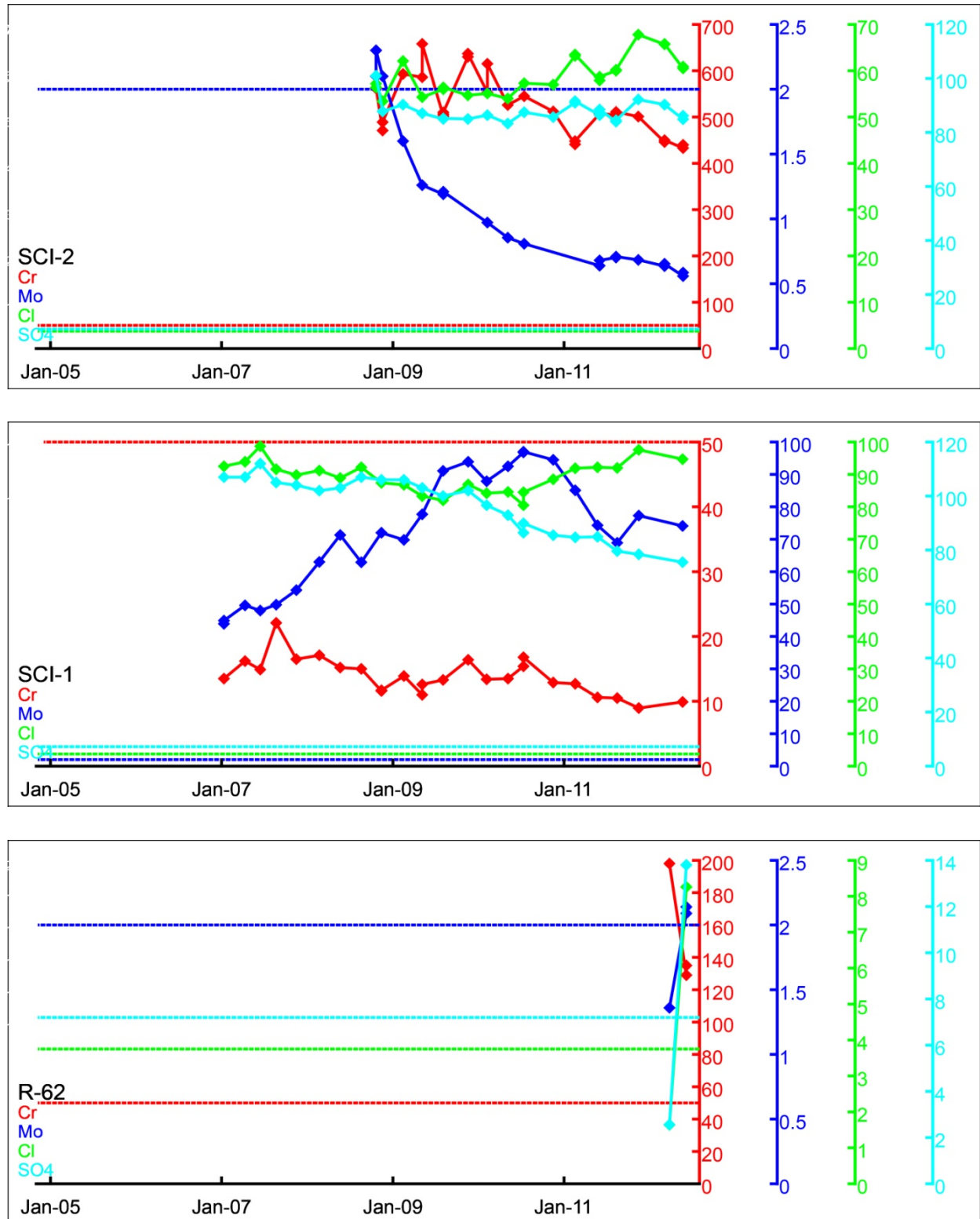


Figure D-3.0-3 Time-series plots for key constituents in Sandia and Mortandad canyon groundwater

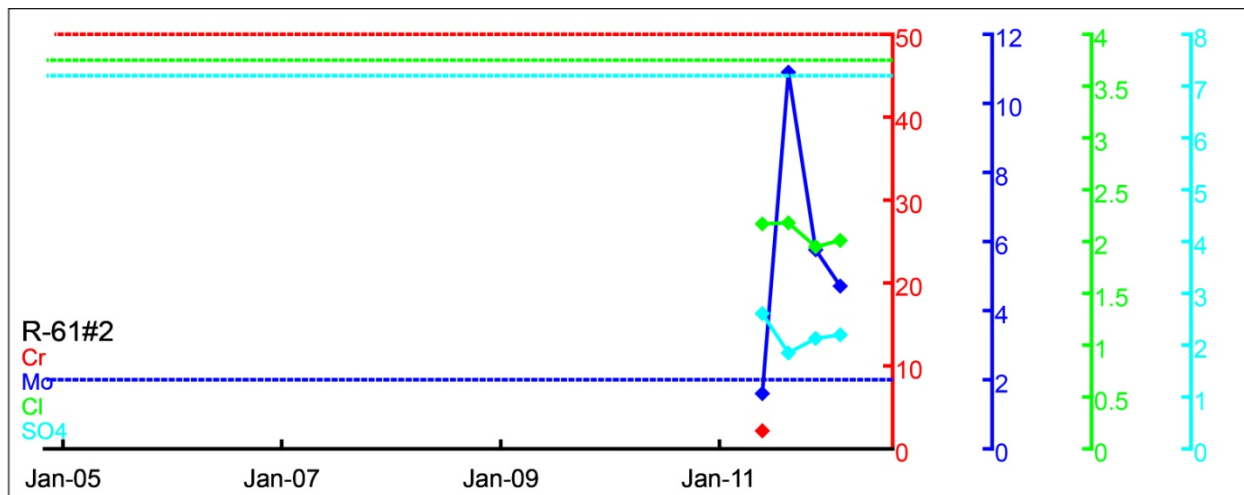
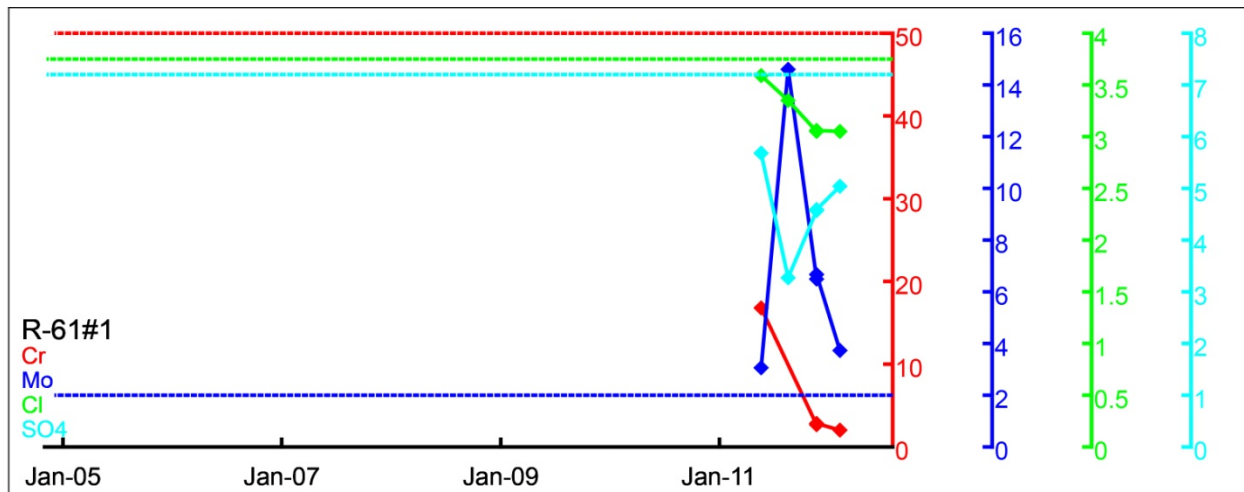
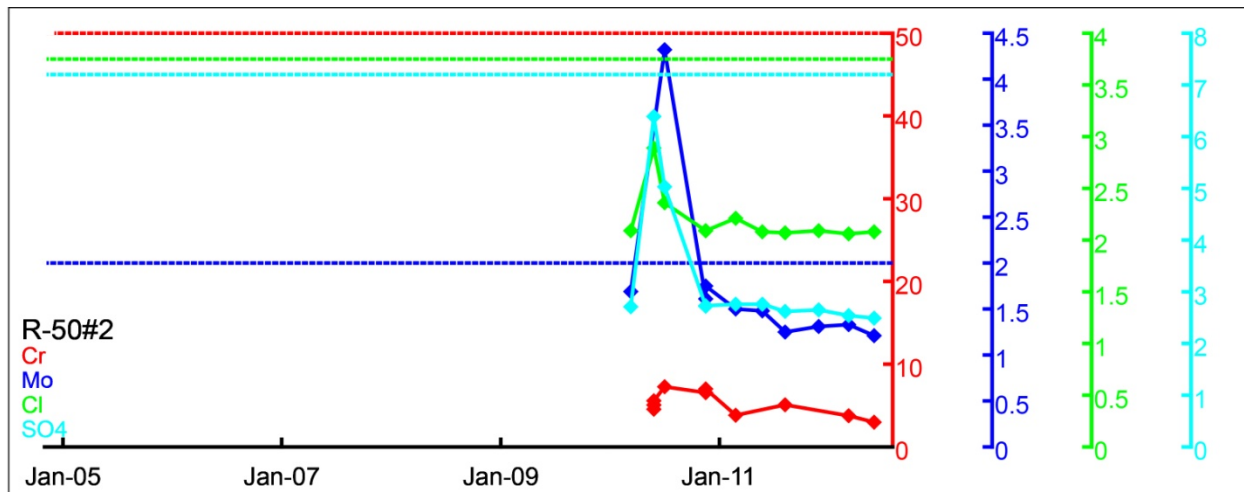


Figure D-3.0-3 (continued) Time-series plots for key constituents in Sandia and Mortandad Canyons groundwater

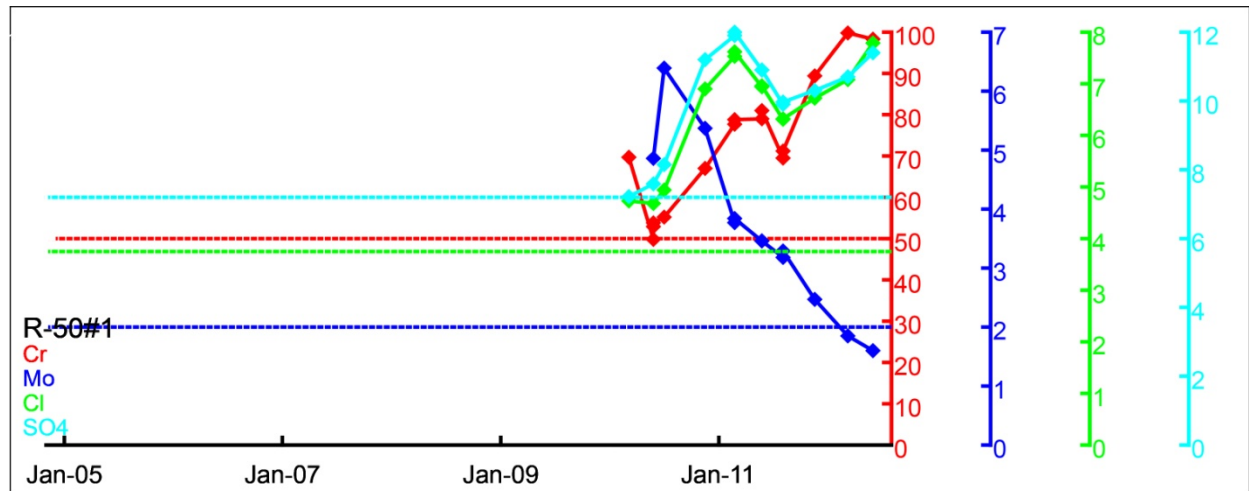
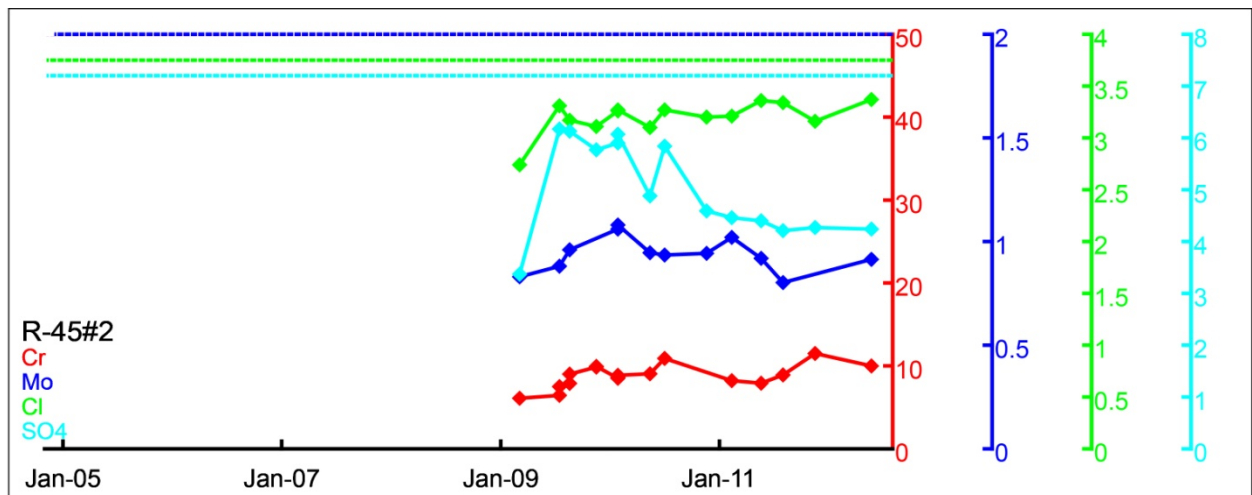
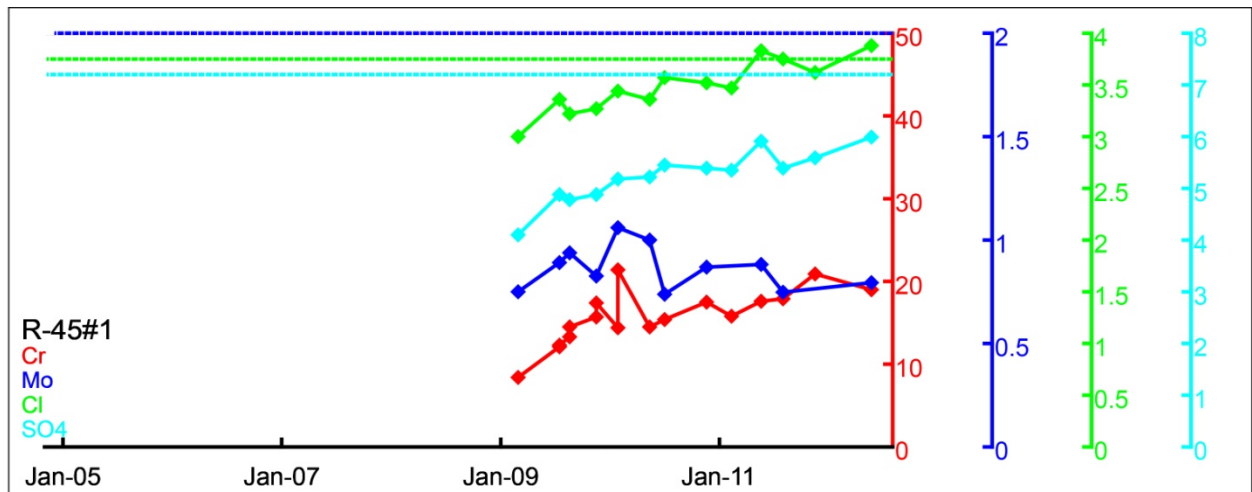


Figure D-3.0-3 (continued) Time-series plots for key constituents in Sandia and Mortandad Canyons groundwater

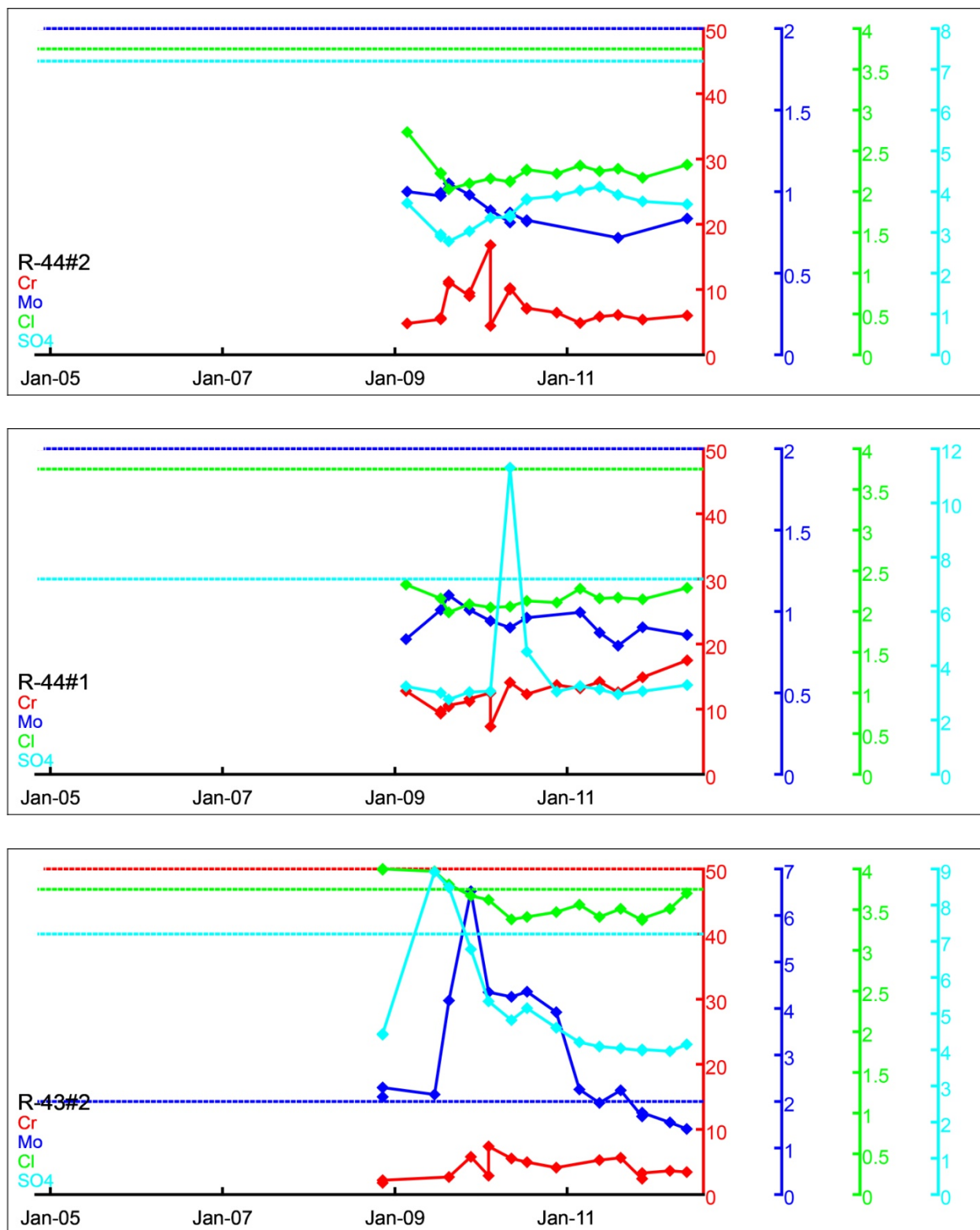


Figure D-3.0-3 (continued) Time-series plots for key constituents in Sandia and Mortandad Canyons groundwater

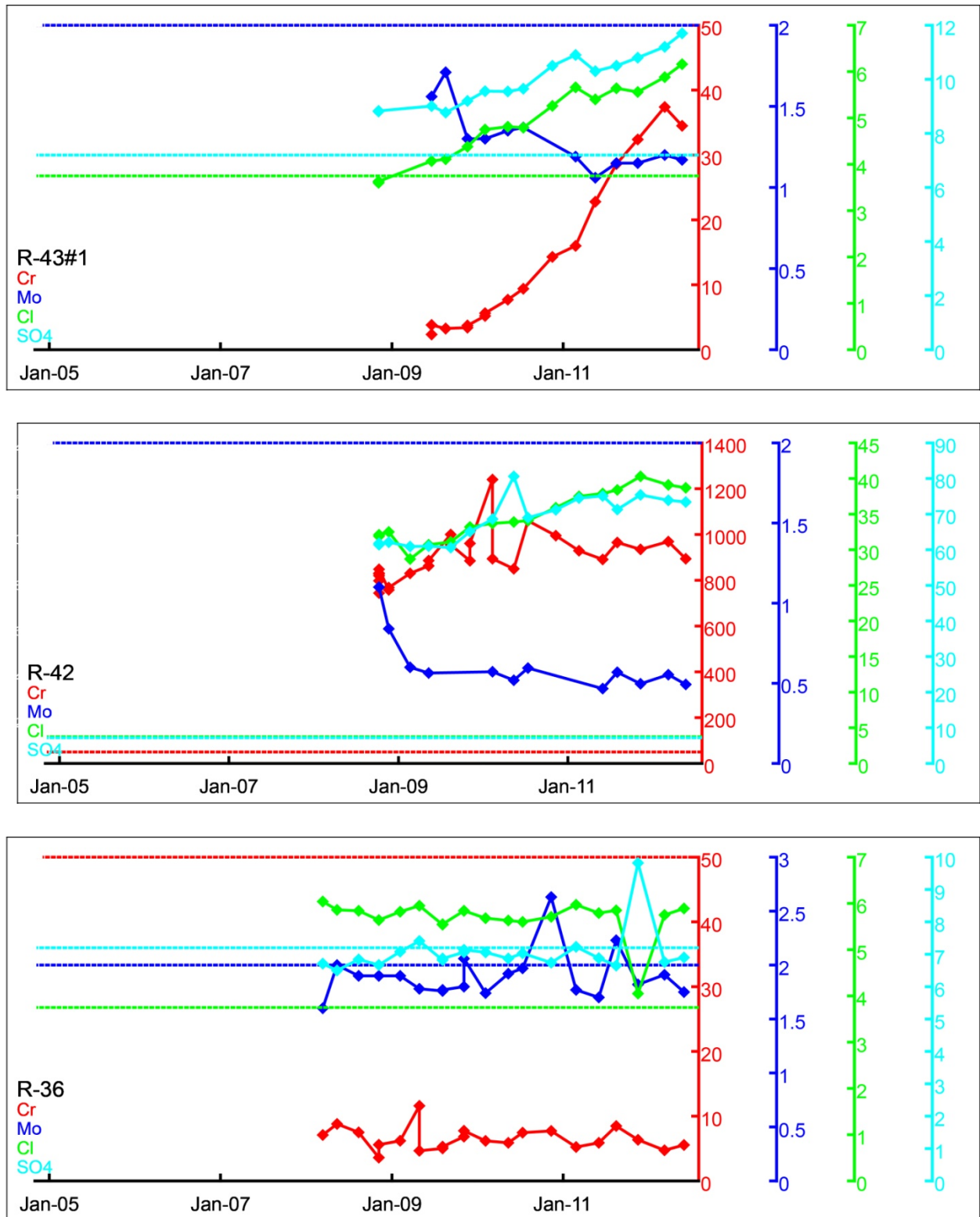


Figure D-3.0-3 (continued) Time-series plots for key constituents in Sandia and Mortandad Canyons groundwater

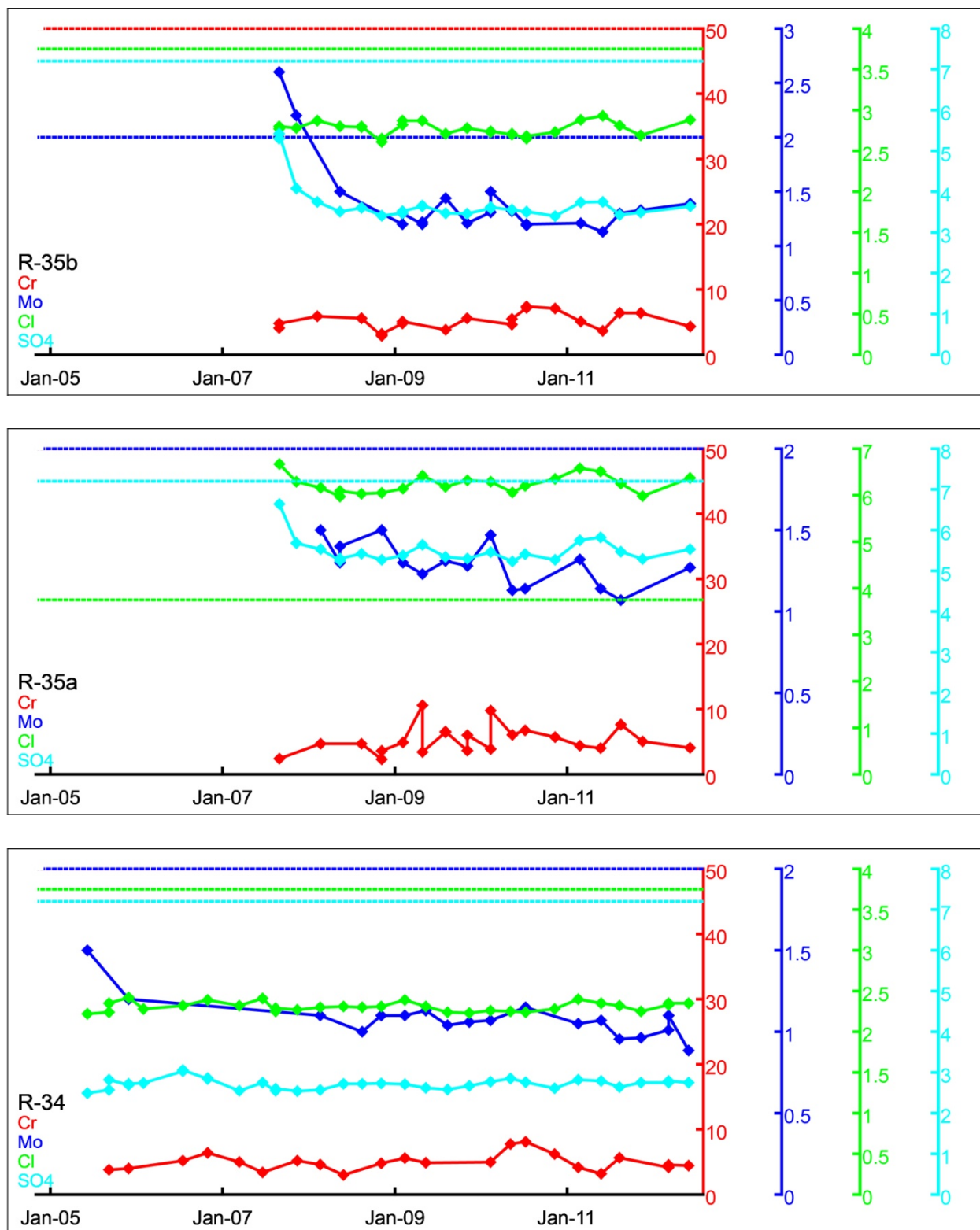


Figure D-3.0-3 (continued) Time-series plots for key constituents in Sandia and Mortandad Canyons groundwater

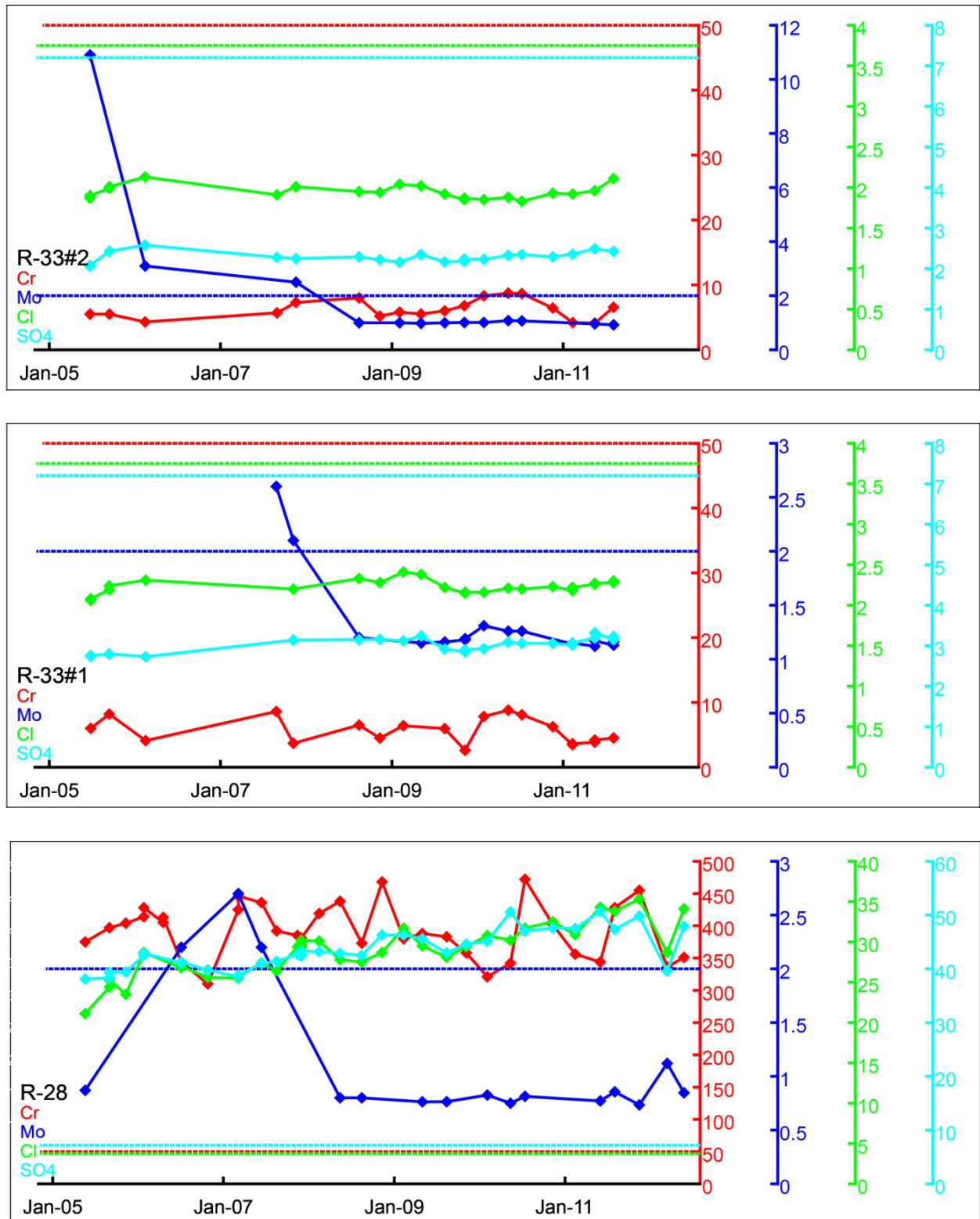


Figure D-3.0-3 (continued) Time-series plots for key constituents in Sandia and Mortandad Canyons groundwater

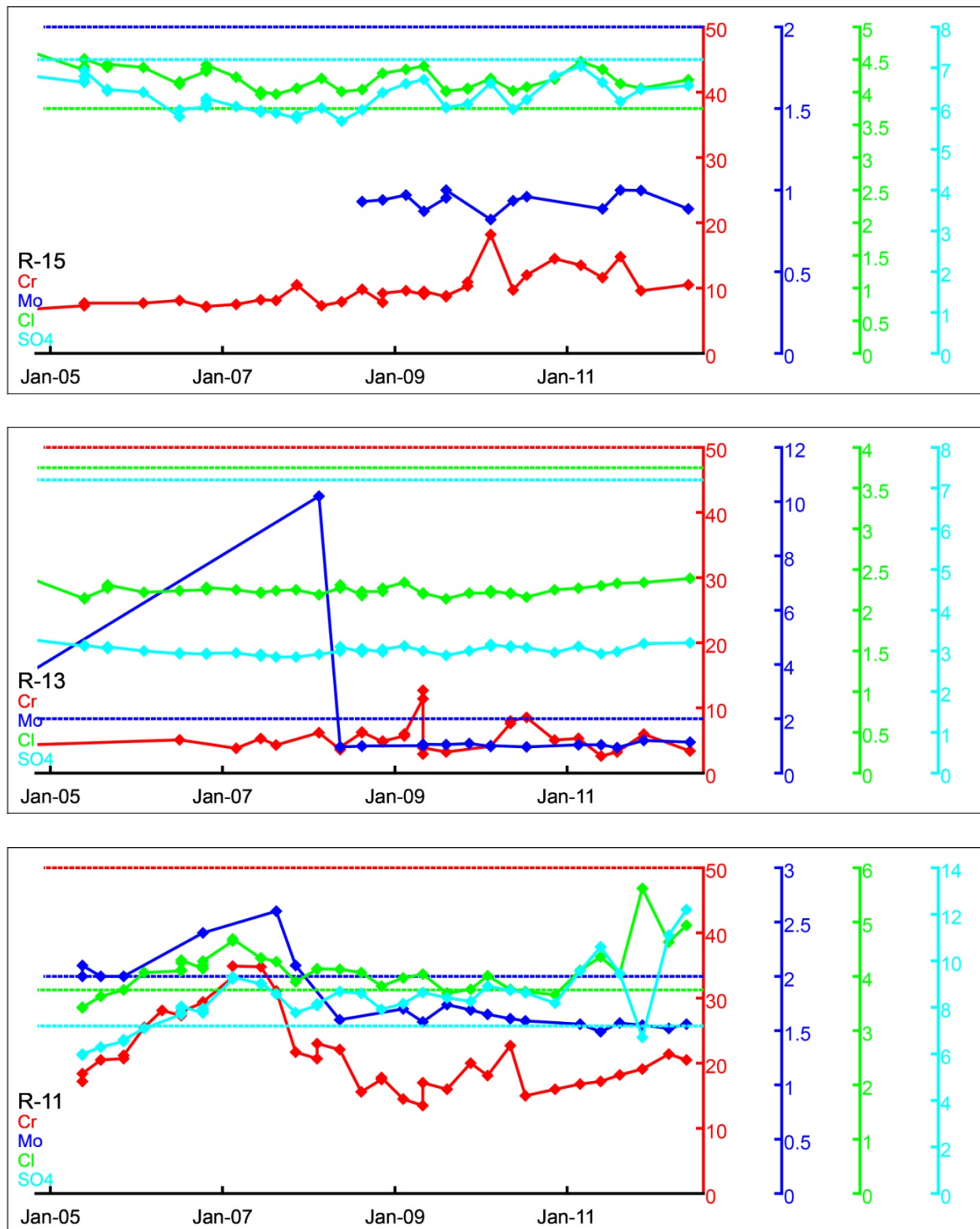


Figure D-3.0-3 (continued) Time-series plots for key constituents in Sandia and Mortandad Canyons groundwater

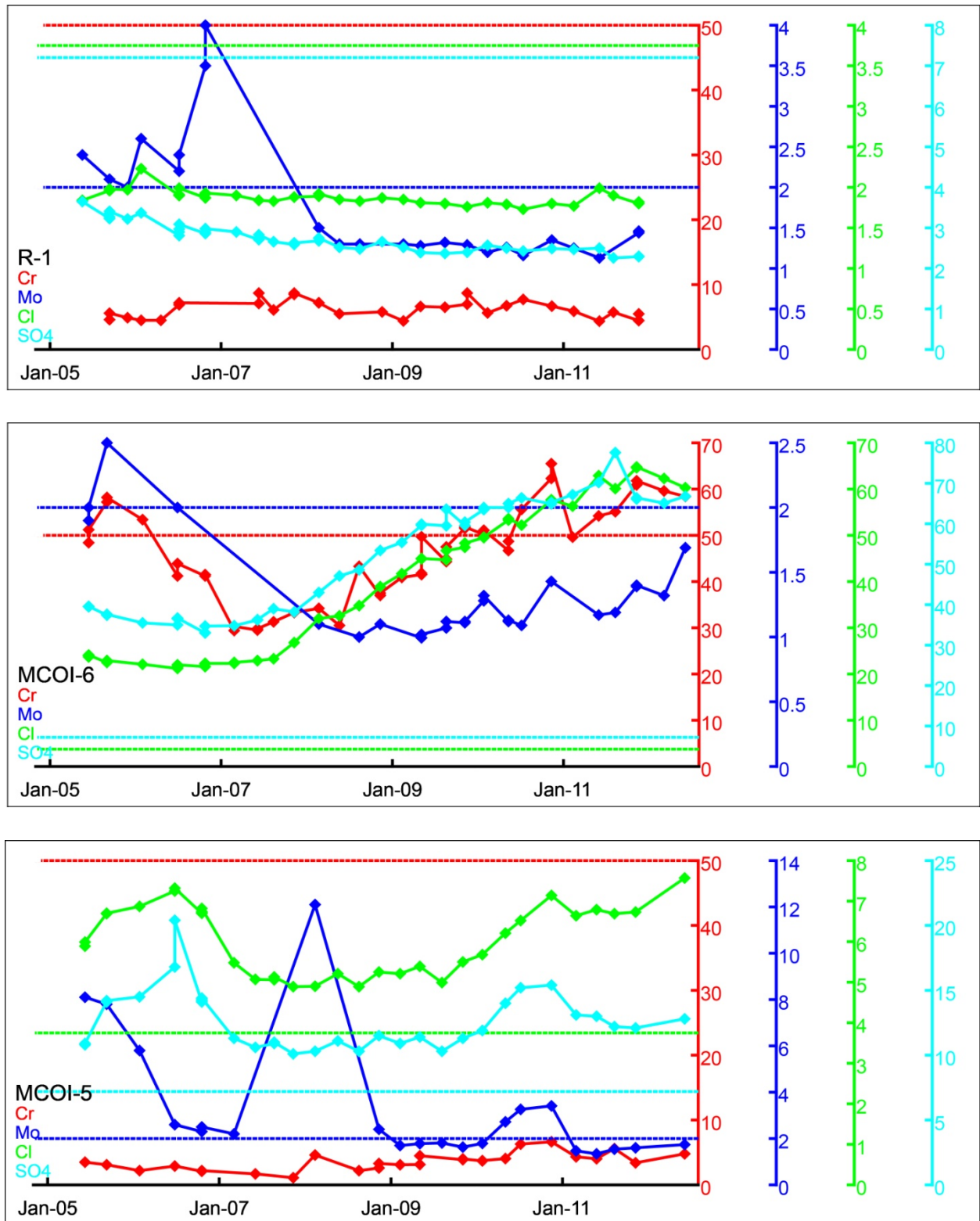


Figure D-3.0-3 (continued) Time-series plots for key constituents in Sandia and Mortandad Canyons groundwater

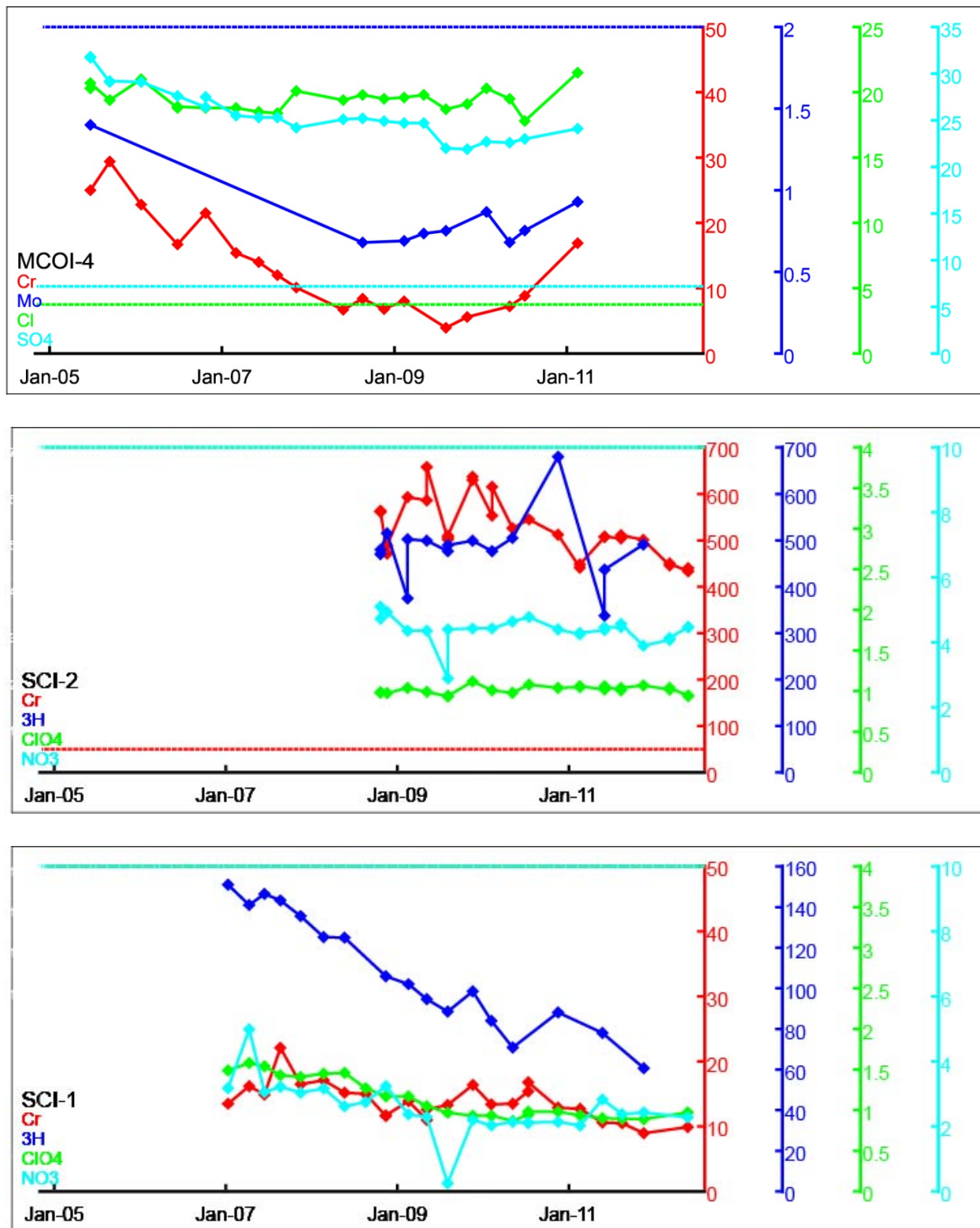


Figure D-3.0-3 (continued) Time-series plots for key constituents in Sandia and Mortandad Canyons groundwater

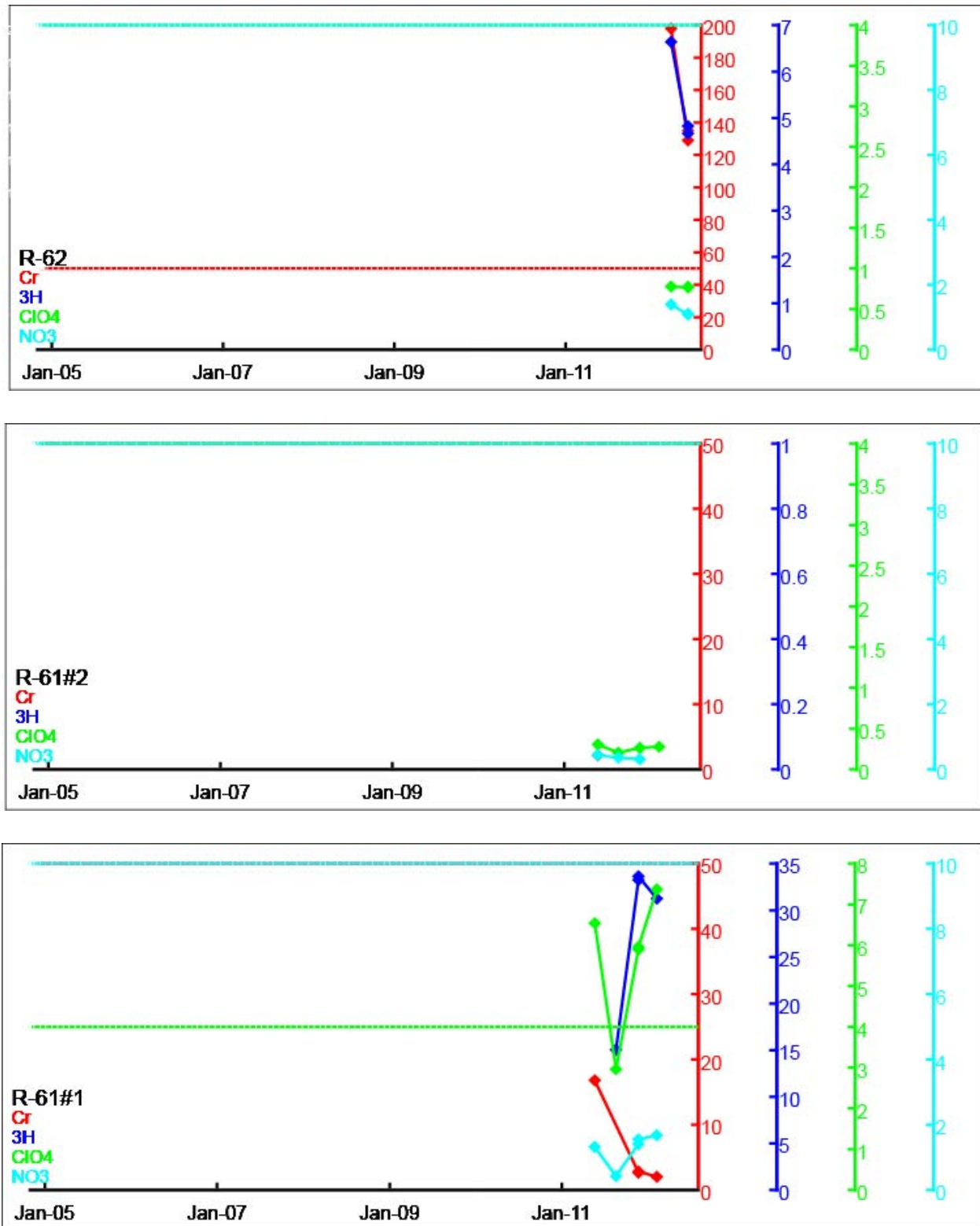


Figure D-3.0-3 (continued) Time-series plots for key constituents in Sandia and Mortandad Canyons groundwater

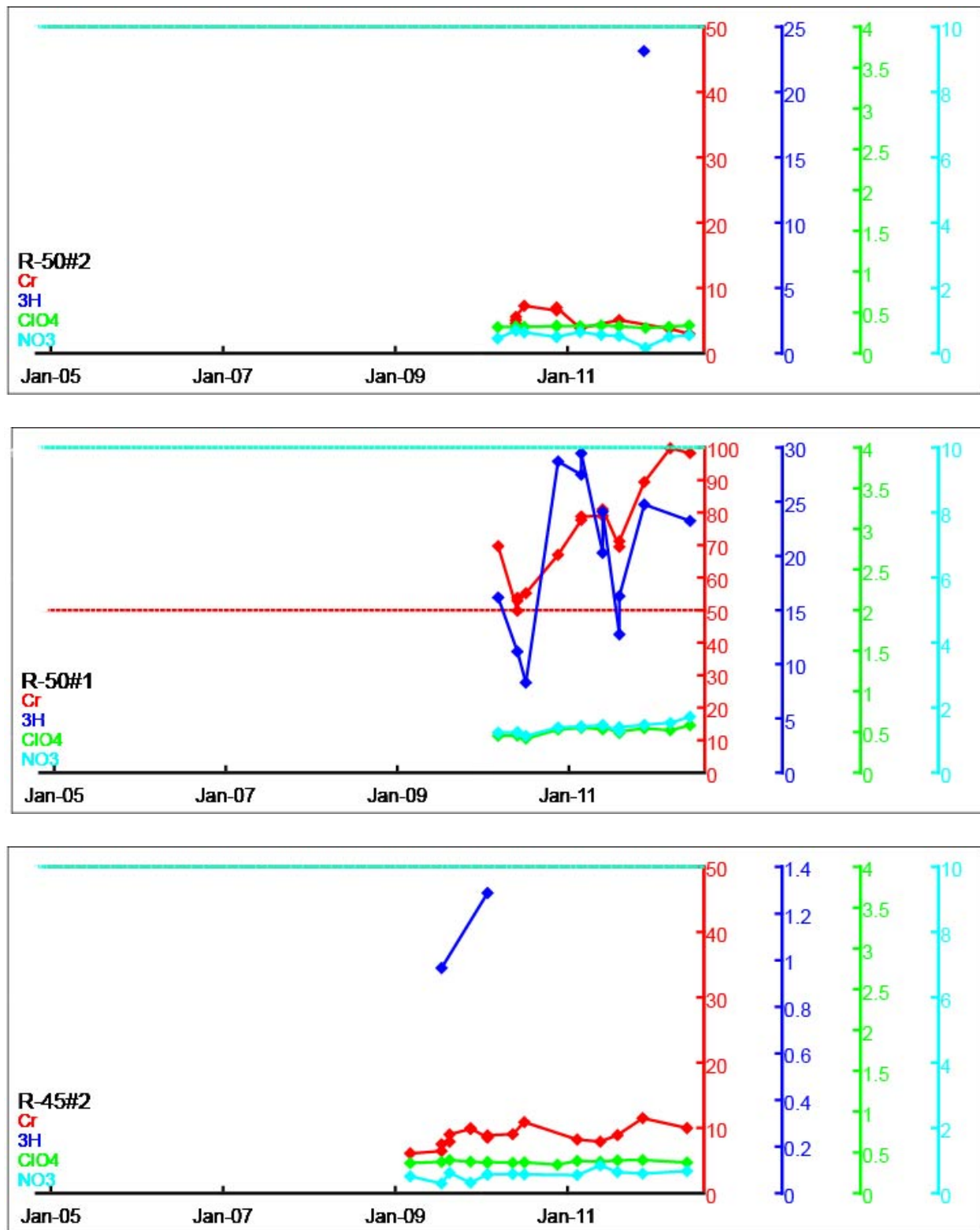


Figure D-3.0-3 (continued) Time-series plots for key constituents in Sandia and Mortandad Canyons groundwater

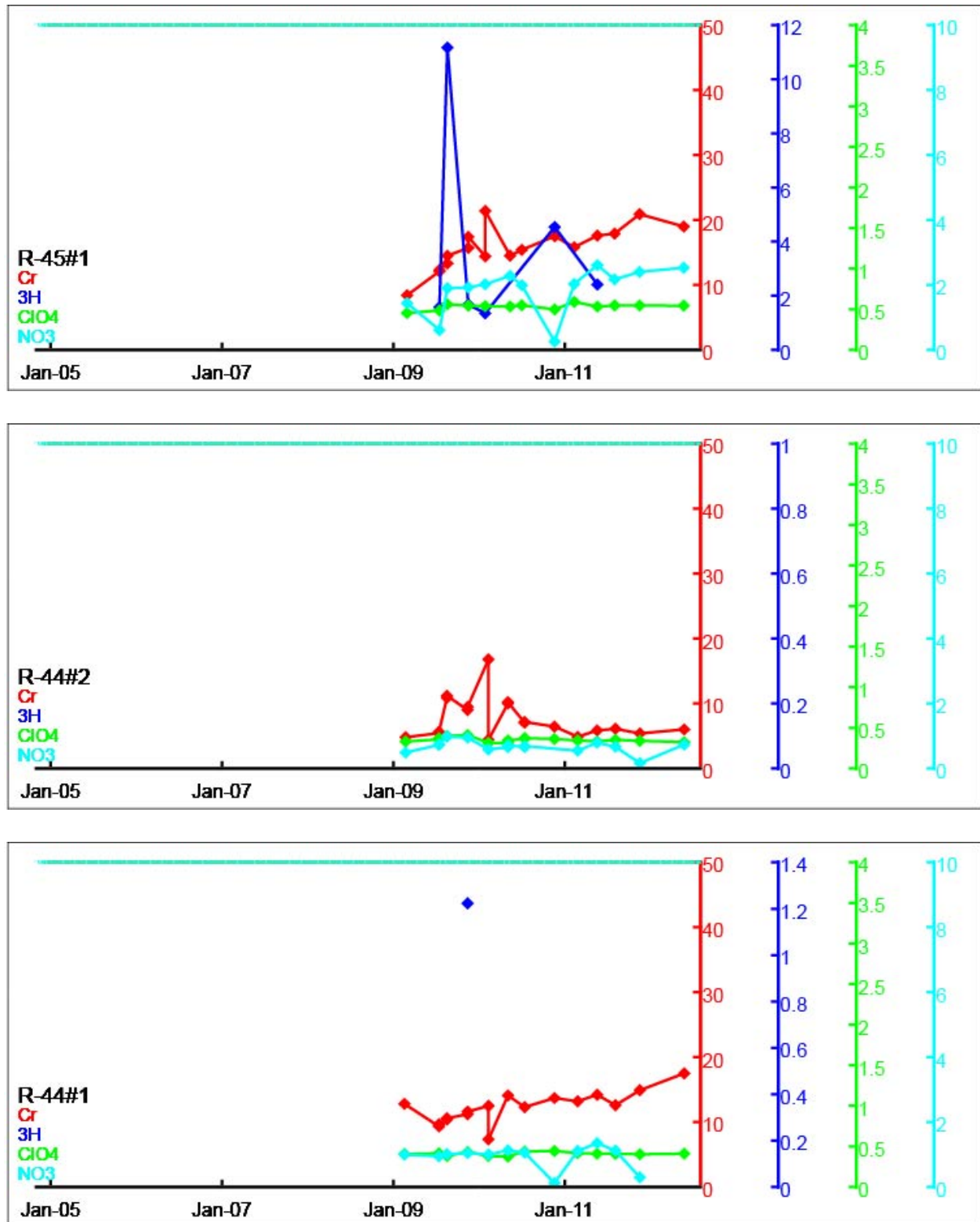


Figure D-3.0-3 (continued) Time-series plots for key constituents in Sandia and Mortandad Canyons groundwater

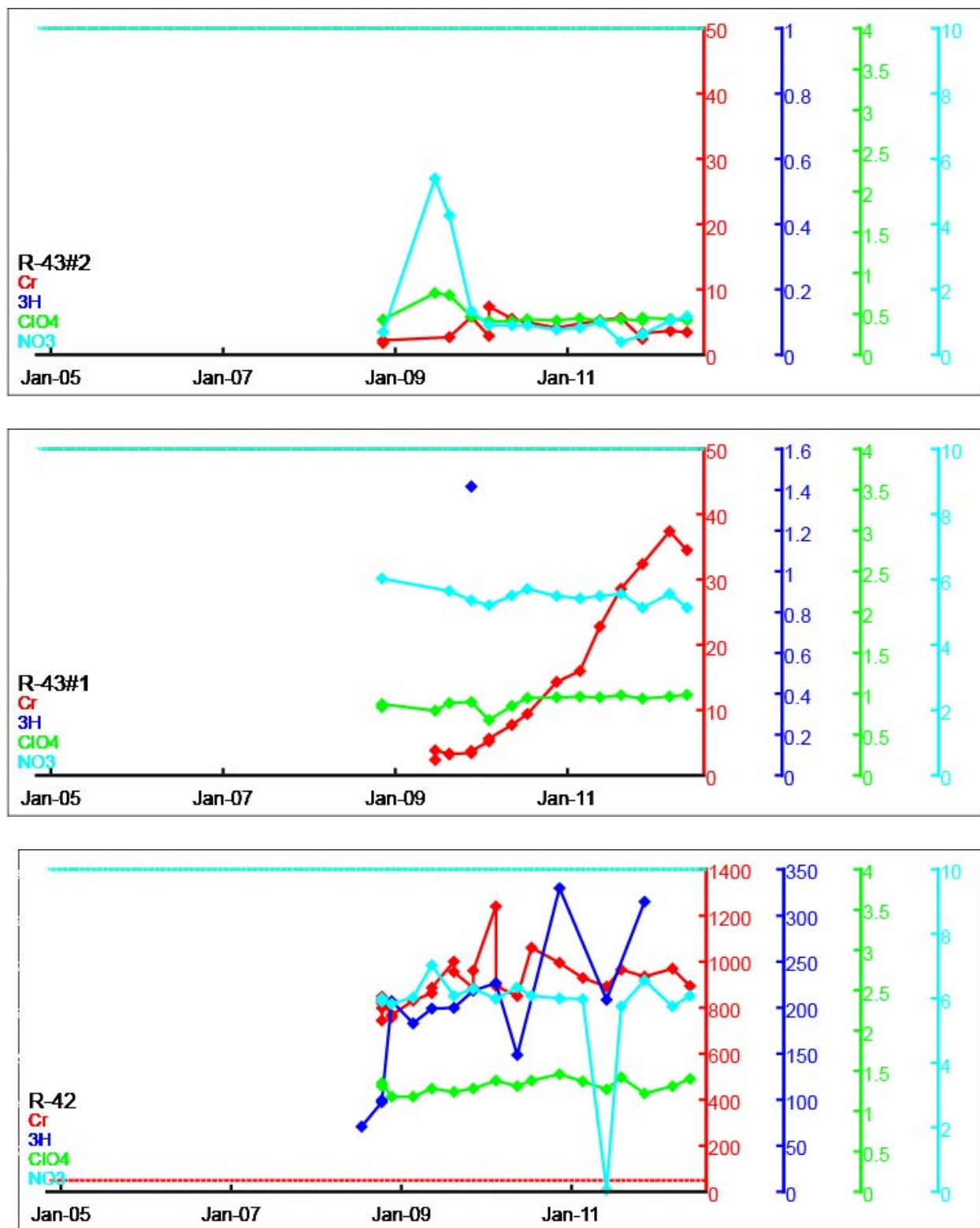


Figure D-3.0-3 (continued) Time-series plots for key constituents in Sandia and Mortandad Canyons groundwater

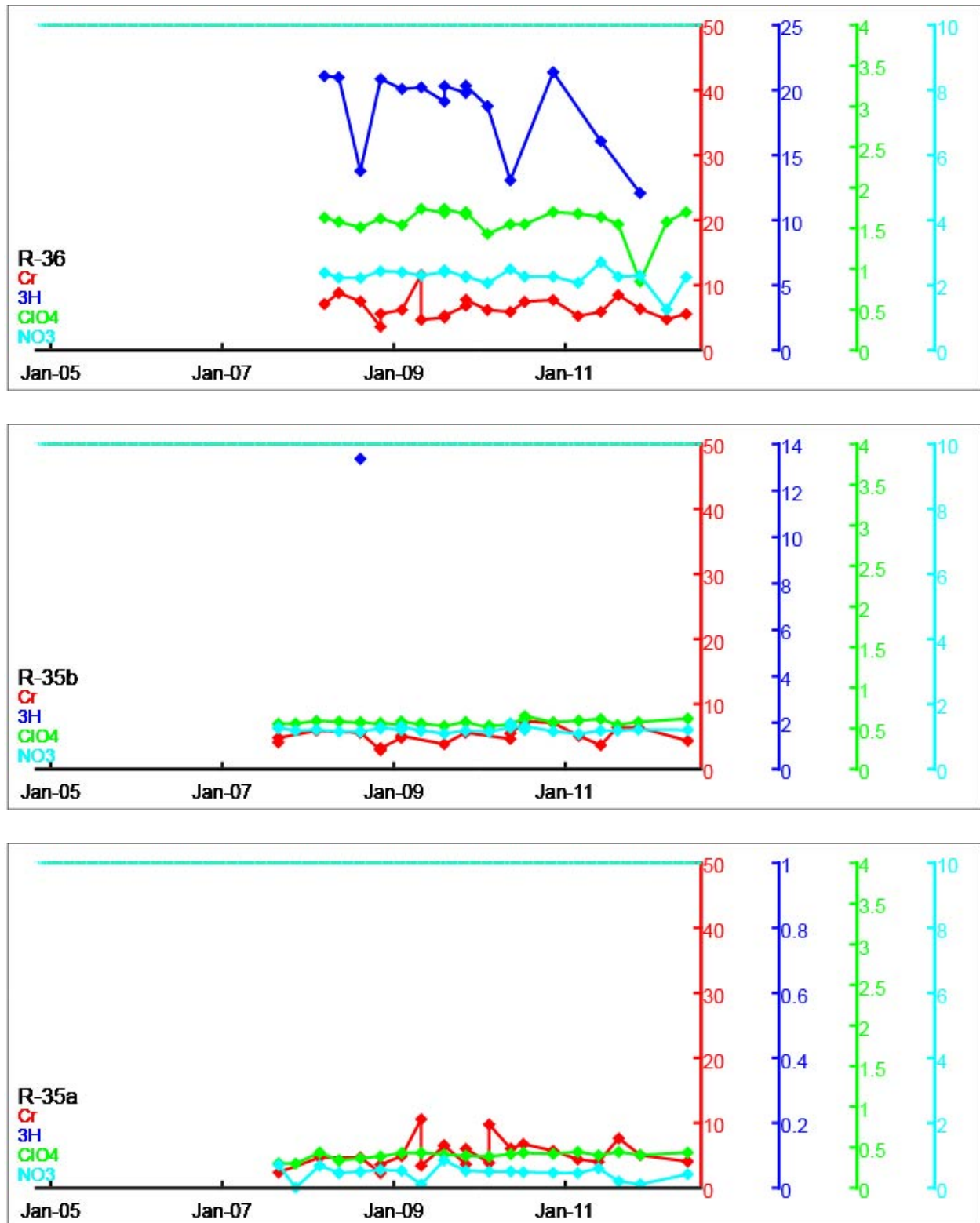


Figure D-3.0-3 (continued) Time-series plots for key constituents in Sandia and Mortandad Canyons groundwater

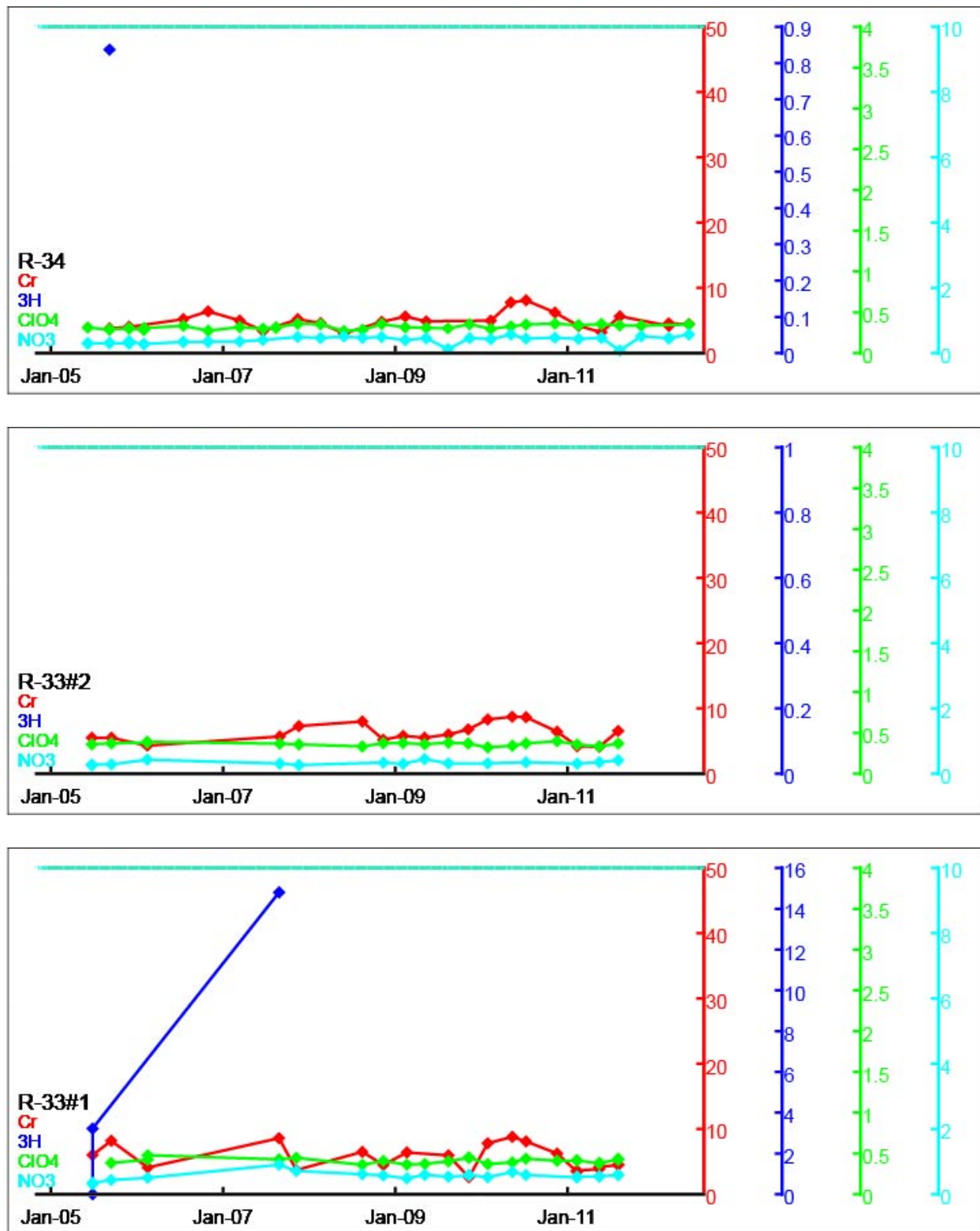


Figure D-3.0-3 (continued) Time-series plots for key constituents in Sandia and Mortandad Canyons groundwater

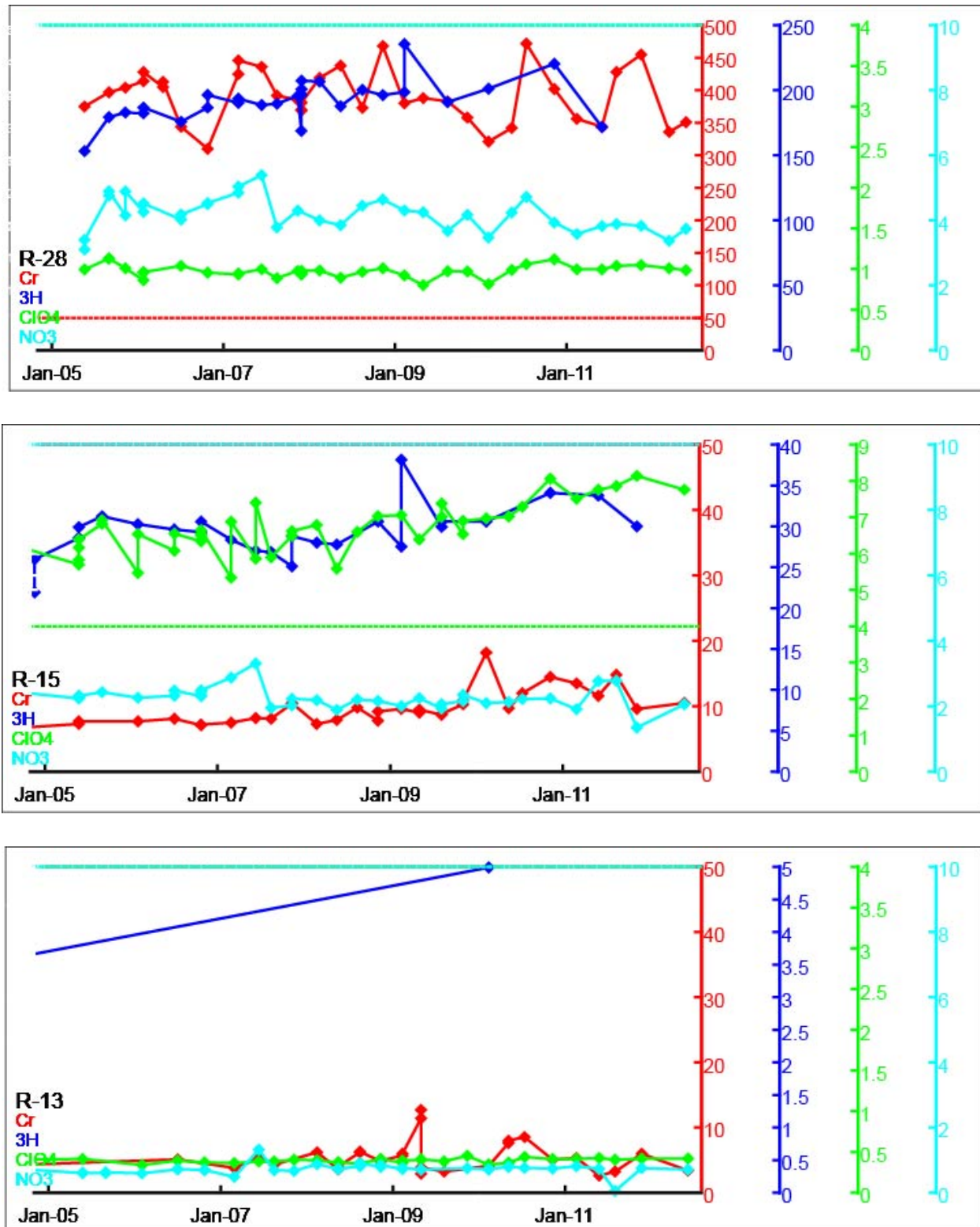


Figure D-3.0-3 (continued) Time-series plots for key constituents in Sandia and Mortandad Canyons groundwater

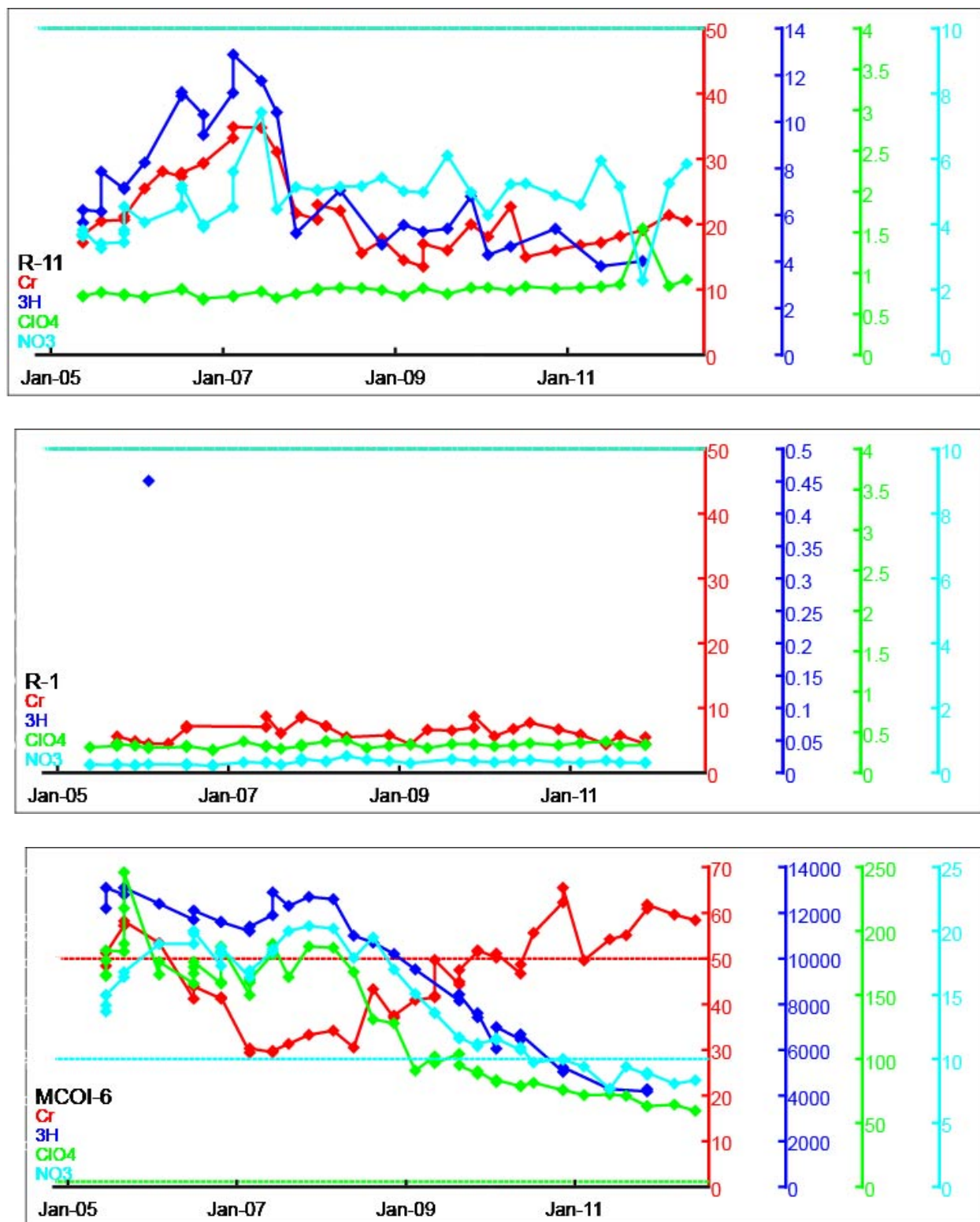


Figure D-3.0-3 (continued) Time-series plots for key constituents in Sandia and Mortandad Canyons groundwater

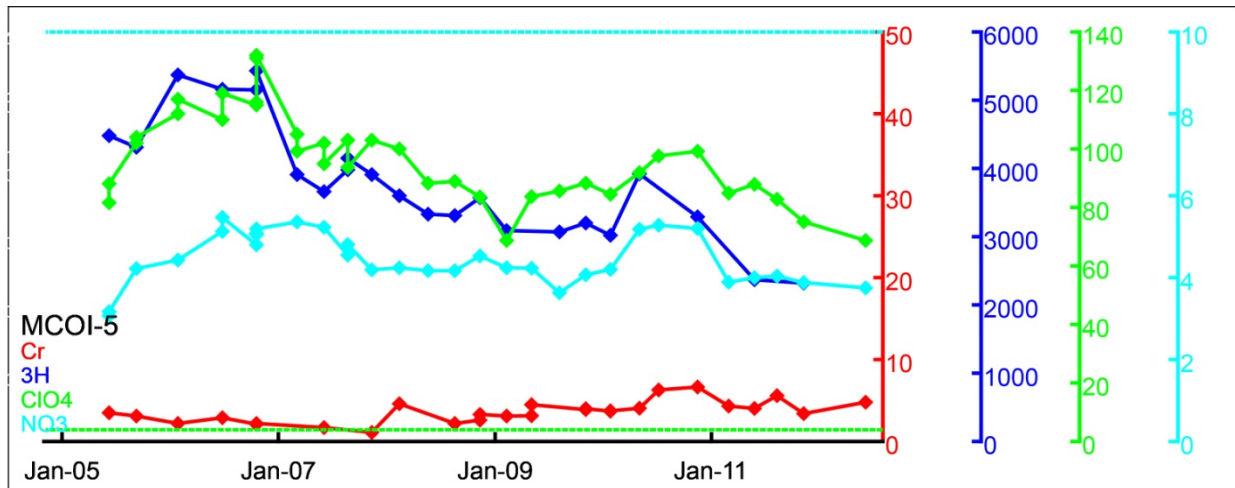
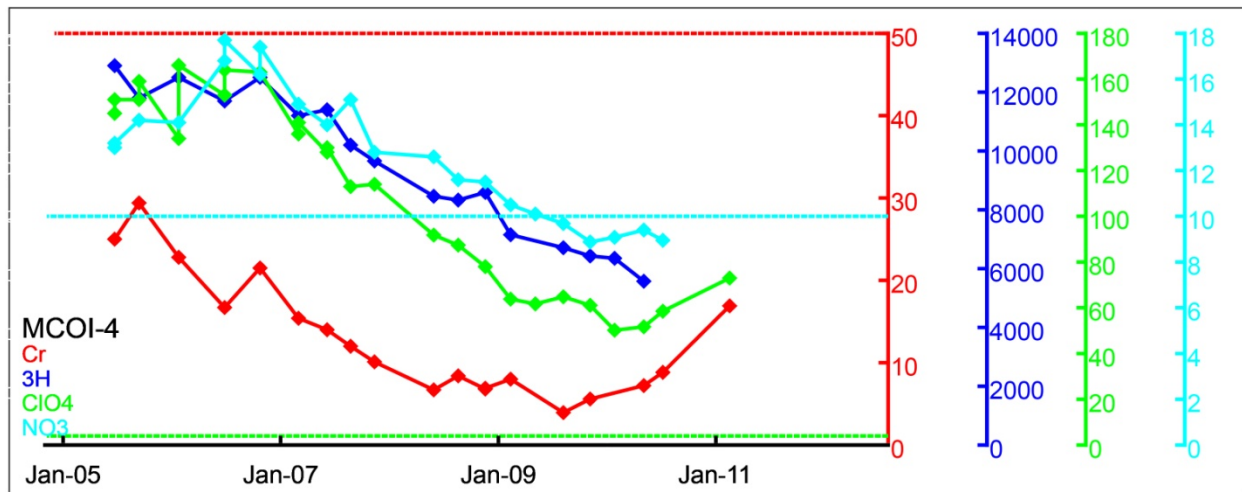


Figure D-3.0-3 (continued) Time-series plots for key constituents in Sandia and Mortandad Canyons groundwater

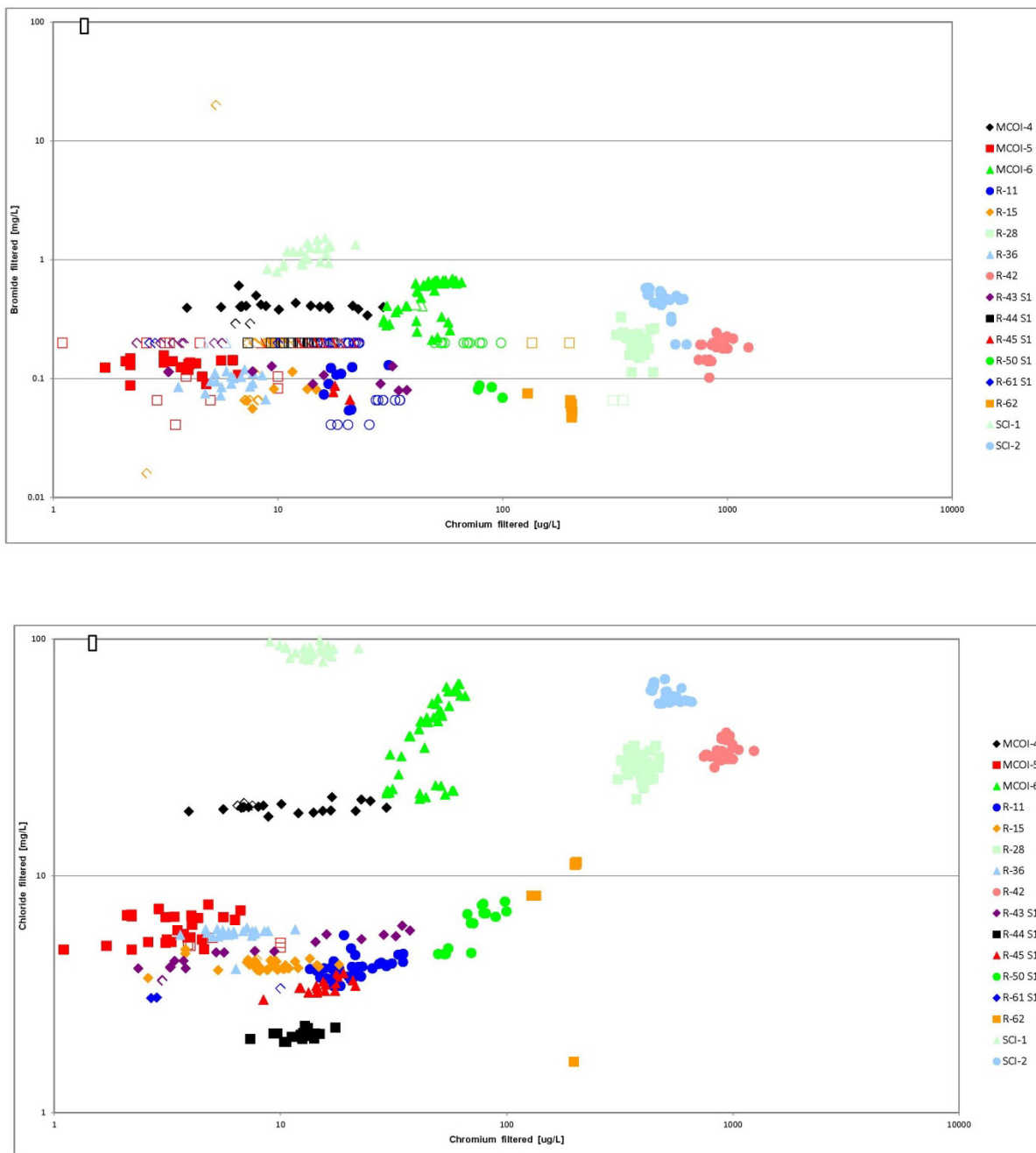


Figure D-3.0-4 Conservative constituents (filtered) versus chromium (filtered) concentrations (log-scale) for groundwaters in contaminated wells in Sandia and Mortandad Canyons

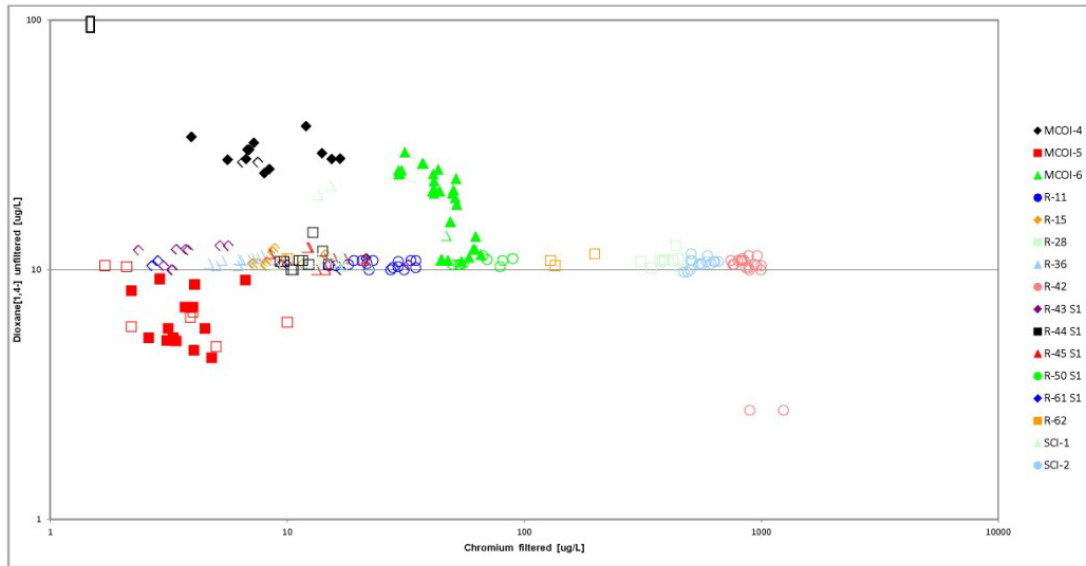
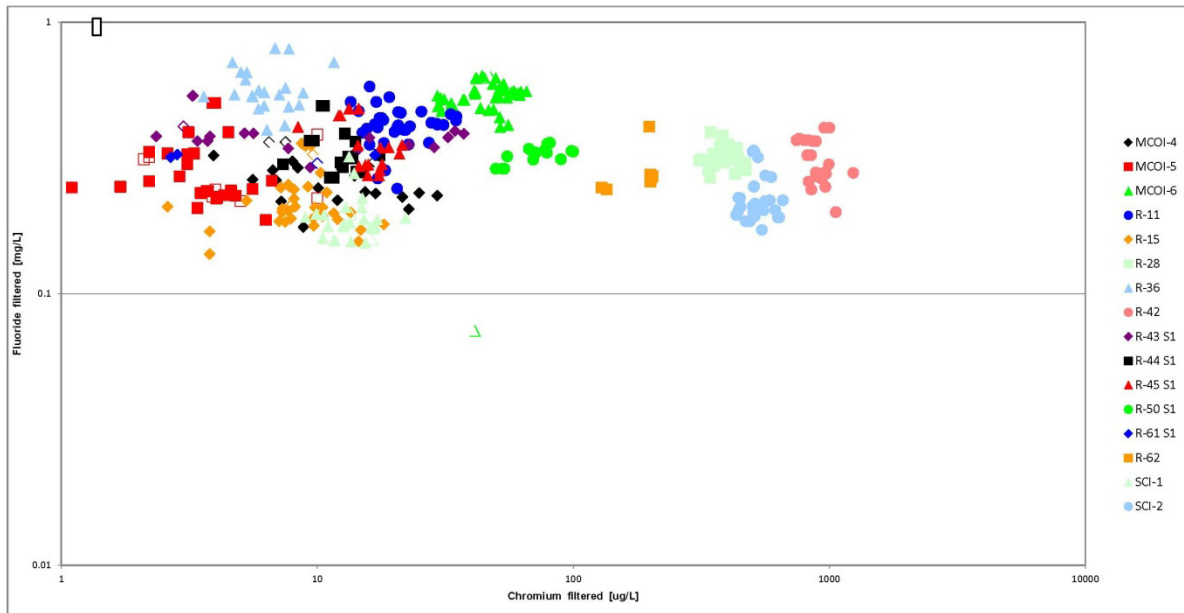


Figure D-3.0-4 (continued) Conservative constituents (filtered) versus chromium (filtered) concentrations (log-scale) for groundwaters in contaminated wells in Sandia and Mortandad Canyons

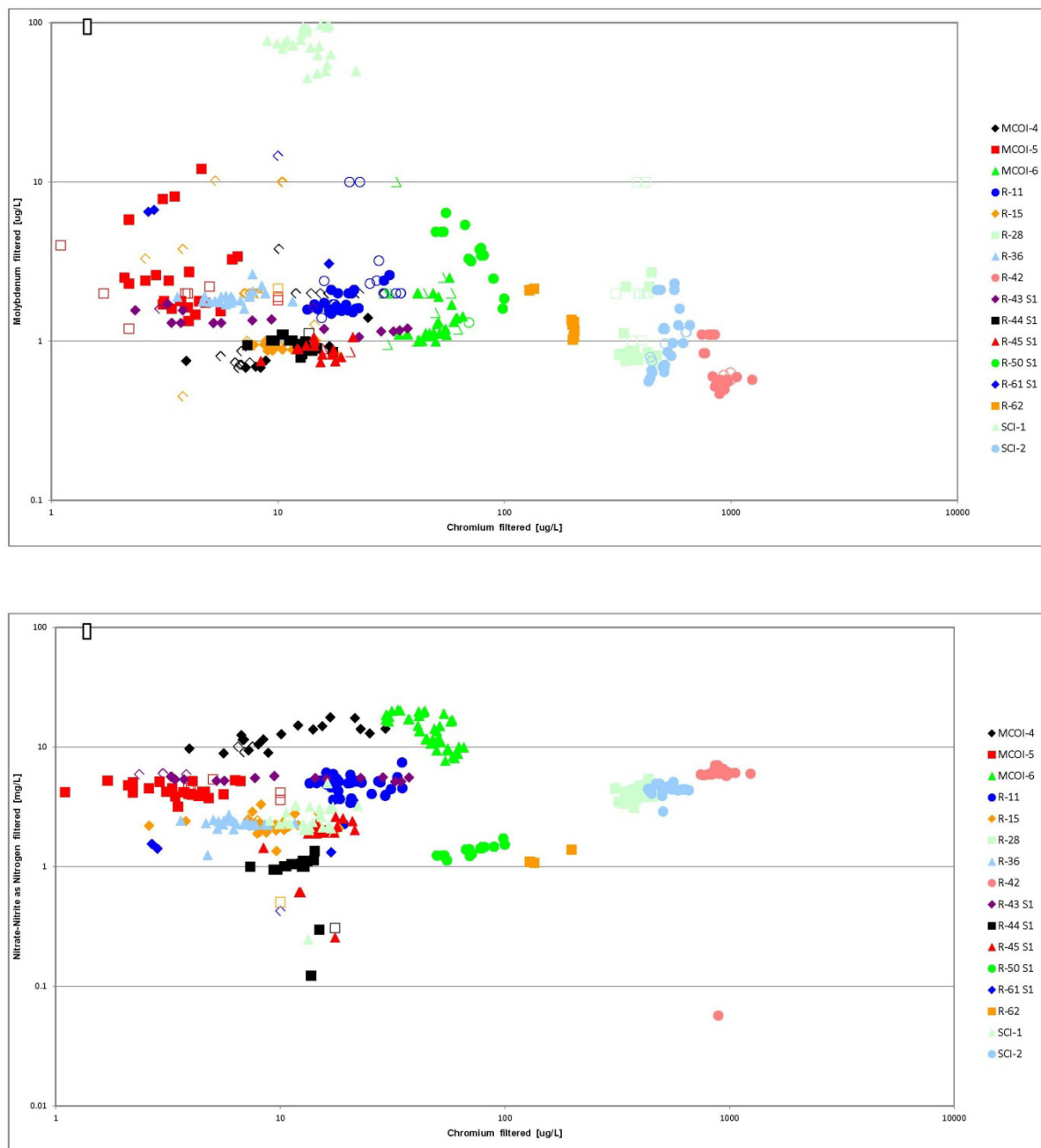


Figure D-3.0-4 (continued) Conservative constituents (filtered) versus chromium (filtered) concentrations (log-scale) for groundwaters in contaminated wells in Sandia and Mortandad Canyons

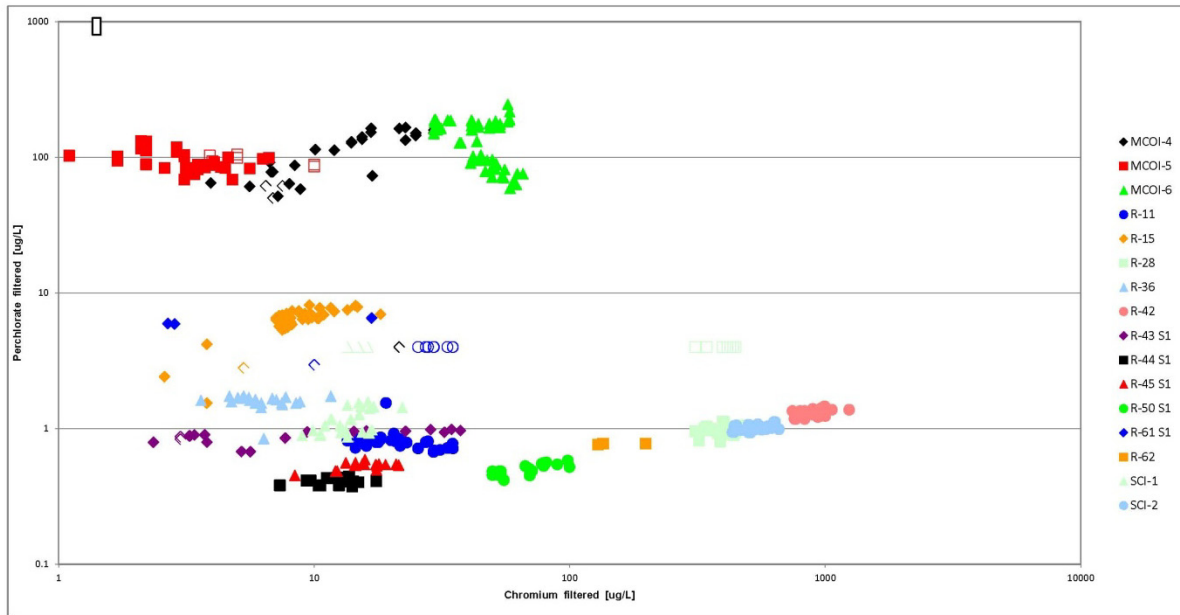
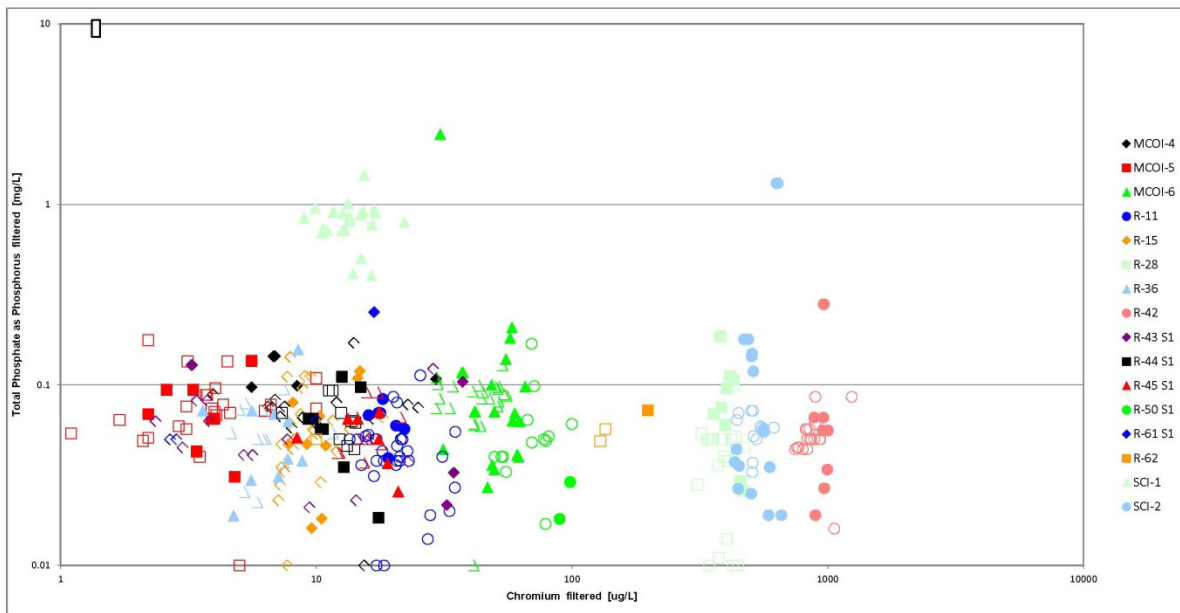


Figure D-3.0-4 (continued) Conservative constituents (filtered) versus chromium (filtered) concentrations (log-scale) for groundwaters in contaminated wells in Sandia and Mortandad Canyons

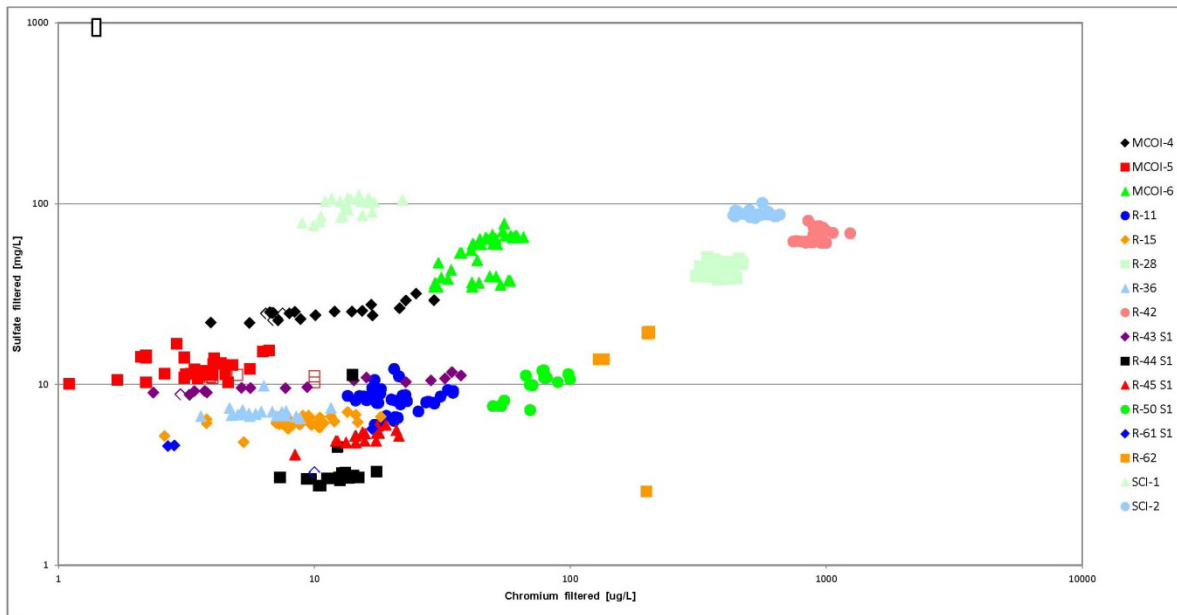


Figure D-3.0-4 (continued) Conservative constituents (filtered) versus chromium (filtered) concentrations (log-scale) for groundwaters in contaminated wells in Sandia and Mortandad Canyons

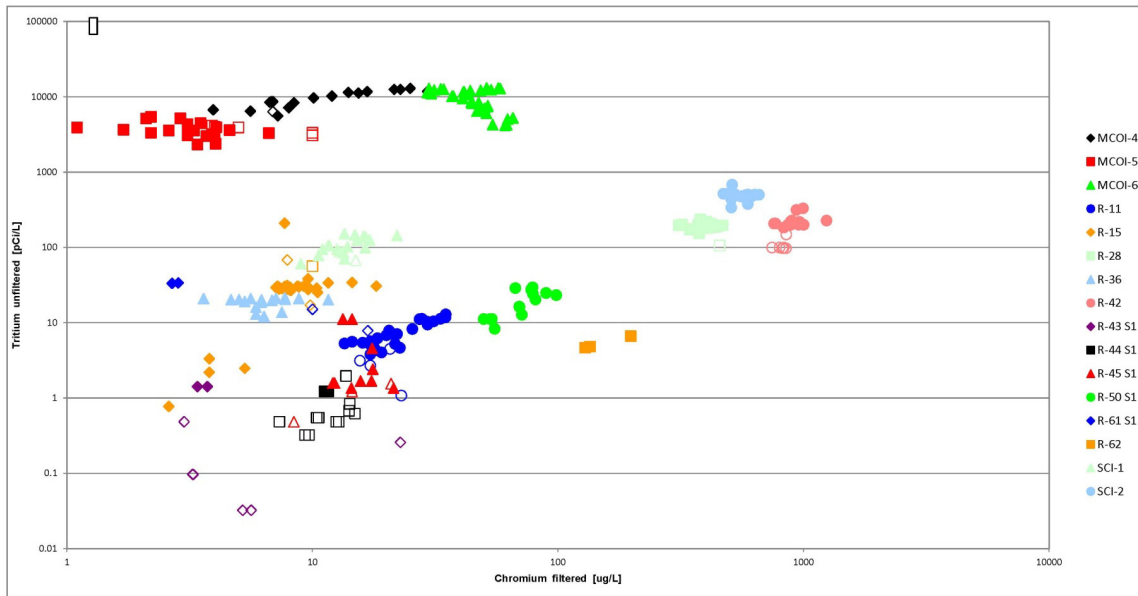


Figure D-3.0-4a Tritium activity (unfiltered) versus chromium (filtered) concentration (log-scale) for groundwaters in contaminated wells in Sandia and Mortandad Canyons

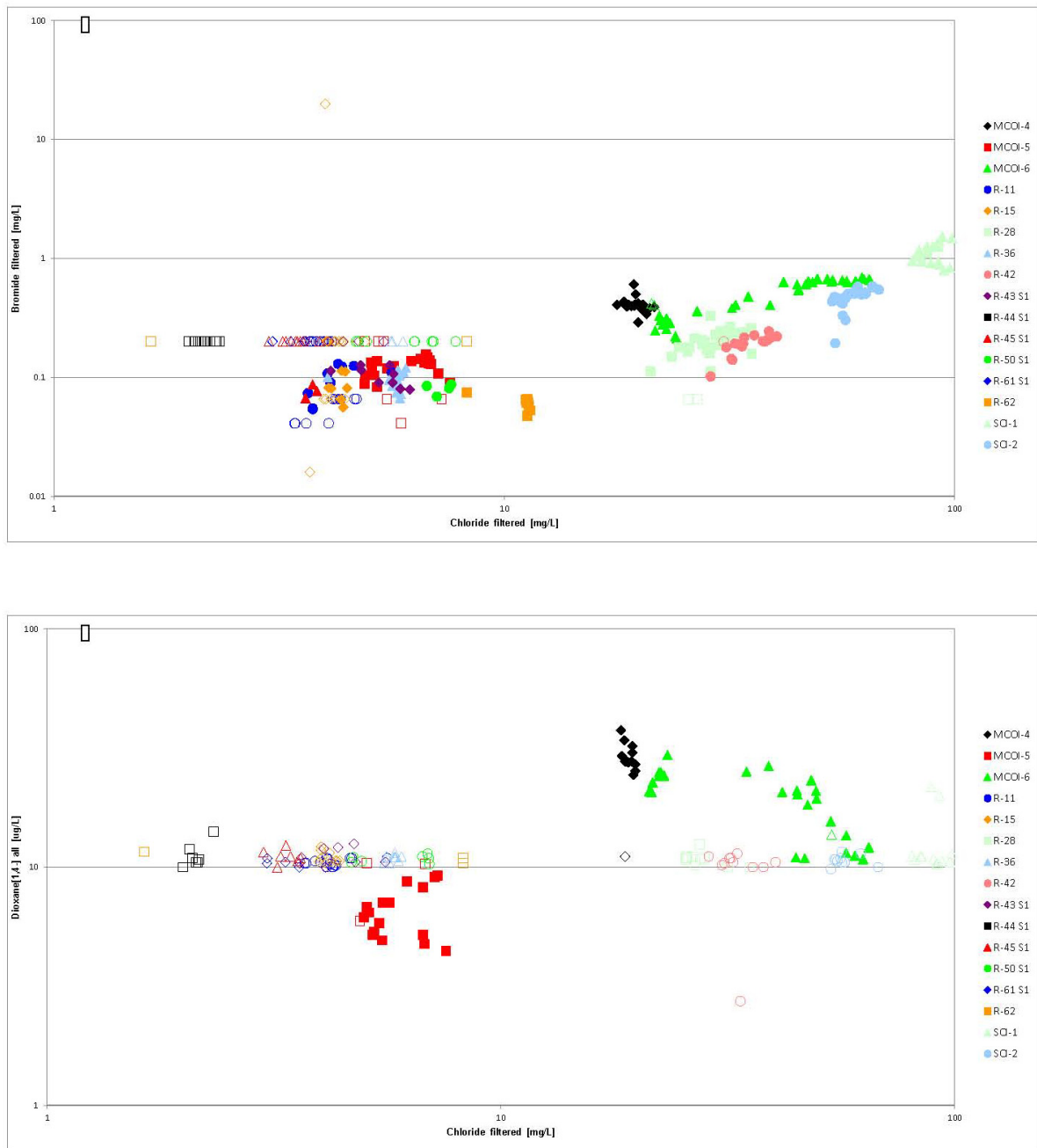


Figure D-3.0-5 Conservative constituents (filtered) versus chloride (filtered) concentrations (log-scale) for groundwaters in contaminated wells in Sandia and Mortandad Canyons

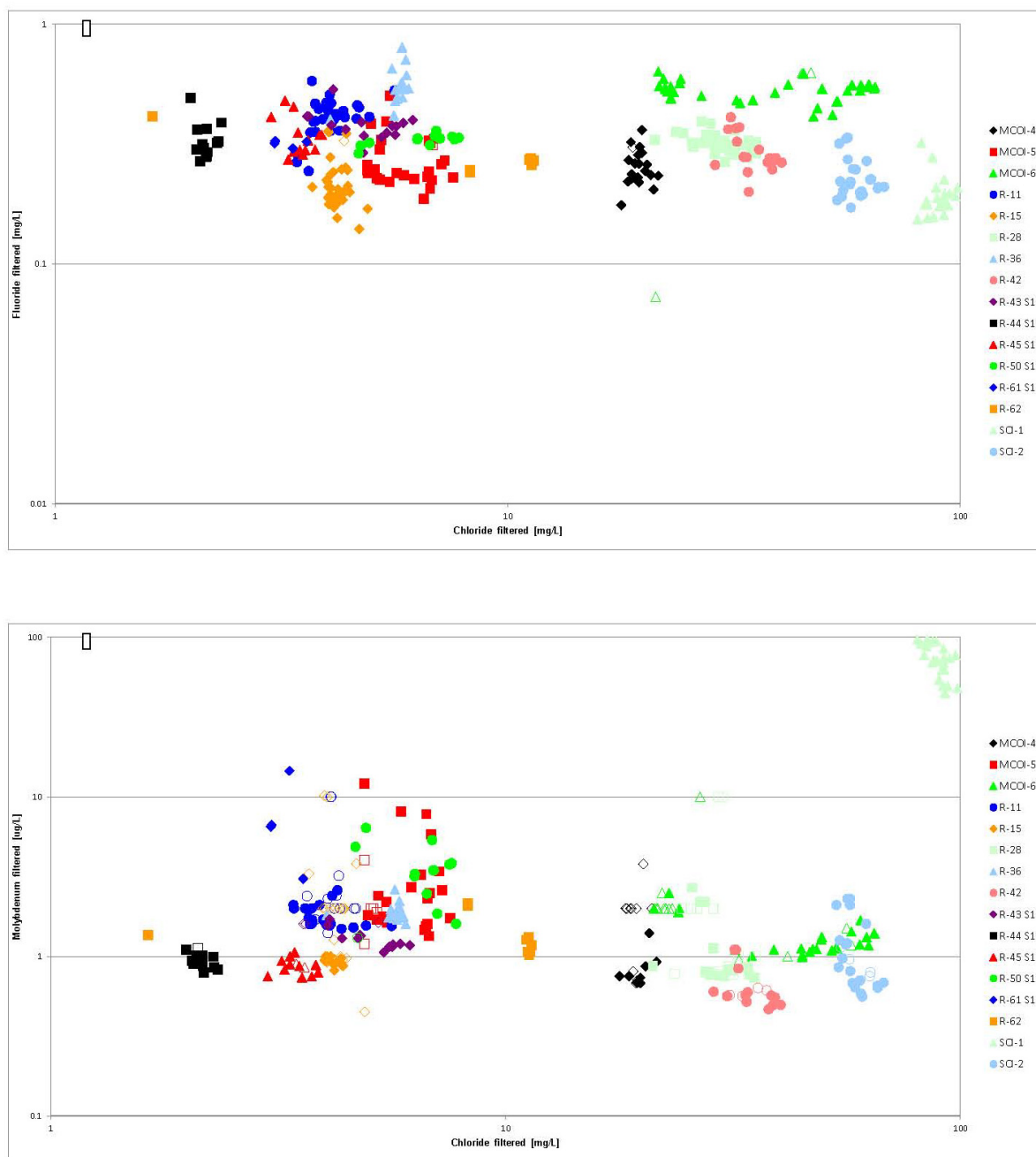


Figure D-3.0-5 (continued) Conservative constituents (filtered) versus chloride (filtered) concentrations (log-scale) for groundwaters in contaminated wells in Sandia and Mortandad Canyons

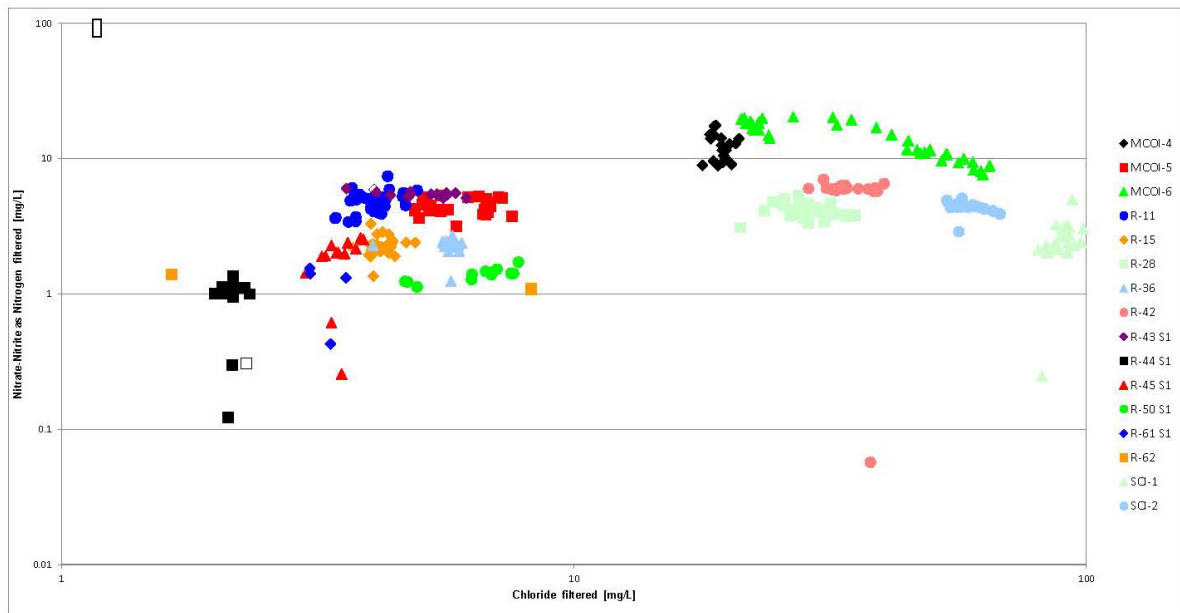
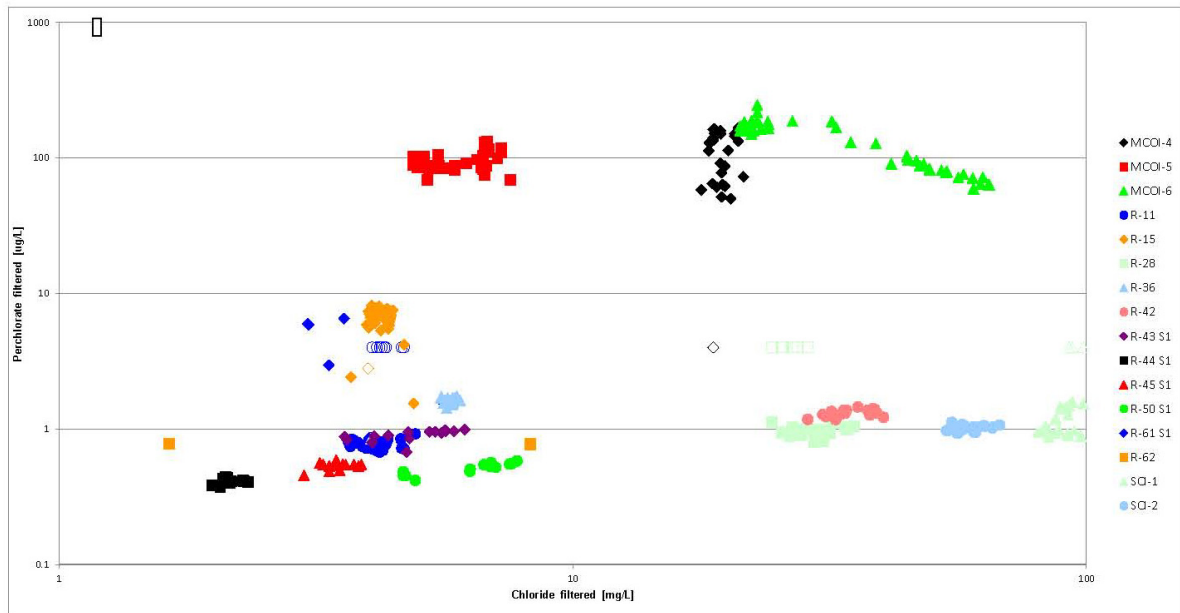


Figure D-3.0-5 (continued) Conservative constituents (filtered) versus chloride (filtered) concentrations (log-scale) for groundwaters in contaminated wells in Sandia and Mortandad Canyons

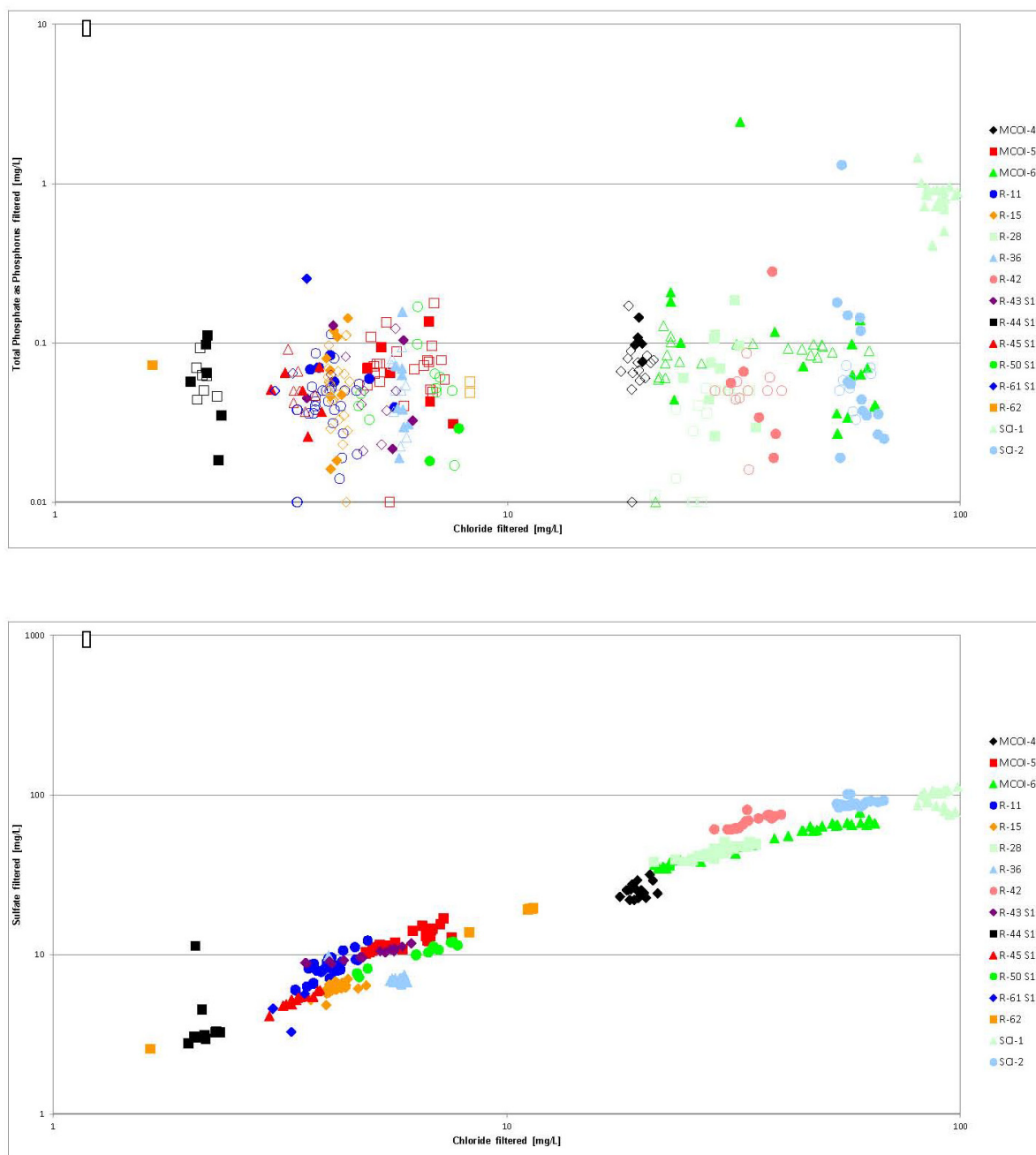


Figure D-3.0-5 (continued) Conservative constituents (filtered) versus chloride (filtered) concentrations (log-scale) for groundwaters in contaminated wells in Sandia and Mortandad Canyons

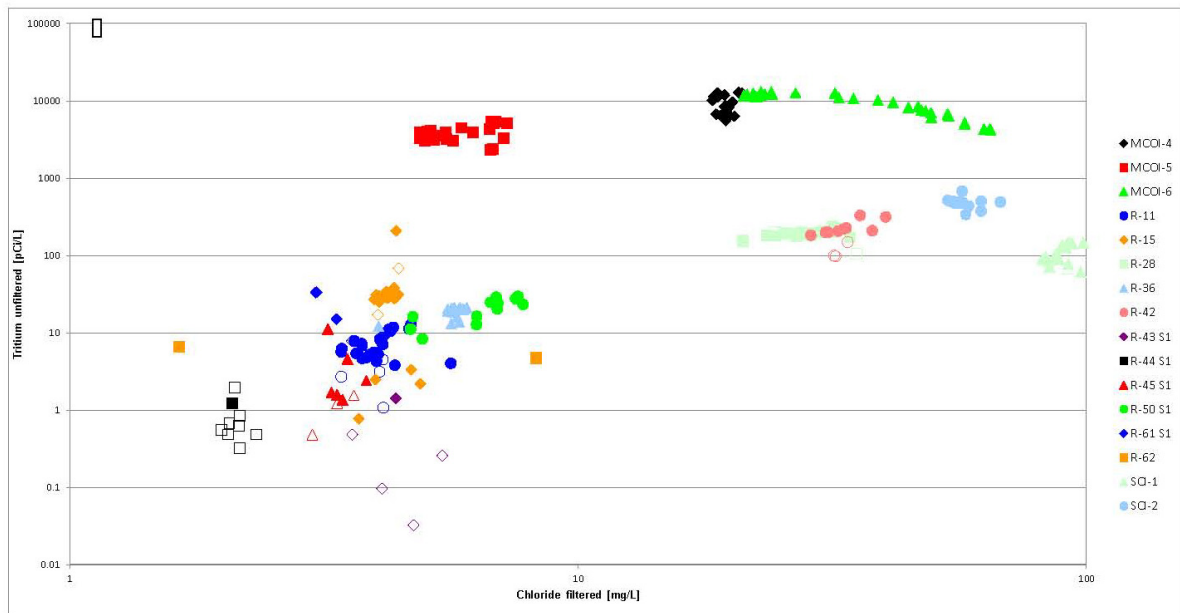


Figure D-3.0-5a Tritium activity (unfiltered) versus chloride (filtered) concentration (log-scale) for groundwaters in contaminated wells in Sandia and Mortandad Canyons

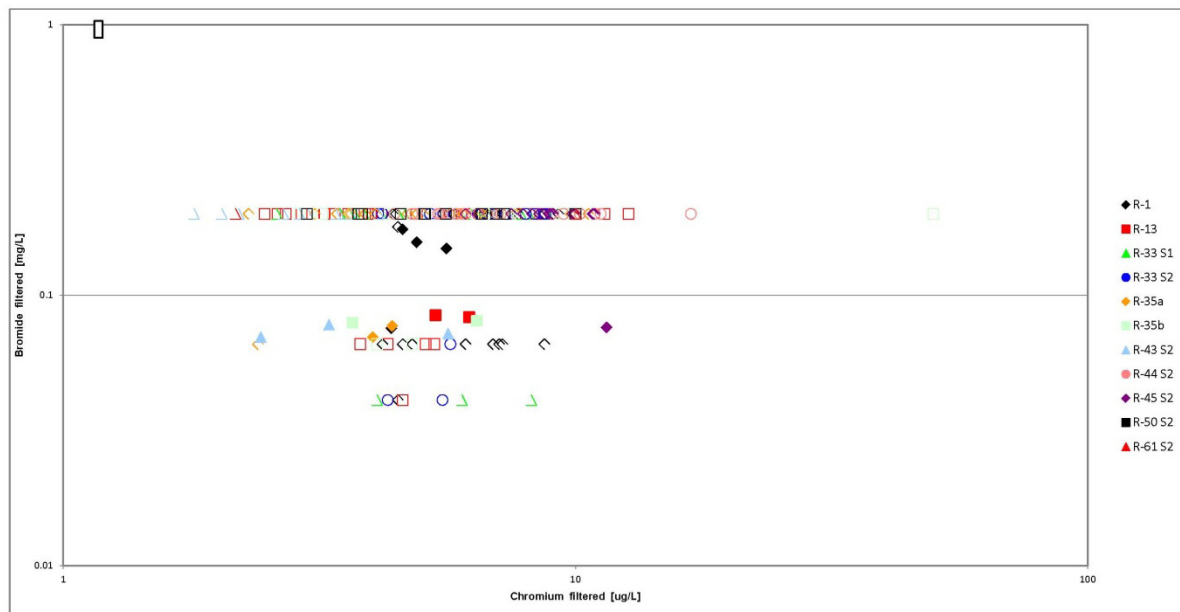


Figure D-3.0-6 Conservative constituents (filtered) versus chromium (filtered) concentrations (log scale) for minimally contaminated wells in Sandia and Mortandad Canyons

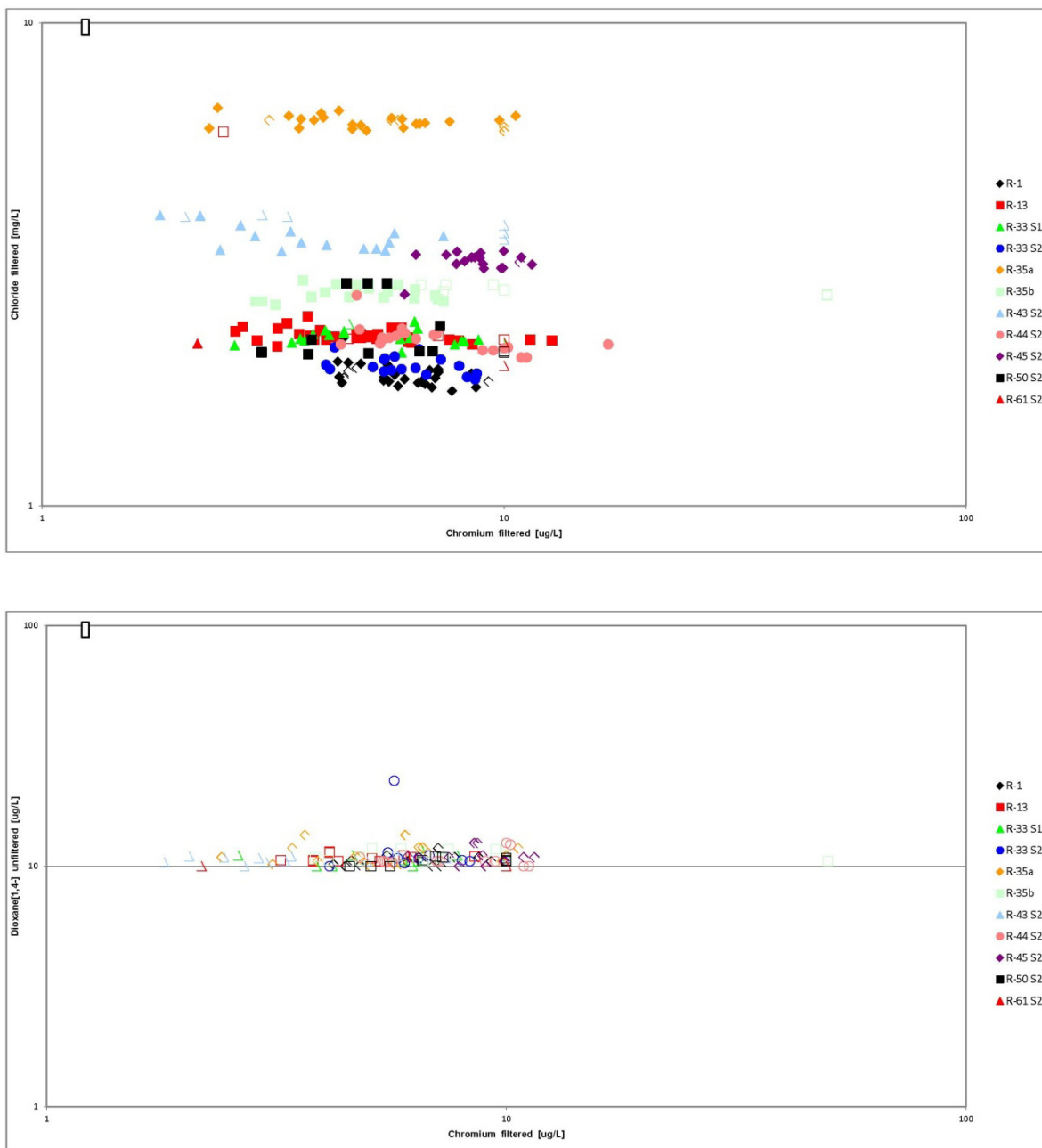


Figure D-3.0-6 (continued) Conservative constituents (filtered) versus chromium (filtered) concentrations (log scale) for minimally contaminated wells in Sandia and Mortandad Canyons

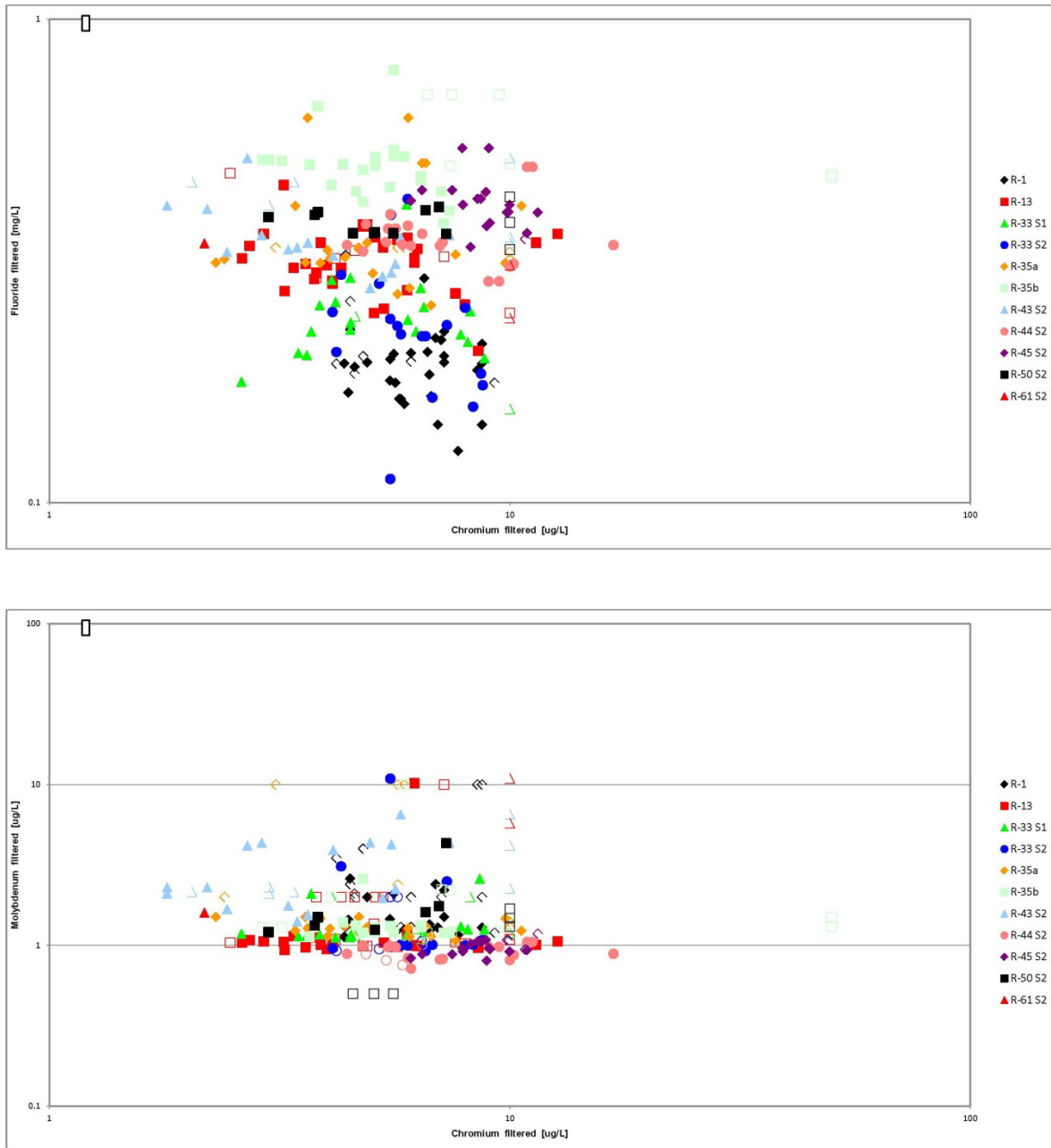


Figure D-3.0-6 (continued) Conservative constituents (filtered) versus chromium (filtered) concentrations (log scale) for minimally contaminated wells in Sandia and Mortandad Canyons

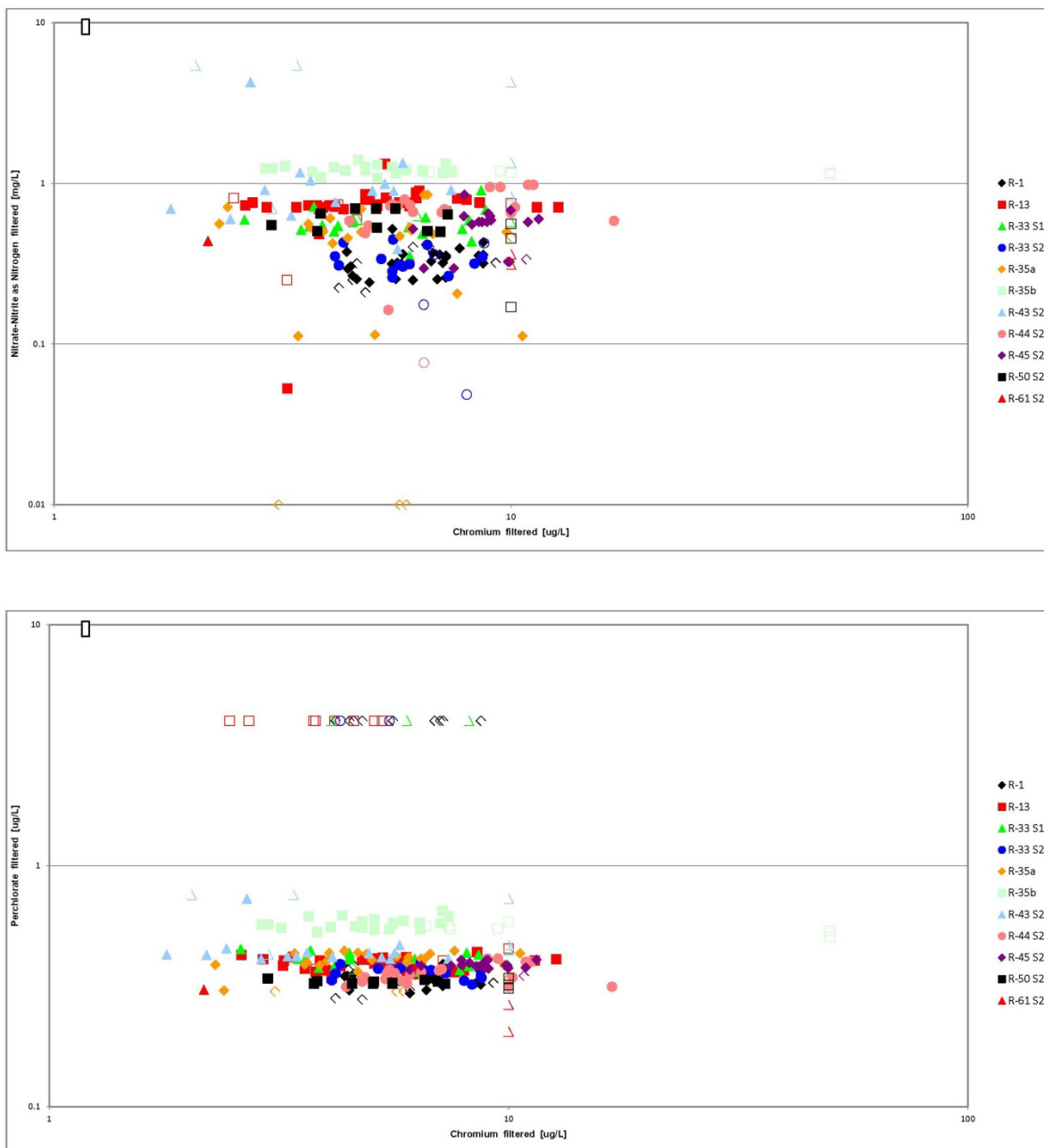


Figure D-3.0-6 (continued) Conservative constituents (filtered) versus chromium (filtered) concentrations (log scale) for minimally contaminated wells in Sandia and Mortandad Canyons

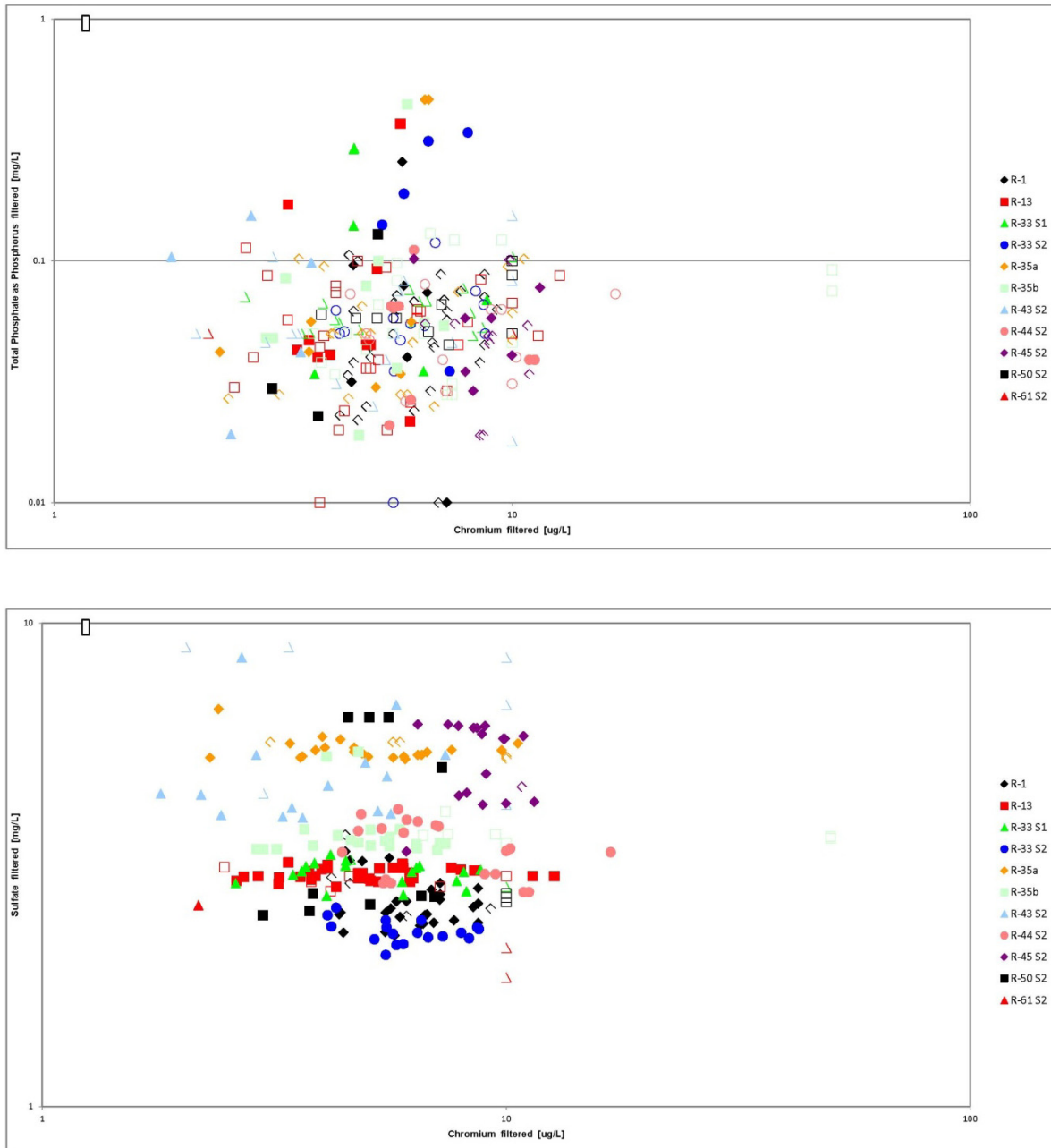


Figure D-3.0-6 (continued) Conservative constituents (filtered) versus chromium (filtered) concentrations (log scale) for minimally contaminated wells in Sandia and Mortandad Canyons

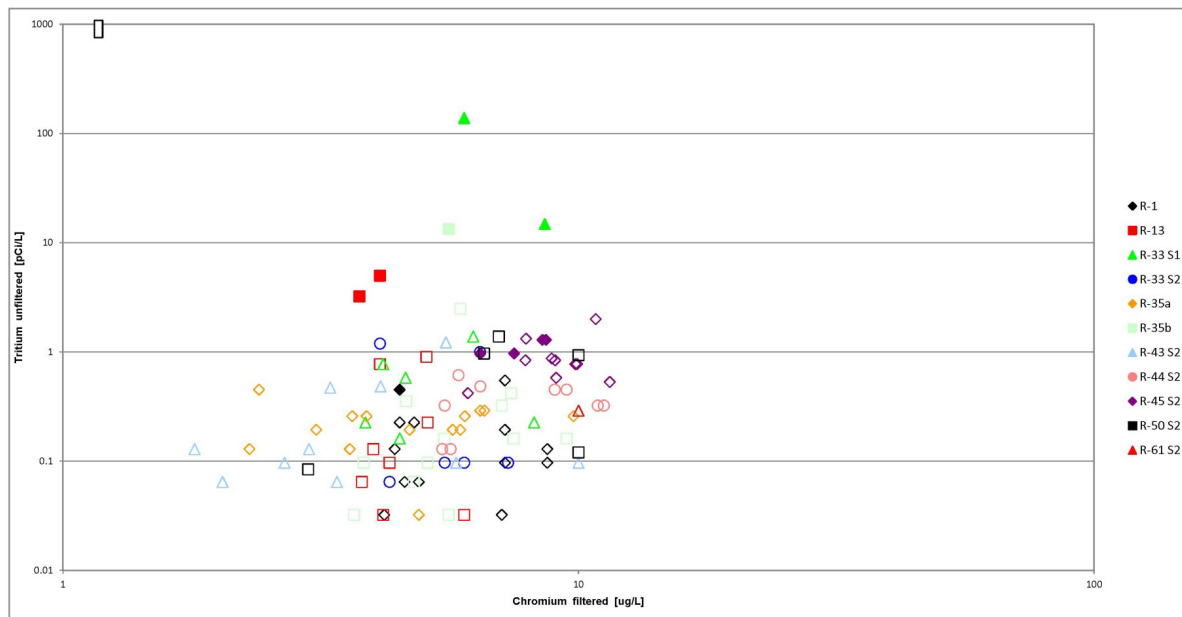


Figure D-3.0-6a Tritium activity (unfiltered) versus chromium (filtered) concentration (log scale) for minimally contaminated wells in Sandia and Mortandad Canyons

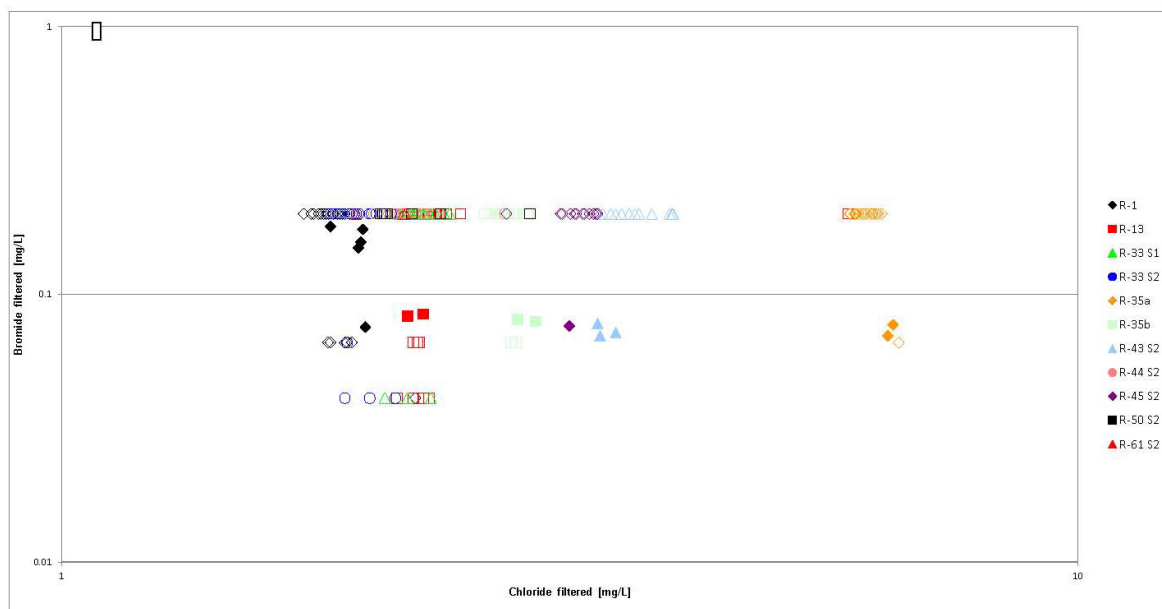


Figure D-3.0-7 Conservative constituents (filtered) versus chloride (filtered) concentrations (log scale) for minimally contaminated wells

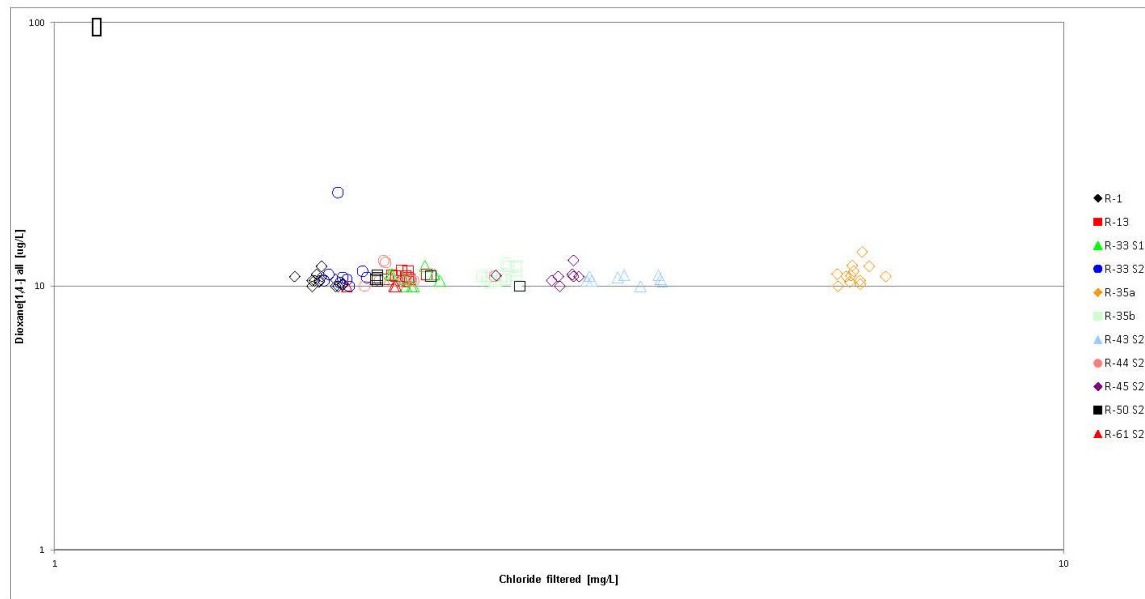
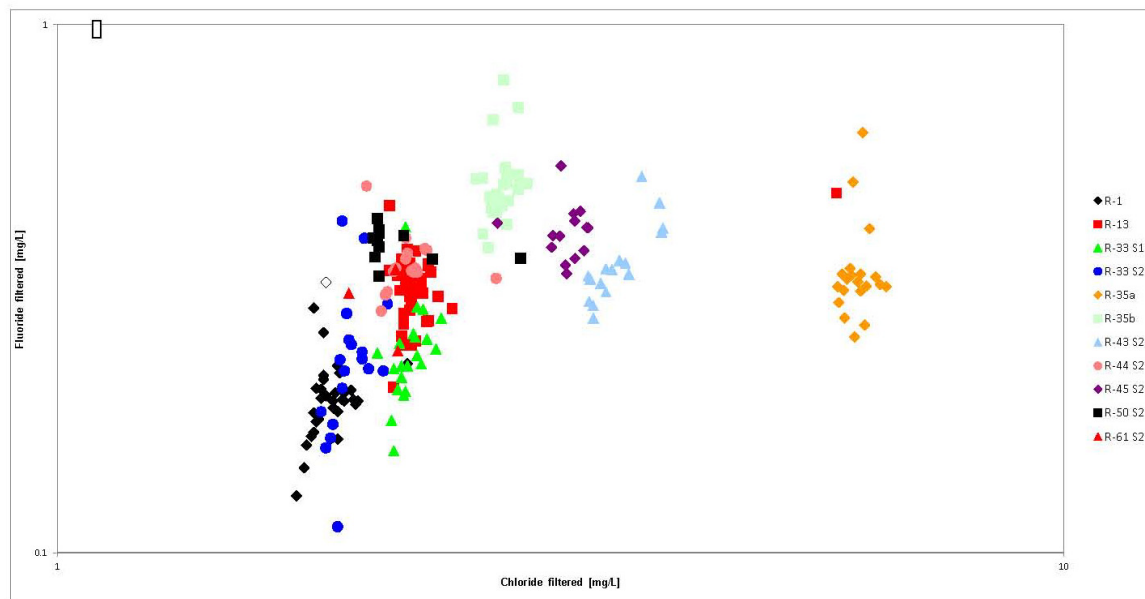


Figure D-3.0-7 (continued) Conservative constituents (filtered) versus chloride (filtered) concentrations (log scale) for minimally contaminated wells

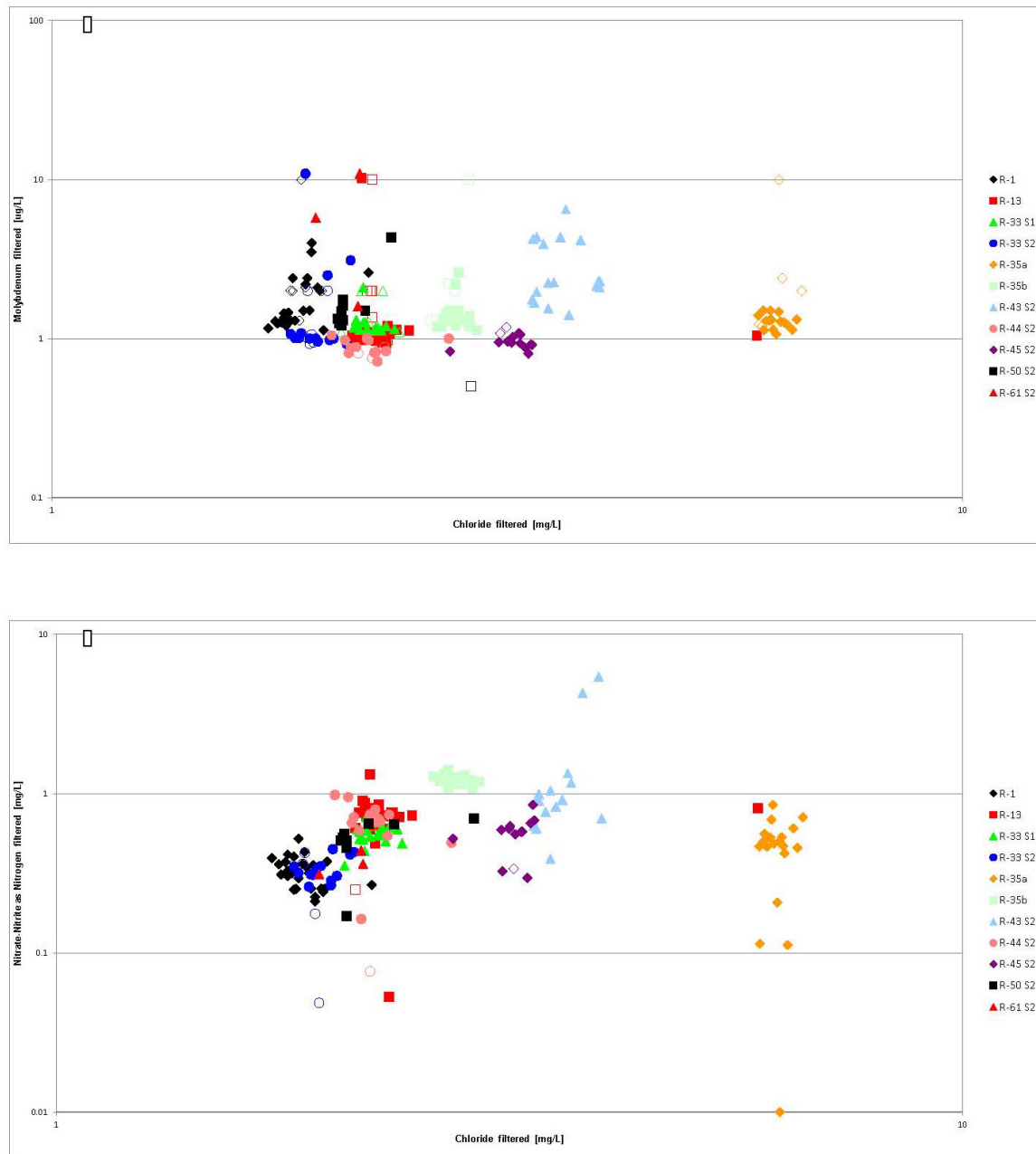


Figure D-3.0-7 (continued) Conservative constituents (filtered) versus chloride (filtered) concentrations (log scale) for minimally contaminated wells

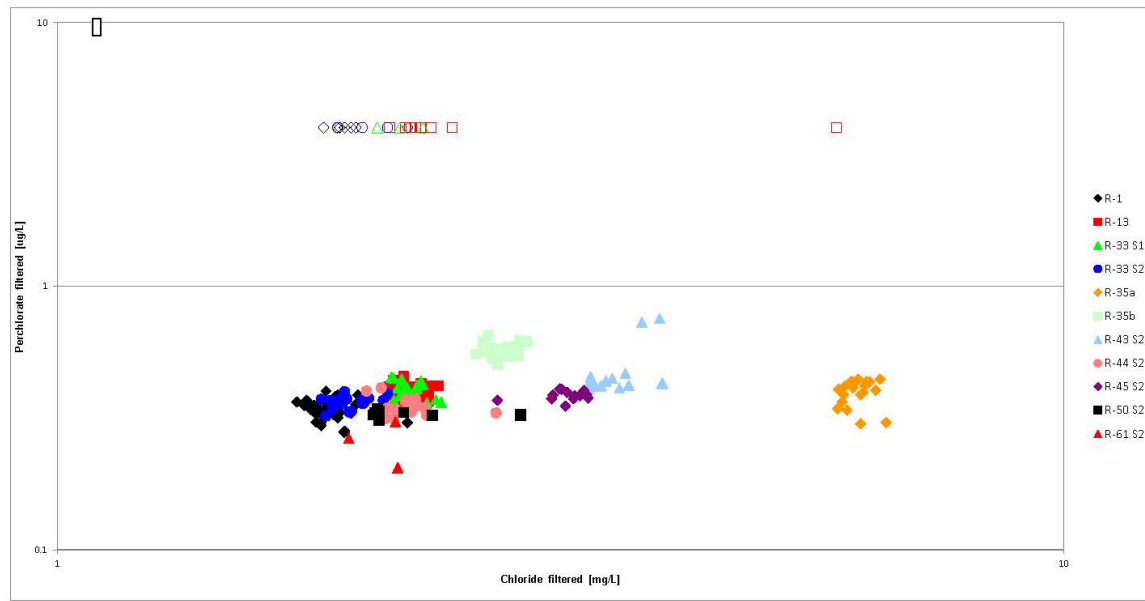
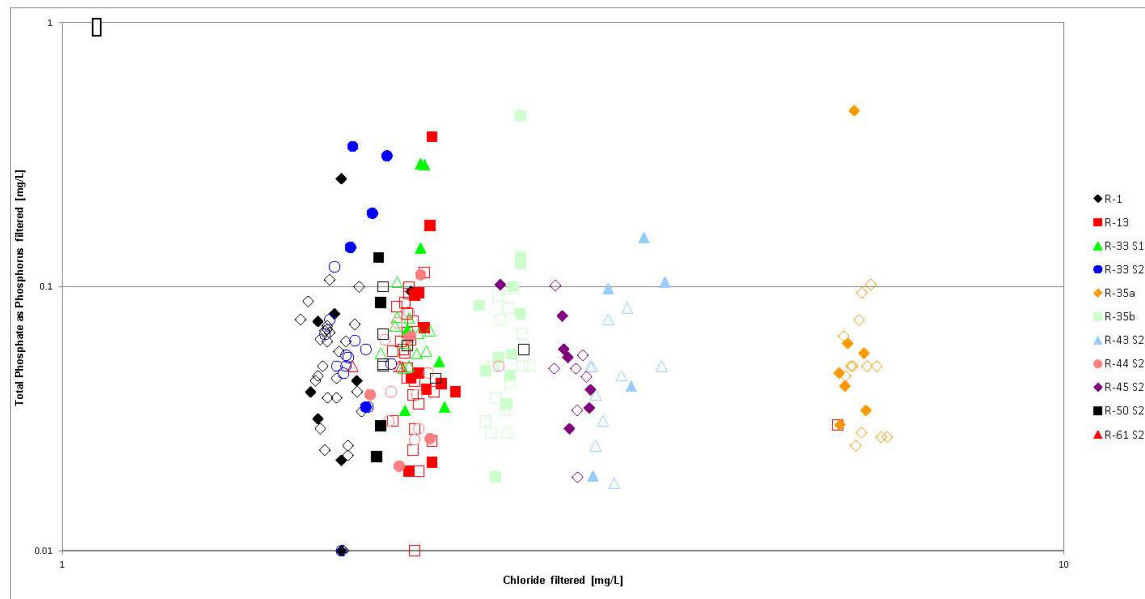


Figure D-3.0-7 (continued) Conservative constituents (filtered) versus chloride (filtered) concentrations (log scale) for minimally contaminated wells

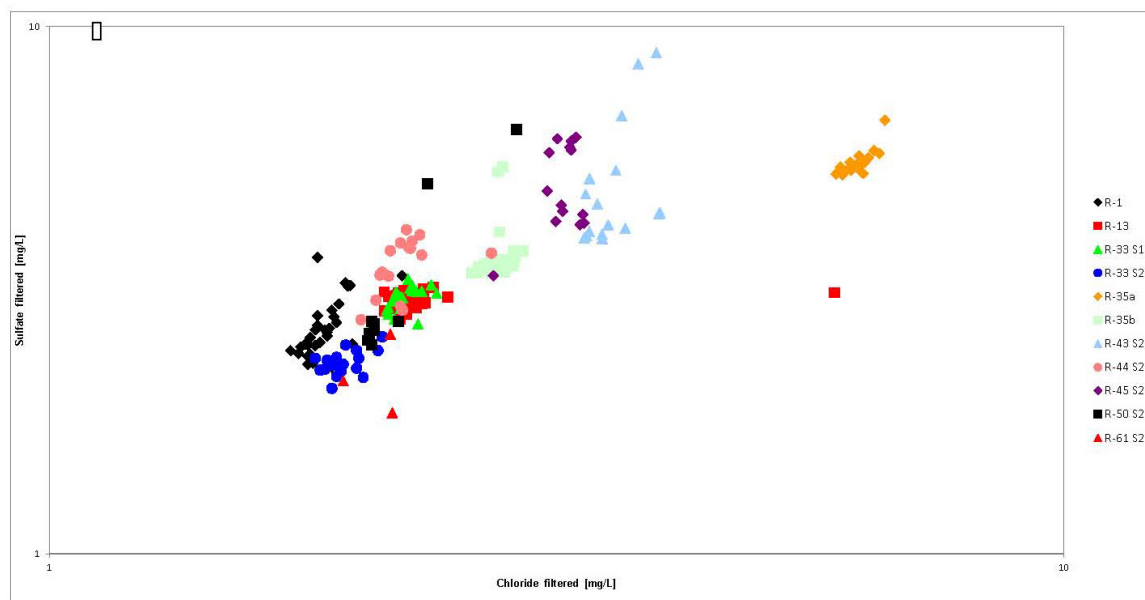


Figure D-3.0-7 (continued) Conservative constituents (filtered) versus chloride (filtered) concentrations (log scale) for minimally contaminated wells

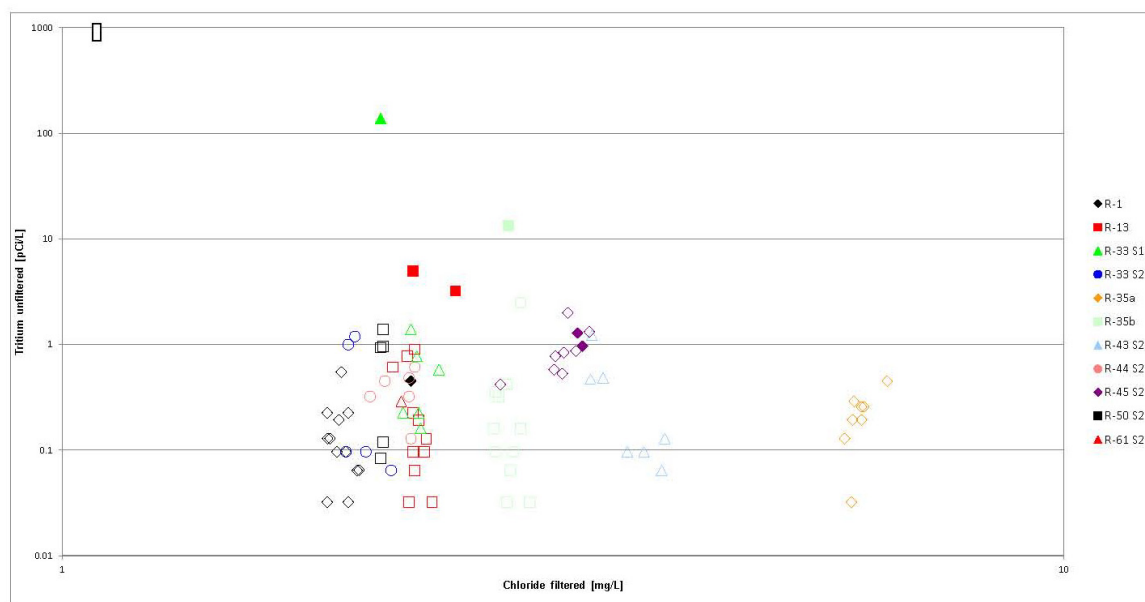


Figure D-3.0-7a Tritium activity (unfiltered) versus chloride (filtered) concentration (log scale) for minimally contaminated wells

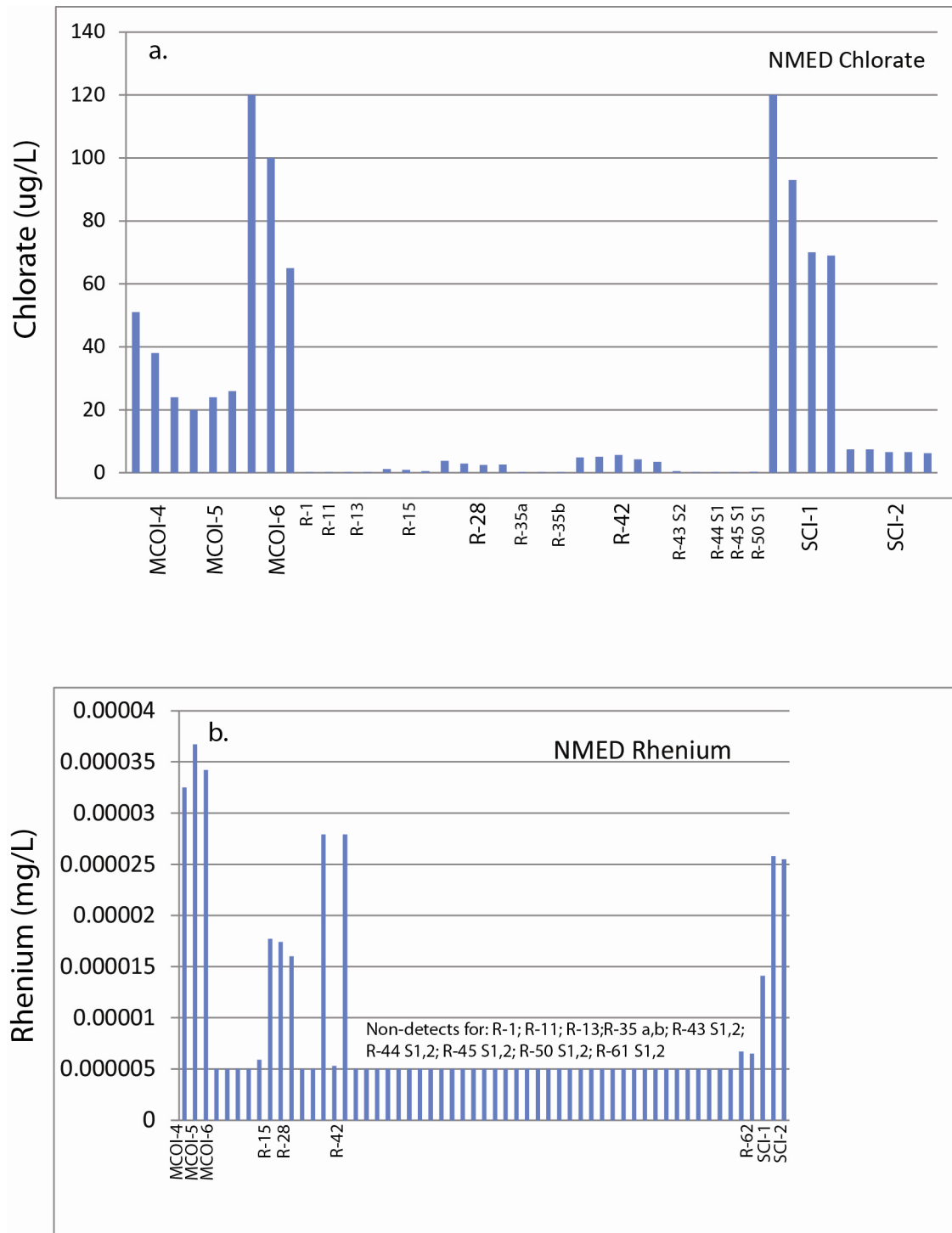


Figure D-3.0-8(a,b) Histogram showing (a) chlorate concentrations and (b) rhenium concentrations in wells within the Chromium Investigation monitoring group based on NMED data

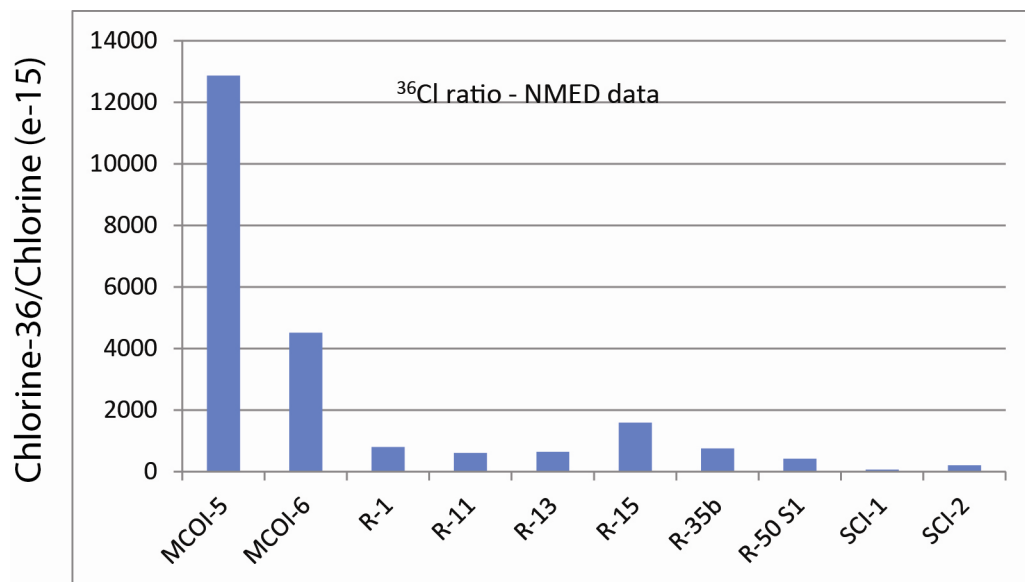


Figure D-3.0-8(c) Histogram of chlorine-36/chlorine (e-15) for selected wells in the Chromium Investigation monitoring group based on NMED data

Table D-2.2-1
Summary of Average Concentrations of Select Inorganic Chemicals
in Sandia Canyon Reach S-5C, S-5EC, and S-5E Sediment Samples

Reach	Arsenic		Chromium		Zinc		Lead	
	Fine Facies	Coarse Facies	Fine Facies	Coarse Facies	Fine Facies	Coarse Facies	Fine Facies	Coarse Facies
	Average	Average	Average	Average	Average	Average	Average	Average
BV	3.98		10.5		60.2		19.7	
S-5C	—*	—	27.1	4.3	50.9	23.2	24.6	6.2
S-5EC	—	—	21.0	4.3	54.0	24.4	19.4	13.3
S-5E	—	—	13.8	3.4	—	—	15.9	6.1

Note: All units are in mg/kg.

* — = Not a COPC in reach (not detected or no detects >BV).

Table D-2.2-2
Summary of Average Concentrations of PCBs
in Sandia Canyon Reach S-5C, S-5EC, and S-5E Sediment Samples

Reach	Aroclor-1254						Aroclor-1260					
	Fine Facies			Coarse Facies			Fine Facies			Coarse Facies		
	Upper Bound on Mean	Mid-Point of Range	Lower Bound on Mean	Upper Bound on Mean	Mid-Point of Range	Lower Bound on Mean	Upper Bound on Mean	Mid-Point of Range	Lower Bound on Mean	Upper Bound on Mean	Mid-Point of Range	Lower Bound on Mean
S-5C	0.047	0.036	0.025	0.032	0.019	0.006	0.072	0.066	0.060	0.024	0.015	0.007
S-5EC	0.026	0.024	0.022	0.014	0.013	0.010	0.035	0.035	0.035	0.009	0.009	0.009
S-5E	0.012	0.010	0.009	0.004	0.003	0.002	0.021	0.021	0.021	0.006	0.006	0.006

Note: All units are in mg/kg.

Table D-2.2-3
Summary of Average Concentrations of Benzo(a)pyrene
in Sandia Canyon Reach S-5C, S-5EC, and S-5E Sediment Samples

Reach	Benzo(a)pyrene					
	Fine Facies			Coarse Facies		
	Upper Bound on Mean	Mid-Point of Range	Lower Bound on Mean	Upper Bound on Mean	Mid-Point of Range	Lower Bound on Mean
S-5C	0.655	0.329	0.003	0.005	0.004	0.003
S-5EC	0.019	0.017	0.015	0.002	0.001	0.0004
S-5E	—*	—	—	—	—	—

Note: All units are in mg/kg.

*— = Not a COPC in reach (not detected).

Table D-2.2-4
Summary of Average Concentrations of TPH-DRO
in Sandia Canyon Reach S-5C, S-5EC, and S-5E Sediment Samples

Reach	TPH-DRO					
	Fine Facies			Coarse Facies		
	Upper Bound on Mean	Mid-Point of Range	Lower Bound on Mean	Upper Bound on Mean	Mid-Point of Range	Lower Bound on Mean
S-5C	49	48	48	3	2	0
S-5EC	28	26	23	6	3	0
S-5E	44	44	44	14	14	14

Note: All units are in mg/kg.

Table D-2.3-1
Estimated Inventory of Select COPCs in Sandia Canyon Reach S-5EC

Geomorphic Unit	Sediment Facies	Area (m2)	Average Thickness (m)	Estimated Volume (m3)	Portion Non-gravel	Density (g/cm3)	Chromium				Aroclor-1254			Aroclor-1260		
							Average Concentration (mg/kg)	Average Concentration in Excess of Background (mg/kg)	Inventory (kg)	% of Total in Reach	Average Concentration (mg/kg)	Inventory (kg)	% of Total in Reach	Average Concentration (mg/kg)	Inventory (kg)	% of Total in Reach
Reach S-5EC																
c1	Coarse	955	0.50	478	0.94	1.23	5.52	0	0.0	0%	0.0385	0.0212	21%	0.0208	0.0115	10%
c2	Coarse	5307	0.21	1114	0.98	1.23	3.34	0	0.0	0%	0.0017	0.0022	2%	0.0023	0.0031	3%
c2f	Coarse	1415	0.62	877	0.97	1.23	4.85	0	0.0	0%	0.0024	0.0025	3%	0.0064	0.0067	6%
c3	Coarse	256	0.26	67	0.95	1.23	1.06	0	0.0	0%	0.0017	0.0001	0%	0.0017	0.0001	0%
f1	Coarse	3608	0.02	72	0.98	1.23	1.06	0	0.0	0%	0.0017	0.0001	0%	0.0017	0.0001	0%
Coarse Facies Subtotal			m³	2608				kg	0.0	0%	kg	0.0263	26%	kg	0.0216	19%
			m³/km	7903				kg/km	0		kg/km	0.0797		kg/km	0.0653	
c1	Fine	955	0.07	67	0.99	1.04	29.6	24.0	1.7	3%	0.0351	0.0024	2%	0.0512	0.0035	3%
c2	Fine	5307	0.27	1433	1.00	1.04	29.6	24.0	35.7	72%	0.0351	0.0524	51%	0.0512	0.0762	64%
c2f	Fine	1415	0.12	170	0.99	1.04	29.6	24.0	4.2	8%	0.0351	0.0061	6%	0.0512	0.0089	8%
c3	Fine	256	0.17	44	0.99	1.04	3.5	0.0	0.0	0%	0.0017	0.0001	0%	0.0032	0.0001	0%
f1	Fine	3608	0.23	830	0.98	1.04	15.3	9.7	8.2	16%	0.0167	0.0142	14%	0.0032	0.0027	2%
f2	Fine	2264	0.07	158	0.98	1.04	3.52	0.0	0.0	0%	0.0017	0.0003	0%	0.0032	0.0005	0%
Fine Facies Subtotal			m³	2701				kg	49.8	100%	kg	0.0754	74%	kg	0.0921	78%
			m³/km	8186				kg/km	151		kg/km	0.2285		kg/km	0.2790	
Reach Total			m³	5309	0.98	1.13	13.86	kg	49.8	100%	kg	0.1017	100%	kg	0.1136	100%
			m³/km	16089				kg/km	151		kg/km	0.3082		kg/km	0.3444	

Table D-2.3-2
Inventory Estimates For Select COPCs in Sandia Canyon Sediment Deposits

Reach	Distance Above Rio Grande, Upstream End (km)	Length (km)	Sampling Status	Chromium				Aroclor-1242				Aroclor-1248				Aroclor-1254				Aroclor-1260			
				Coarse Facies Inventory (kg)	Fine Facies Inventory (kg)	Total Inventory (kg)	Percent of Total Inventory	Coarse Facies Inventory (kg)	Fine Facies Inventory (kg)	Total Inventory (kg)	Percent of Total Inventory	Coarse Facies Inventory (kg)	Fine Facies Inventory (kg)	Total Inventory (kg)	Percent of Total Inventory	Coarse Facies Inventory (kg)	Fine Facies Inventory (kg)	Total Inventory (kg)	Percent of Total Inventory	Coarse Facies Inventory (kg)	Fine Facies Inventory (kg)	Total Inventory (kg)	Percent of Total Inventory
Outfall 01A001 to S-1S	16.22	0.06	Not sampled	0.6	2	2	0.01%	0	0	0	0%	0	0	0	0%	0.00	0.00	0.01	0.0%	0.01	0.04	0.05	0.2%
S-1S	16.16	0.20	Sampled	2	7	9	0.05%	0	0	0	0%	0	0	0	0%	0.01	0.01	0.02	0.1%	0.03	0.13	0.16	0.5%
S-1N	16.16	0.20	Sampled	0.1	0.4	0.5	0.003%	0	0	0	0%	0.0002	0.01	0.01	0.2%	0.00	0.01	0.01	0.0%	0.01	0.01	0.02	0.1%
S-2W	15.96	0.03	Sampled	1	1	2	0.01%	0	0	0	0%	0.004	0.002	0.01	0.2%	0.00	0.00	0.01	0.0%	0.01	0.00	0.01	0.02%
culvert, landfill bridge	15.93	0.15	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
S-2	15.78	0.68	Sampled	5,361	9,773	15,134	85.0%	1.5	4.0	5.5	88%	0.9	2.4	3.3	100%	9.68	21.44	31.12	88%	6.84	17.61	24.44	81%
S-2 to S-3W	15.10	0.76	Not sampled	49	90	139	0.8%	0	0	0	0%	0	0	0	0%	0.03	0.07	0.10	0.3%	0.04	0.09	0.13	0.4%
S-3W	14.34	0.21	Sampled	14	25	38	0.2%	0	0	0	0%	0	0	0	0%	0.01	0.02	0.03	0.1%	0.01	0.03	0.04	0.1%
S-3W to S-3E	14.13	1.35	Not sampled	63	188	251	1.4%	0	0	0	0%	0	0	0	0%	0.07	0.10	0.16	0.5%	0.08	0.15	0.22	0.7%
S-3E	12.78	0.20	Sampled	6	32	38	0.2%	0	0	0	0%	0	0	0	0%	0.01	0.01	0.02	0.1%	0.01	0.02	0.03	0.1%
S-3E to S-4W	12.58	1.16	Not sampled	78	211	290	1.6%	0	0	0	0%	0	0	0	0%	0.08	0.17	0.25	0.7%	0.08	0.22	0.29	1.0%
S-4W	11.42	0.23	Sampled	25	47	71	0.4%	0	0	0	0%	0	0	0	0%	0.02	0.06	0.07	0.2%	0.02	0.06	0.08	0.3%
S-4W to S-4E	11.19	1.15	Not sampled	61	682	744	4.2%	0	0	0	0%	0	0	0	0%	0.07	1.01	1.09	3.1%	0.09	1.45	1.53	5.1%
S-4E	10.04	0.31	Sampled	0	305	305	1.7%	0	0	0	0%	0	0	0	0%	0.02	0.47	0.49	1.4%	0.02	0.69	0.72	2.4%
S-4E to S-5C	9.73	0.65	Not sampled	0	428	428	2.4%	0.1	0.1	0.2	2.7%	0	0	0	0%	0.09	0.68	0.77	2.2%	0.09	1.06	1.15	3.8%
S-5C	9.08	0.24	Sampled	0	80	80	0.4%	0.1	0.1	0.1	2.0%	0	0	0	0%	0.05	0.14	0.19	0.5%	0.04	0.25	0.29	1.0%
S-5C to S-5EC	8.84	0.10	Not sampled	0	24	24	0.1%	0.0003	0.01	0.01	0.2%	0	0	0	0%	0.01	0.04	0.05	0.2%	0.01	0.06	0.06	0.2%
S-5EC	8.74	0.33	Sampled	0	50	50	0.3%	0	0	0	0%	0	0	0	0%	0.03	0.08	0.10	0.3%	0.02	0.11	0.13	0.4%
S-5EC to S-5E	8.41	1.71	Not sampled	0	155	155	0.9%	0	0.02	0.02	0.3%	0	0	0	0%	0.08	0.23	0.31	0.9%	0.06	0.36	0.42	1.4%
S-5E	6.70	0.23	Sampled	0	7	7	0.04%	0.001	0.01	0.01	0.1%	0	0	0	0%	0.00	0.01	0.01	0.03%	0.01	0.02	0.02	0.1%
S-5E to S-6W	6.47	3.05	Not sampled	0	46	46	0.3%	0.4	0.04	0.4	6.7%	0	0	0	0%	0.33	0.06	0.39	1.1%	0.28	0.12	0.40	1.3%
S-6W	3.42	0.20	Sampled	0	0	0	0.00%	0	0	0	0%	0	0	0	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
S-6W to S-6E	3.22	2.77	Not sampled	0	0	0	0.00%	0	0	0	0%	0	0	0	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
S-6E	0.45	0.20	Sampled	0	0	0	0.00%	0	0	0	0%	0	0	0	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
S-6E to Rio Grande	0.25	0.25	Not sampled	0	0	0	0.00%	0	0	0	0%	0	0	0	0%	0.00	0.00	0.00	0%	0.00	0.00	0.00	0%
Total		16.42		5,661	12,153	17,814	100%	2.1	4.2	6.3	100%	0.9	2.4	3.3	100%	10.60	24.60	35.20	100%	7.72	22.48	30.20	100%

Note: Modified from Table D-1.3-2 of Sandia Canyon investigation report by addition of Reach S-5EC.

Appendix E

Geophysics Report for Contractor

Final Report

Geophysical Survey of the Wetland Area of Upper Sandia Canyon

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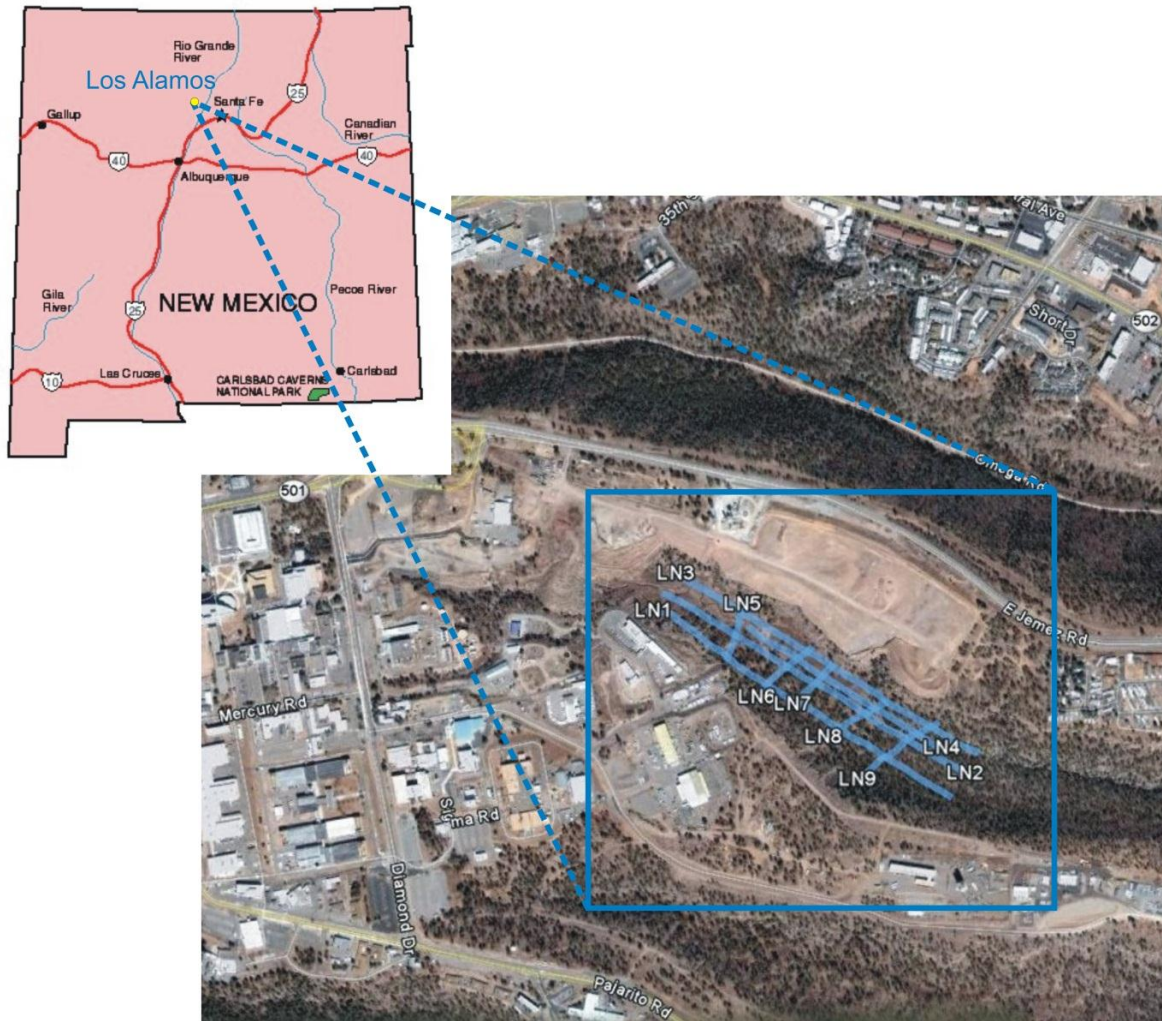
TABLE OF CONTENTS

1.0	INTRODUCTION	1
1.1	SCOPE.....	2
1.2	OBJECTIVES	2
2.0	BACKGROUND	3
3.0	DATA ACQUISITION AND PROCESSING METHODOLOGY	5
3.1	SURVEY AREA AND LOGISTICS.....	5
3.2	EQUIPMENT.....	5
3.3	DATA PROCESSING	7
4.0	DISCUSSION OF RESULTS.....	11
4.1	2D RESISTIVITY PROFILE RESULTS	11
	4.1.1 2D RESISTIVITY PROFILE 1	14
	4.1.2 2D RESISTIVITY PROFILE 2	15
	4.1.3 2D RESISTIVITY PROFILE 3	17
	4.1.4 2D RESISTIVITY PROFILE 4	18
	4.1.5 2D RESISTIVITY PROFILE 5	19
	4.1.6 2D RESISTIVITY PROFILE 6	21
	4.1.7 2D RESISTIVITY PROFILE 7	22
	4.1.8 2D RESISTIVITY PROFILE 8	24
	4.1.9 2D RESISTIVITY PROFILE 9	25
4.2	3D RESISTIVITY MODEL RESULTS.....	27
5.0	CONCLUSIONS.....	32
6.0	REFERENCES	34
	APPENDIX A. ELECTRICAL RESISTIVITY 2D RESULTS	35

1.0 INTRODUCTION

This report documents direct current (DC) electrical resistivity-based geophysical characterization activities completed in the wetland area near the headwaters of Sandia Canyon at the U.S. Department of Energy (DOE) Los Alamos National Laboratory in Los Alamos, New Mexico (Figure 1).

Figure 1. Upper Sandia Canyon, Los Alamos National Laboratory Location Map.



1.1 SCOPE

The scope of this electrical resistivity characterization survey included:

- Data acquisition along four parallel longitudinal lines on strike with the Sandia Canyon and five supplementary lines placed orthogonally to the longitudinal lines. The five supplementary lines (and one longitudinal line) were arranged according to the results of the initial three longitudinal lines (Line 1 to Line 3),
- Data processing and inversion, including the use of methods and controls to ensure quality assurance consistent with geophysical characterization across the DOE complex
- Data visualization that included the use of two-dimensional (2D) contouring of individual resistivity profiles,
- Compilations of resistivity cross sections from three-dimensional (3D) inverse modeling results.

1.2 OBJECTIVES

The overall objective for this geophysical investigation was to collect and analyze electrical resistivity data to identify low resistivity regions in the wetland of upper Sandia Canyon. Low resistivity values are indicative of increased moisture content, changes in geologic lithologies, perched water, or an increased concentration of electrolytes compared to background conditions.

The three specific objectives for the survey were:

- Determine if electrical resistivity data can be used to identify features that may represent infiltration zones beneath the upper Sandia Canyon wetland,
- Identify horizontal electrical features in bedrock that may represent perched zones in the upper vadose zone beneath the upper Sandia Canyon wetland,
- Determine if electrical resistivity data can be used to identify planer geological structures (e.g. faults or fracture zones) that may localize infiltration and/or affect potential groundwater pathways.

2.0 BACKGROUND

Sandia Canyon is located at Los Alamos National Laboratory (LANL) in north-central New Mexico. This canyon was contaminated by past Laboratory operations. The “Investigation Report for Sandia Canyon” (LANL-UR-09-6450) documents the contamination history and sources since the Laboratory began operation in 1943 and includes relevant information to this project located in TAs 03, 60, and 61:

- Effluent water releases to Sandia Canyon have occurred since the early 1950s and continue today, with the primary sources being treated sanitary wastewater and cooling tower blowdown.
- Potassium dichromate was used from 1956 to 1972 to treat cooling tower blowdown from a power plant, resulting in the release of approximately 31,000 to 72,000 kg (69,000 to 160,000 lb) of hexavalent chromium into upper Sandia Canyon. Because of its relative mobility, hexavalent chromium is the primary contaminant of concern in groundwater.
- Since 1992, Laboratory treated sewage effluent and releases from TA-03 steam plant boilers were major sources of surface water released to upper Sandia Canyon. Currently, effluent releases to the canyon average 1700 m³/d (390,000 gal/d).
- The long-term discharges and runoff support the thriving wetland near the head of Sandia Canyon and have supplied a sufficient water volume to facilitate contaminant transport in the canyon. The wetland contains abundant solid organic matter that serves both as a chemical reductant and as an adsorbent to contaminants, particularly chromium, that flow through the wetland.
- Based on surface-water balance study conducted from July 2007 to June 2008, an average water flux of 15,000 m³/yr (12 acre-ft/yr) is estimated to infiltrate into bedrock beneath the wetland, along an area that includes splays of the Rendija Canyon fault zone. This volume represents approximately 2% of the surface water (both effluent and runoff) flowing into the canyon during the period of the study and indicates that faults and fractures in this area may be secondary pathways for deep infiltration.

The Pajarito Plateau is located in the western part of the Española basin where rocks of the Jemez and Cerros del Rio volcanic fields overlie and interfinger with Neogene basin-fill sedimentary rocks. The plateau is an east-sloping tableland bounded on the west by the Jemez Mountains volcanic field and on the east by the Rio Grande valley. The plateau is deeply dissected, and it consists of numerous fingerlike mesas separated by deep canyons containing east- to southeast-draining streams that are mostly ephemeral and intermittent. The Sandia Canyon wetland is located near the headwaters of one of these deep and narrow drainages incised into the welded tuff units that cap the plateau. Geologic units in the vicinity of the wetlands include, in descending order, Quaternary ignimbrites of the Tshirege and Otowi Members of the Bandelier Tuff (separated by volcaniclastic deposits of the Cerro Toledo Formation), Pliocene dacite lavas, and Pliocene fanglomerate deposits of the Puye Formation. The vadose zone in the vicinity of the wetlands is approximately 365 m (1200 ft) thick. Shallow groundwater occurs within canyon-floor alluvium beneath the wetland. Perched intermediate-depth groundwater may occur within bedrock units of the vadose zone, but there are no deep wells to determine its presence or absence near the wetlands. Regional groundwater saturation occurs at depths greater than 365 m (1200 ft) in coarse-grained sedimentary rocks of the Puye Formation.

3.0 DATA ACQUISITION AND PROCESSING METHODOLOGY

3.1 SURVEY AREA AND LOGISTICS

The acquisition of electrical resistivity data involves the injection of current into the ground between two electrodes, and the measurement of electrical potential between two other electrodes, repeated for multiple combinations of the available electrodes. Data acquisition along two-dimensional (2D) profiles within the upper section of the Sandia Canyon began on September 12, 2011 and was completed on September 20, 2011. A total of nine 2D profiles were collected; survey layout is displayed in Figure 2. Table 1 lists the details of the acquired profiles.

Table 1. Two-dimensional Resistivity Profile Details (Start and End Positions Reported in State Plane, New Mexico Central)

Profile #	Electrode spacing (feet)	Length (feet)	Orientation	Start Position (Easting and Northing, feet)		End Position (Easting and Northing, feet)	
1	20	2343	NW-SE	1621211	1773814	1623197	1772572
2	20	2399	NW-SE	1621268	1773932	1623332	1772710
3	20	2354	NW-SE	1621363	1774064	1623389	1772866
4	10	1578	NW-SE	1621850	1773707	1623188	1772870
5	10	404	SW-NE	1621704	1773477	1621813	1773867
6	10	500	SW-NE	1621908	1773236	1622284	1773566
7	10	374	SW-NE	1622153	1773186	1622422	1773445
8	10	509	SW-NE	1622359	1772966	1622805	1773210
9	10	653	SW-NE	1622590	1772677	1623119	1773060

3.2 EQUIPMENT

Data were collected using a Supersting™ R8 multichannel electrical resistivity system (Advanced Geosciences, Inc. (AGI), Texas) and associated cables, electrodes, and battery power supply. The Supersting™ R8 meter is commonly used in surface geophysical projects and has

proven itself to be reliable for long-term, continuous acquisition. The stainless steel electrodes were laid out along profiles with a constant electrode spacing (Table 1). Multi-electrode systems allow for automatic switching through preprogrammed combinations of four electrode measurements. A pole-pole electrode configuration was used for the acquisition of profiles 1 through 9. For further details on the electrode configuration, see Binley and Kemna (2005). The pole-pole electrode configuration involves positioning one pole from both the transmitter (Tx) and receiver (Rx) pairs at a fixed and distant location from the survey area. Table 2 lists the remote electrode coordinates for the pole-pole electrode configuration profiles. In general, the pole-pole electrode configuration provides improved overall depth penetration than other configurations of data acquisition; typically a result of the current pathways being steeper inclined due to the effect of the distance remote electrodes.

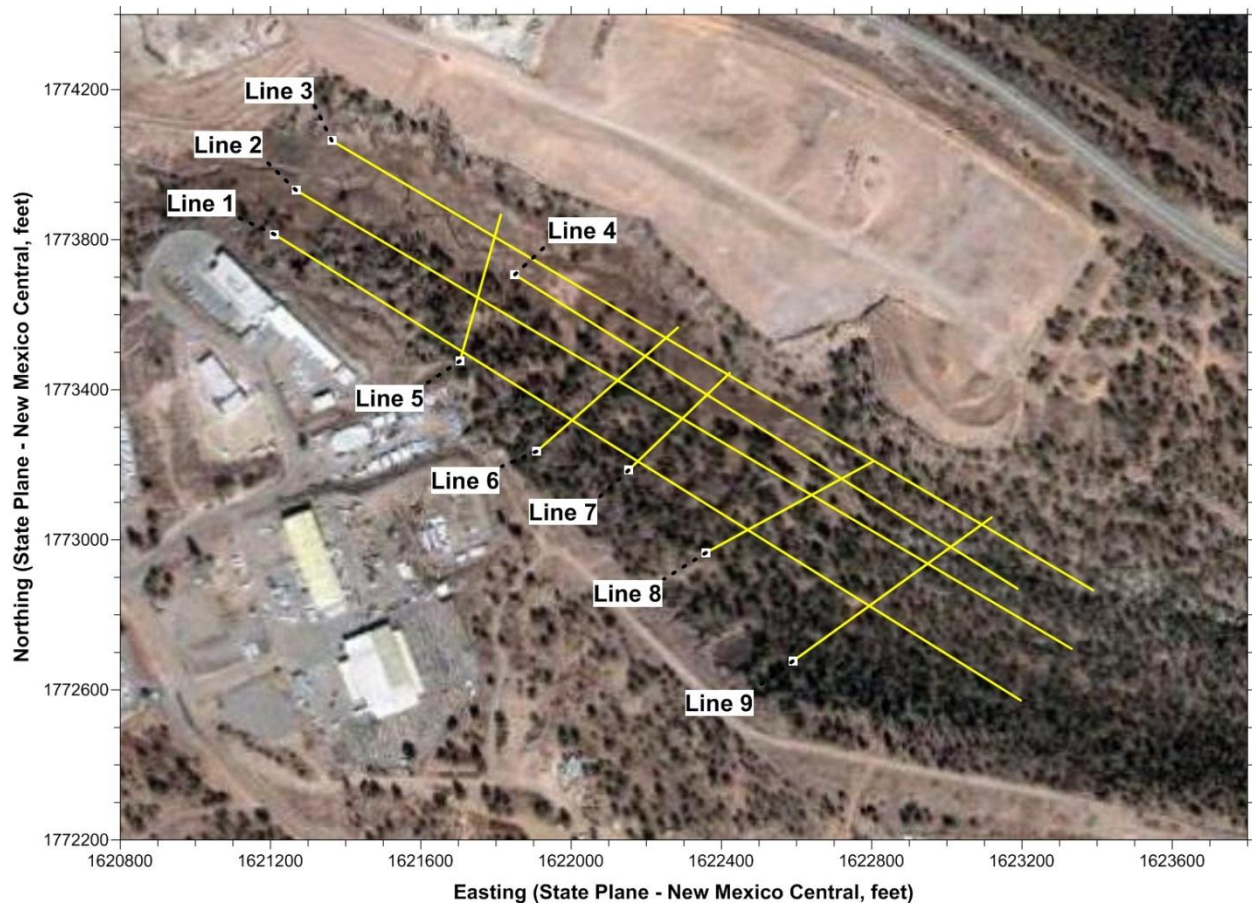
Table 2. Remote Reference Electrode Locations for the Pole-Pole Electrode Configuration Profiles (State Plane, New Mexico Central)

Remote	X (feet)	Y (feet)
Tx	1616458	1775044
Rx	1630250	1771962

Electrode locations were surveyed using a Leica[®] 1200 Global Positioning System (GPS). Elevations for each electrode were then obtained from Light Detection And Ranging (LIDAR) data provided for the area and incorporated into the subsequent inverse modeling.

[®] Leica is a registered trademark of Leica Technology.

Figure 2. Two-dimensional Resistivity Profile Layout for the Upper Sandia Canyon Survey Area.



3.3 DATA PROCESSING

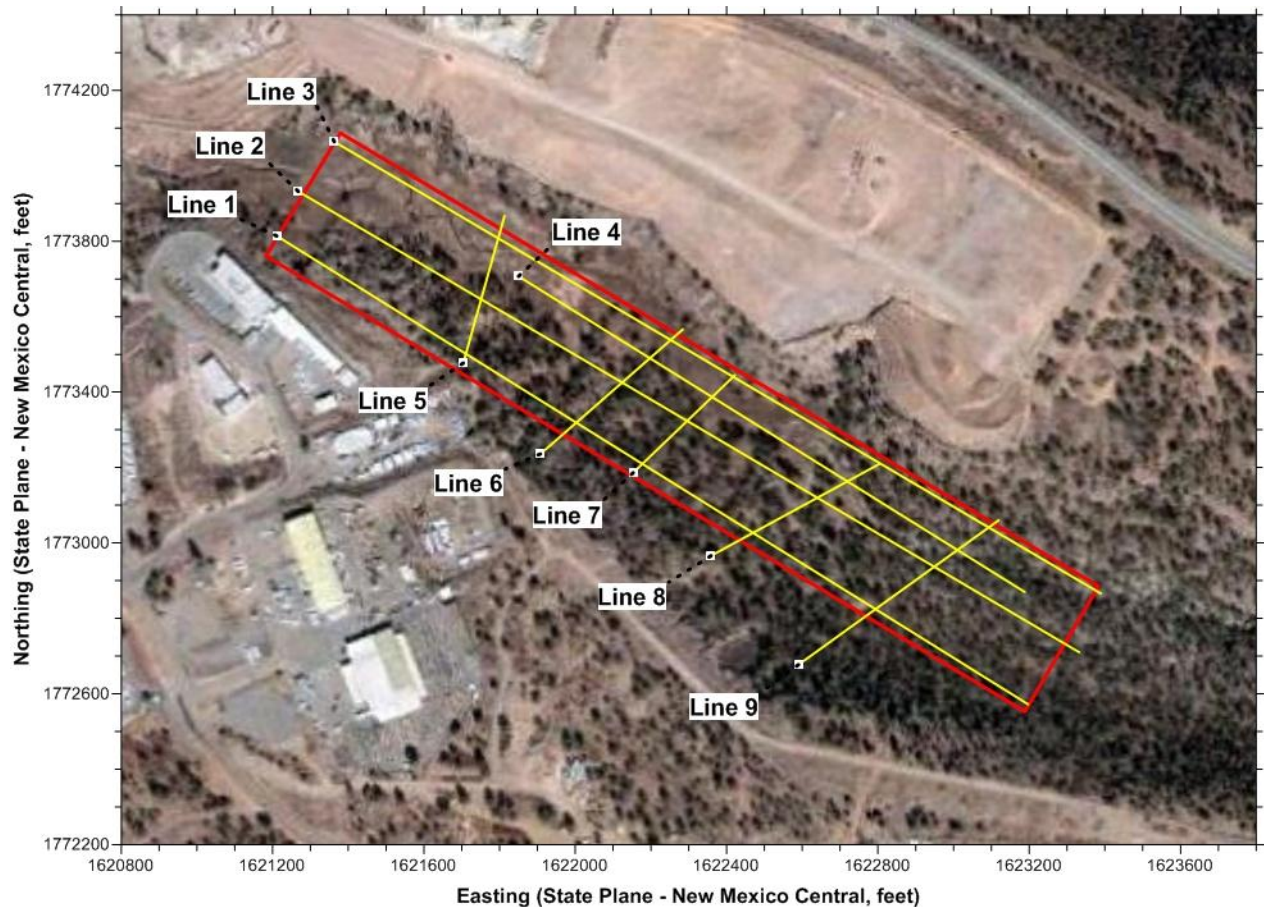
Measurements of electrical resistivity with ERT systems inevitably contain errors from a variety of sources, including poor electrode contact, random device errors, and external effects. An assessment of these errors provides some means of quality control of the data. The process of data editing identifies and eliminates erroneous data points, but no data modification (rounding, averaging, smoothing, or splining) is performed.

The recorded electrical resistivity data were downloaded each day for analysis. Error statistics are computed within the Supersting™ R8 for multiple readings (or stacks) on each electrode configuration. The error values on these multiple readings are used as rejection criteria, where data with errors greater than 5% were removed from the data set. Additional important diagnostic data parameters from the raw data include voltage/current (V/I , or transfer resistance,

in ohms), voltage (Volts), and electrical current (Amps) output. The rationale is to seek out and remove spurious points that do not conform to the data population or points that violate potential theory. The aim was to remove data outside of the statistical population – measurements with negative V/I , low voltage (<0.01 V), or low current (<10 mA) were removed from the data set.

The data were inverse modeled using the Res2Dinv and Res3Dinv software packages. The software uses an ‘Occam’s’ style inversion (Constable *et al.*, 1987) which produces a smooth model of the subsurface electrical resistivity that fits the acquired data within certain tolerances. The inversion proceeded in an iterative manner until the data misfit was below an acceptable level, 10% for all cases presented in this report. A built in assumption of 2D inverse modeling is that the resistivity in the cross-line direction is constant. At sites with complex resistivity structure, the 2D assumption may introduce significant error, and the resulting 2D images can contain significant distortions (Bentley and Gharibi, 2004). Hence, in areas with the potential for complex three-dimensional (3D) electrical targets, i.e. faults, fractures, perched water tables, etc., whose dimensions out of the plane of the 2D resistivity profile cannot be assumed to remain constant, it is possible that distortions will be observed in the resulting inversion models. The distortions can take the form of under- or over-estimation of the modeled resistivity value of features, location errors for electrical conductive features, or incorporating out-of-plane features into the 2D profiles. One method to reduce the distortions caused by the 2D assumption is to incorporate the individual 2D profile data into a 3D inverse model. This was achieved using the Res3Dinv software package. The data from the individual 2D profiles was georeferenced and incorporated into a 3D grid format. The outline of the 3D grid is displayed in Figure 3. A number of the original 2D profiles were truncated to reduce regions of the model with anticipated poor sensitivity due to low data density. The model grid cell size was chosen to be 40 by 40 by 40 feet, the latter determines the increment for the resulting model resistivity depth slices. The 3D inverse modeling included a total of 28,391 measurements, with the chosen final model taking 3 iterations with an acceptable data misfit of 9.8%.

Figure 3. Three-dimensional Inverse Modeling Grid Outline (Red Rectangle) Overlain onto the Two-dimensional Resistivity Profile Layout for the Upper Sandia Canyon Survey Area.



As a ‘rule of thumb’ the maximum depth to which the resistivity model is well constrained by the data is approximately 20% of the length of the line. To obtain a more quantitative estimate of the maximum depth we used the “Depth Of Investigation” (DOI) method outlined in Oldenburg and Li (1999). The method measures how sensitive the inverted resistivity model is to the initial starting model as a ratio, the R-value, of two different starting models. Due to the limited additional information to constrain the geophysical data we used three homogeneous models with single resistivity values of 40, 100, and 4000 ohm-m. The different starting models did not produce significantly different final resistivity models, with resulting R-values close to zero.

The resulting output resistivity model was subsequently processed and visualized using the Surfer (Golden Software, Inc., Golden, CO) and Rockworks (Rock Ware, Inc. Golden, CO) software.

4.0 DISCUSSION OF RESULTS

4.1 2D RESISTIVITY PROFILE RESULTS

The 2D resistivity model results are presented as 2D profiles in Plates 1 through 11 found in Appendix A at the end of this report. Common color contouring scales were used throughout and there is no vertical exaggeration in the 2D profile figures. Electrically conductive (low resistivity) subsurface regions are represented by cool hues (purple to green) and electrically resistive regions are represented by warm hues (orange to red). To help emphasize particular features in each section a log scale of model resistivity is used in the profile figures. When data span multiple orders of magnitude, it is appropriate to display a log transformation. Table 3 lists the data statistics for each profile.

We also present annotated 2D profiles in Figures 4 through 12 in this section of the report. The locations of the points of intersection for the various profiles are indicated along the ground surface contour for reference. In addition, fault and monocline locations are indicated by colored diamonds along the ground surface contour; these were taken from the regional geological map (Lewis *et al*, 2009 – Animation 1). They are used for comparison with interpreted features in the model resistivity profiles.

Fracture, fault, and fissure mapping with electrical resistivity is fairly common, and has been presented in numerous studies. The main component to finding these structural features is the offset in model resistivity contouring or a large change in resistivity values along a lineation consistent with a change in geology. Considering the small throws along the faults identified in Lewis *et al* (2009), we would most likely interpret the presence of a fault based on an offset in model resistivity contours. In our interpretations, we cannot determine if low resistivity associated with faults and fractures is the result of increased water content, compared to surrounding material, or represents higher clay content associated with fault gouge.

Borehole investigations further downstream of the current survey area in lower Sandia Canyon have identified perched water at several locations; including within the alluvium layer, on the top surface of the Cerros del Rio basalt, and at the base of the Cerros del Rio basalt formation (LA-UR-09-6450). In the wetland, shallow perched groundwater occurs in the alluvium above the

welded bedrock tuffs. There are no boreholes in the wetland deep enough to characterize potential vadose-zone perched groundwater zones. However, within the electrical resistivity profiles we might expect perched groundwater to be represented by horizontal lenses of low resistivity, based on the increase in the degree of saturation in these normally unsaturated geological units.

Table 3. Two-dimensional Resistivity Profiles Data Statistics.

Profile #	Raw data count	Rejected data count	Measured Apparent Resistivity (ohm-m)		
			Minimum	Maximum	Median
1	7871	1984	817	836.2	271.5
2	7751	996	91.4	1184.3	297.0
3	7878	780	28.7	4481.1	224.0
4	3484	367	123.6	2930.4	306.3
5	925	11	74.1	900.1	360.1
6	1378	64	90.7	928.7	355.8
7	930	39	63.4	2337.7	287.1
8	1483	63	124.1	2932.5	351.2
9	2336	216	132.5	3347.4	506.1

In general the nine profiles display a number of comparable features across the surveyed area. A near-surface conductive layer is observed in the western half of the surveyed area and extends from the land surface to approximately 40 feet depth. The conductive layer is observed along varying lengths of profiles 1 through 4 along the long axis of the canyon, and across the majority of profiles 5 through 8. This conductive layer appears to be absent in profile 9, where alluvium is thin to absent as Sandia Canyon begins to incise a narrow canyon into bedrock tuffs farther down canyon. The near-surface conductive layer generally corresponds to the wetland area of the canyon, although patchy regions of near-surface conductivity also occur beneath the canyon-floor alluvial slope south of the wetland (see profile 1). A resistive region is observed directly beneath the conductive layer in the models that extends down to the depth limit (approximately 6900 feet elevation) of the shorter profiles (5 through 9), and to approximately the 6600 feet elevation contour for the longitudinal profiles (1 through 4). The upper part of the resistive region, above 7000 to 7100 feet elevation, contains long segments of horizontal, highly resistive values that probably correspond to welded tuffs of the Tshirege Member that underlie the alluvial deposits in this area. The resistivity values for this resistive feature, corresponding to areas not overlain by the alluvium deposits, range between approximately 1250 and 20,000 ohm-m.

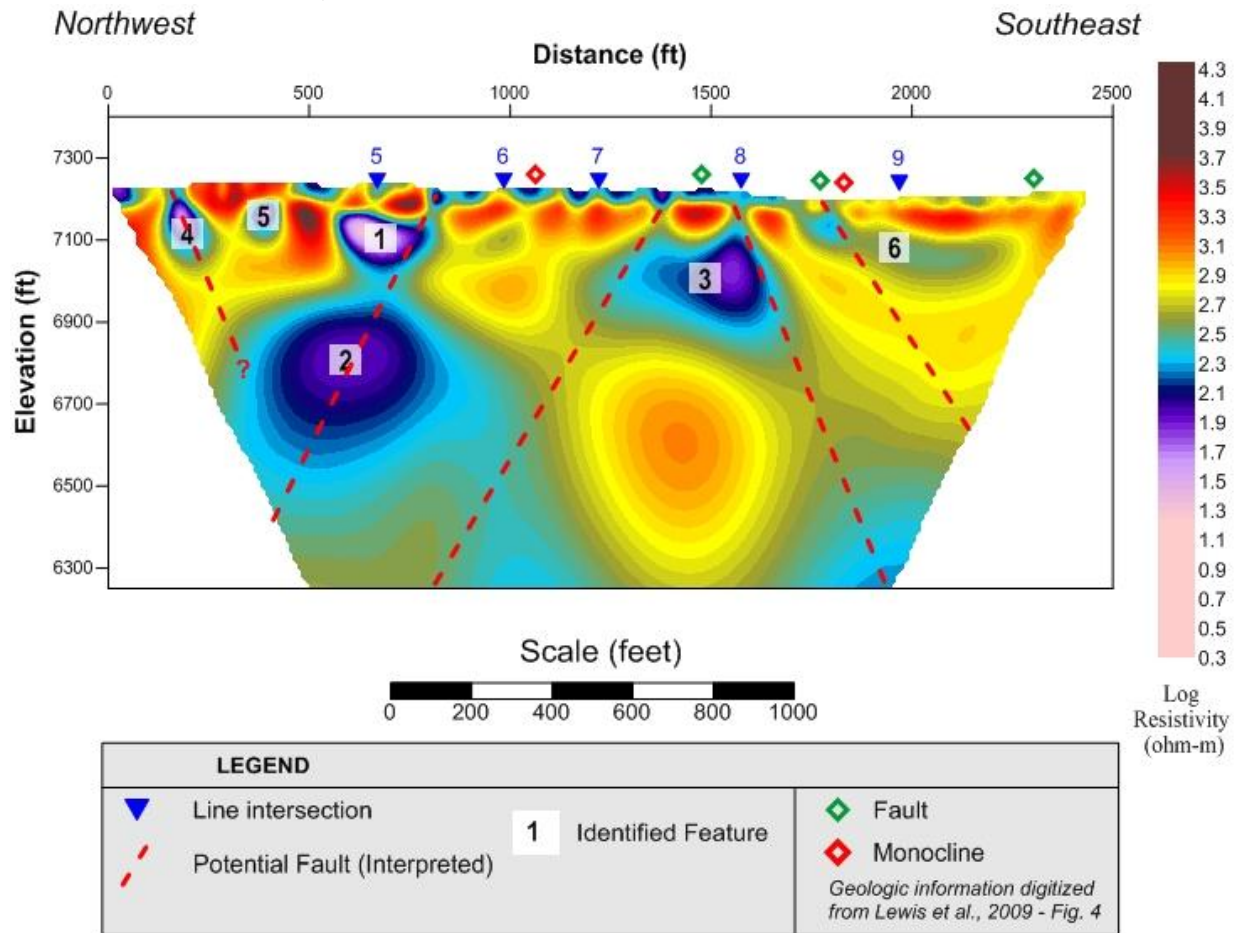
Where continuous, the highly resistive rocks of the Tshirege Member probably represent a significant barrier to the infiltration of surface and alluvial water into the subsurface near the wetland. Conversely, conductive zones extending from the surface through the upper bedrock units may indicate clay- and/or moisture-rich areas where the tuff is penetrated by infiltration pathways, including faults or fractures. Beneath the 6600 feet elevation contour, a more conductive layer is observed for profiles 1 through 4, extending to the penetration depth limit of the resistivity models, possibly relating to a change in lithology. A number of conductive anomalies are superimposed over this general structure for the nine profiles and are discussed in more detail in the following sections.

4.1.1 2D Resistivity Profile 1

Figure 4 displays the modeled resistivity results for profile 1. Profile 1 parallels the axis of Sandia Canyon, but does not cross the canyon floodplain or wetlands except at the extreme western end of the line. A near-surface conductive layer extends from approximately 800 to 1600 feet along the profile length, with an average thickness of 10 feet. This potentially relates to elevated moisture in near-surface alluvium that makes up the alluvial slope south of the wetlands. The base of this layer appears undulated in areas, the effect is also apparent to a lesser extent in the near-surface region of the model between 1600 to 2500 feet along the profile, this is possibly resulting from a combination of poor electrode coupling and high contact resistance, due to ground surface conditions and heterogeneous surface materials, affecting the modeling results. A highly resistive layer underlies this conductive layer and appears to outcrop between approximately 200 and 500, and 1800 and 2500 feet along the profile. Between 500 and 1800 feet along the profile, the resistive layer appears discontinuous in places due to a number of conductive features. A number of conductive anomalies are observed in this profile. The most notable of these is the conductive feature labeled (1), located between 600 and 750 feet along the profile length, at an elevation of 7100 feet. The feature appears to be connected to a much broader conductive feature at depth, labeled (2). These two features may be manifestations of a fault, with the ranges of resistivity values representing possible differences in saturation or varying clay content along the fault plane. The conductive feature labeled (3) is located above several offsets in the contouring of the underlying resistive layer. This may indicate a number of faults running through this region of the resistivity model, as indicated in the figure. The two conductive features labeled (4) and (5), located at approximately 200 and 400 feet along the profile, are slightly more near-surface than the previous anomalies. The feature labeled (4) may represent another fault, being located above an offset in the model resistivity contours. In addition, both features may be related to a perched water table, potentially associated with the base of the alluvium layer. Feature (4) appears to extend to the ground surface in an otherwise resistive near-surface layer, suggesting a potential flow pathway. While feature (5) appears to be isolated within a resistive background, these are 2D representations and these features may extend out of the plane of the resistivity model. The final feature, labeled (6), is located between 1800 and 2200 feet along the profile and tends to dip slightly towards the east. There are several faults identified in Lewis et al (2009) that project through the beginning and end of this feature,

suggesting this conductive region may represent one or more faults. Alternatively this conductive region may represent enhanced water or clay contents in an east-dipping stratigraphic unit; the western end appears to connect to alluvium near the eastern end of the wetland and may represent an infiltration pathway.

Figure 4. Profile 1 Model Resistivity Results - Identifying Electrical Resistivity Features of Interest, includes Visual Aids of Potential Structural Features.

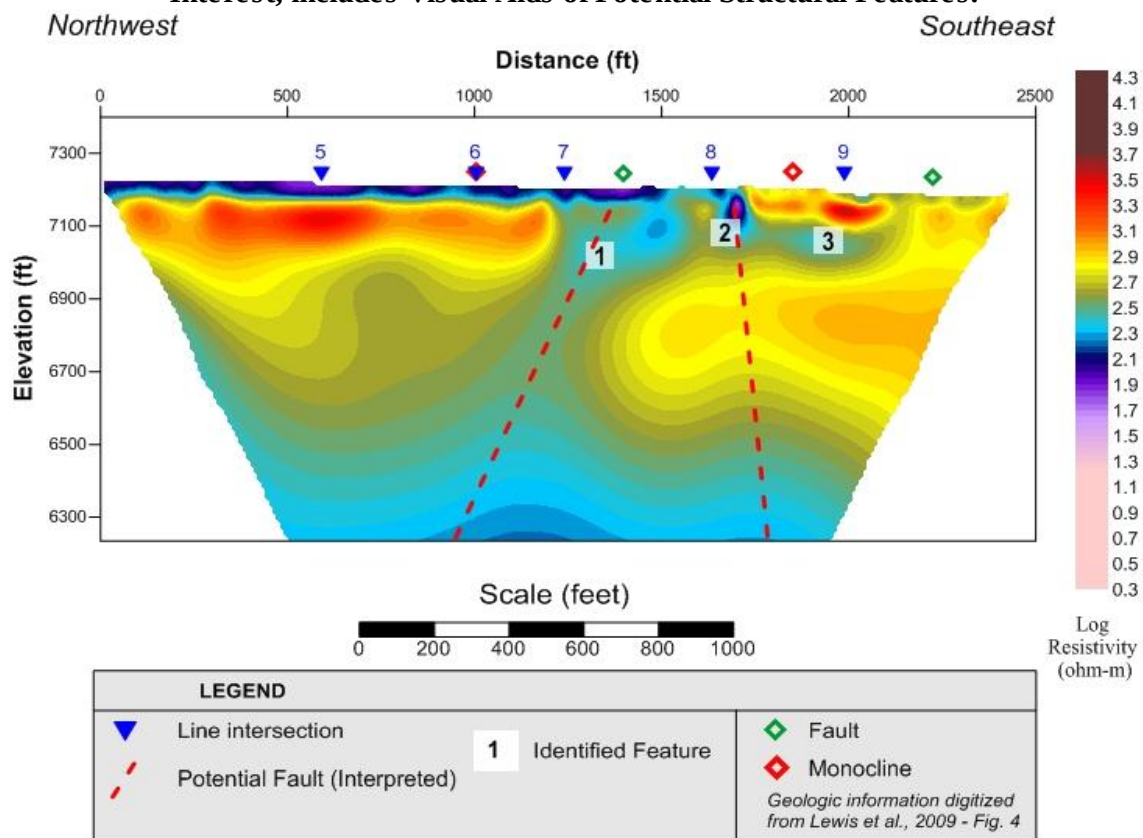


4.1.2 2D Resistivity Profile 2

Figure 5 displays the modeled resistivity results for profile 2, acquired parallel to and to the north of profile 1. The near-surface conductive layer discussed previously extends between 0 and 1700 feet along the profile, located within the canyon-floor flood plain and southern margin of the wetland, displaying an average thickness of 25 feet. East of 1700 feet, the near-surface rocks are resistive where the canyon becomes incised and the line crosses bedrock exposures of welded tuff. The main anomaly in this profile is a conductive linear feature, labeled (1), at

approximately 1400 feet along the profile. This feature dips toward the west and extends down to the underlying conductive layer at approximately 6600 feet elevation. A clear offset in the resistivity model contours can be observed for this feature, potentially indicating a fault structure. Even though profile 2 is more proximal to the canyon axis the resistivity values of this feature are higher than those discussed for profile 1, possibly suggesting a lower degree of saturation or less clay content along the potential fault. The conductive feature labeled (2), located at the eastern terminus of the wetland, extends down from the ground surface to the 7000 feet elevation contour. A slight offset in the underlying model resistivity contours could indicate a fault at this location. The final conductive feature in this profile, labeled (3), which corresponds to the general location along the profile of the feature labeled (6) in profile 1. In this case the feature is not associated with significant offsets in the model resistivity contours and may represent enhanced water or clay contents in an east-dipping stratigraphic unit.

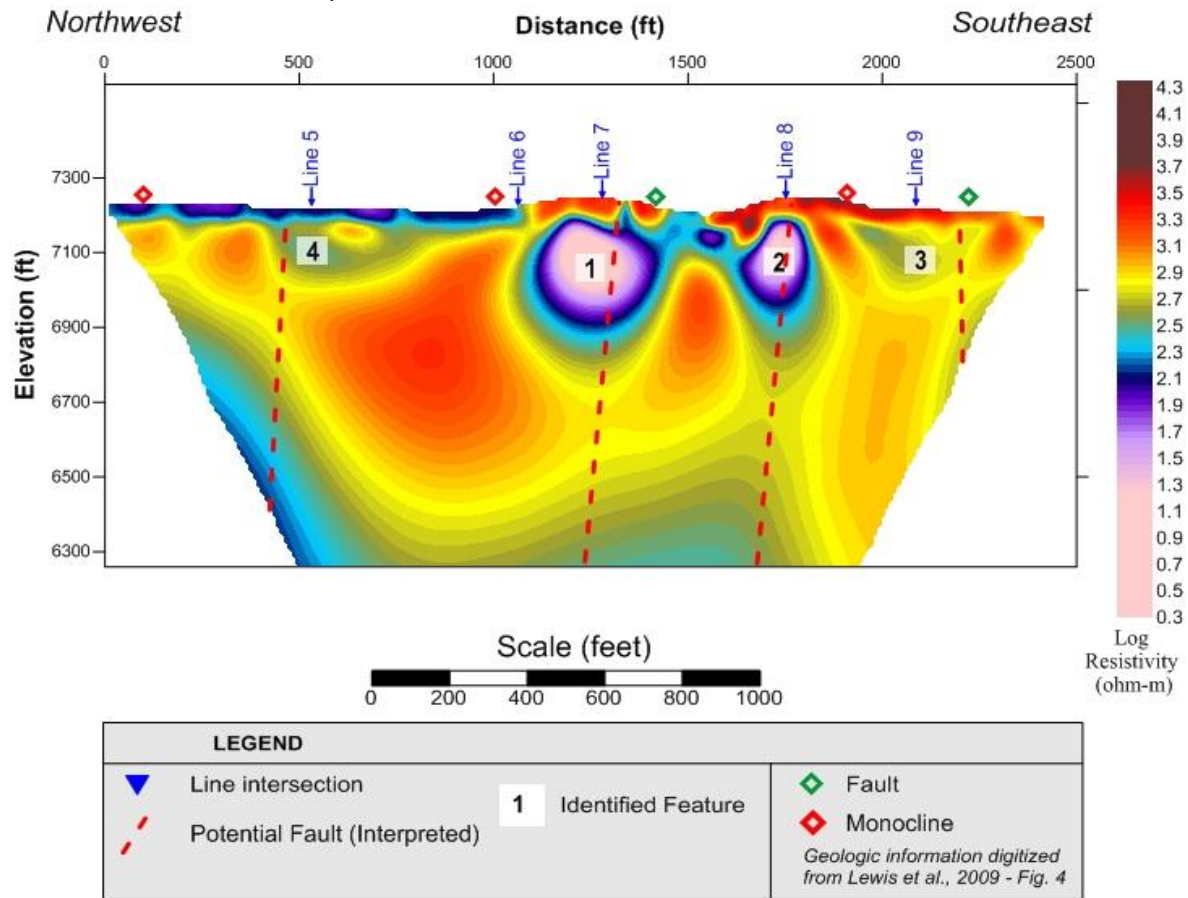
Figure 5. Profile 2 Model Resistivity Results - Identifying Electrical Resistivity Features of Interest, includes Visual Aids of Potential Structural Features.



4.1.3 2D Resistivity Profile 3

Figure 6 displays the modeled resistivity results for profile 3, acquired parallel to and to the north of profile 2. The near-surface conductive layer discussed previously extends between 0 and 1100 feet along the profile, located within the northern part of the canyon floor floodplain and wetland, and it has an average thickness of 20 feet. East of 1100 feet, the near-surface rocks are largely resistive, where the line crosses a high talus slope along the north wall of the canyon before ending on bedrock exposures of welded tuff. A small near-surface conductive zone at 1500 feet appears to correspond to a tributary drainage on the side of Sandia Canyon. At depth, there are two obvious conductive anomalies, labeled (1) and (2), centered on 1300 and 1750 feet along the profile respectively. The offset in the model resistivity contours associated with these two features continues to extend to depth beneath these bulls eyes in low resistivity. The location of these two features corresponds well to previously identified potential fault traces and hence could represent fault planes. The low resistivity, 2.5 to 250 Ωm ($\log_{10}$ resistivity 0.4 to 2.4) associated with the upper sections of these features, the lowest values observed for the 2D profiles, may reflect high clay contents, high water contents, or lower resistivity values for the pore water. The latter may originate from an increase in the ionic concentration of the groundwater. The conductive feature labeled (3) on the profile, located at a distance of 2000 feet along the profile, generally corresponds to the locations along the profiles of feature (6) in profile 1 and feature (3) in profile 2. It is also associated with an offset in the underlying model resistivity contours. This combined with the proximity to the projected location of a previously identified fault trace indicates this feature may represent a fault. The final feature, labeled (4), is a sub horizontal zone with a westward dip located directly underneath the near-surface conductive layer. The depth (~125 feet) and sub horizontal orientation of this feature suggest it is stratigraphically controlled bedrock zone with enhanced water or clay contents. However, we also observe an offset in the underlying model resistivity contours possibly indicating another fault in this region. The edge of the model resistivity in this region indicate more conductive values below the 6900 elevation contour, potentially reinforcing the fault interpretation of feature (4). It should be remembered that the edges of these models are the least sensitive due to the low data density.

Figure 6. Profile 3 Model Resistivity Results - Identifying Electrical Resistivity Features of Interest, includes Visual Aids of Potential Structural Features.

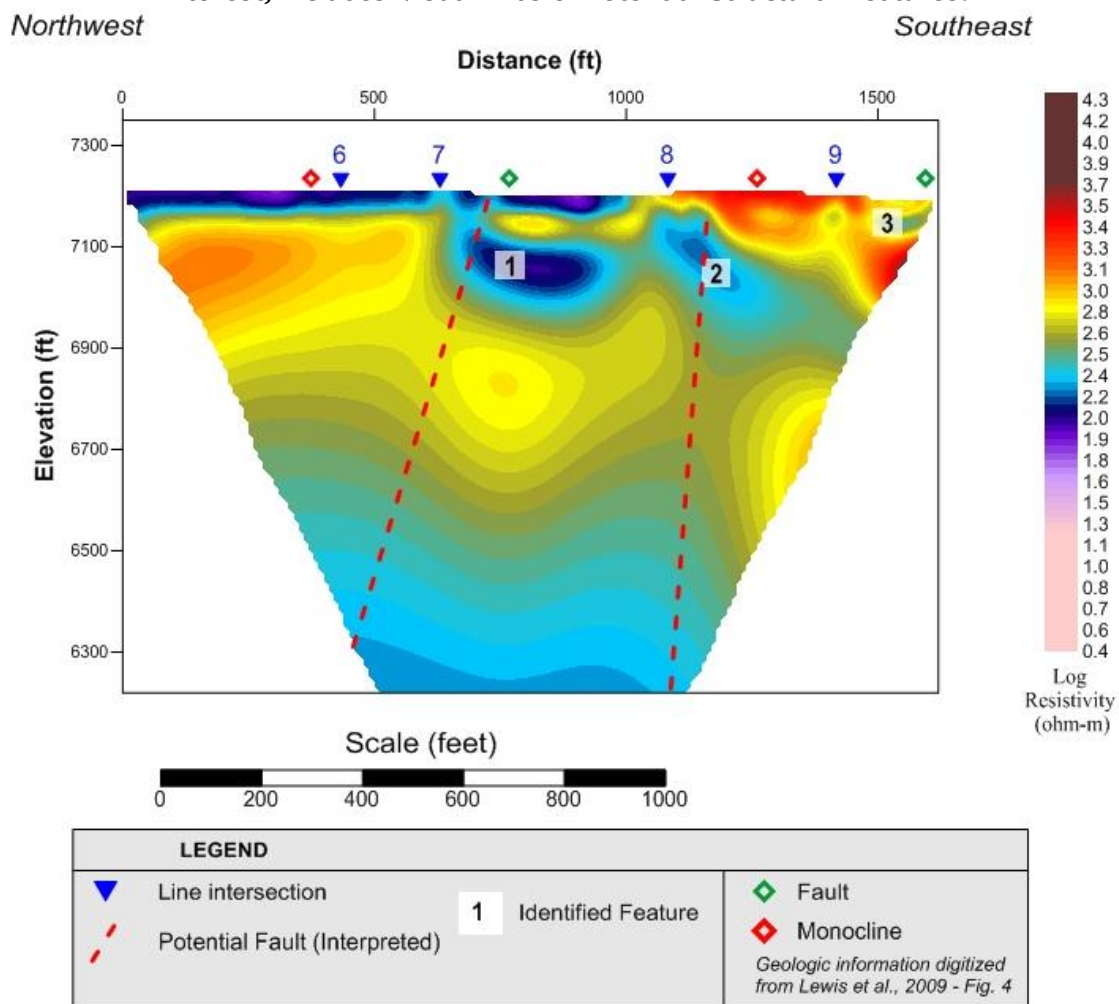


4.1.4 2D Resistivity Profile 4

Figure 7 displays the modeled resistivity results for profile 4, acquired parallel to, and in between profiles 2 and 3. The near-surface conductive layer discussed previously extends between 0 and 1000 feet along the profile, located within the central part of the canyon floor floodplain and wetland, and it has an average thickness of 25 feet. East of 1000 feet, the near-surface rocks are resistive where the profile crosses a talus slope and bedrock exposures of welded tuff. At depth, there are two significant conductive features of interest, labeled (1) and (2). Both of these features appear to be associated with offsets in the underlying model resistivity contours, and may represent faults. In addition, feature (1), located at 800 feet along the profile, is in close proximity to the projected location of a previously identified potential fault trace. Another conductive feature, labeled (3), is observed in the near-surface at 1600 feet along the profile. It

is difficult to identify what may be causing this feature due to its location at the edge of the model where sensitivity is lowest.

Figure 7. Profile 4 Model Resistivity Results - Identifying Electrical Resistivity Features of Interest, includes Visual Aids of Potential Structural Features.

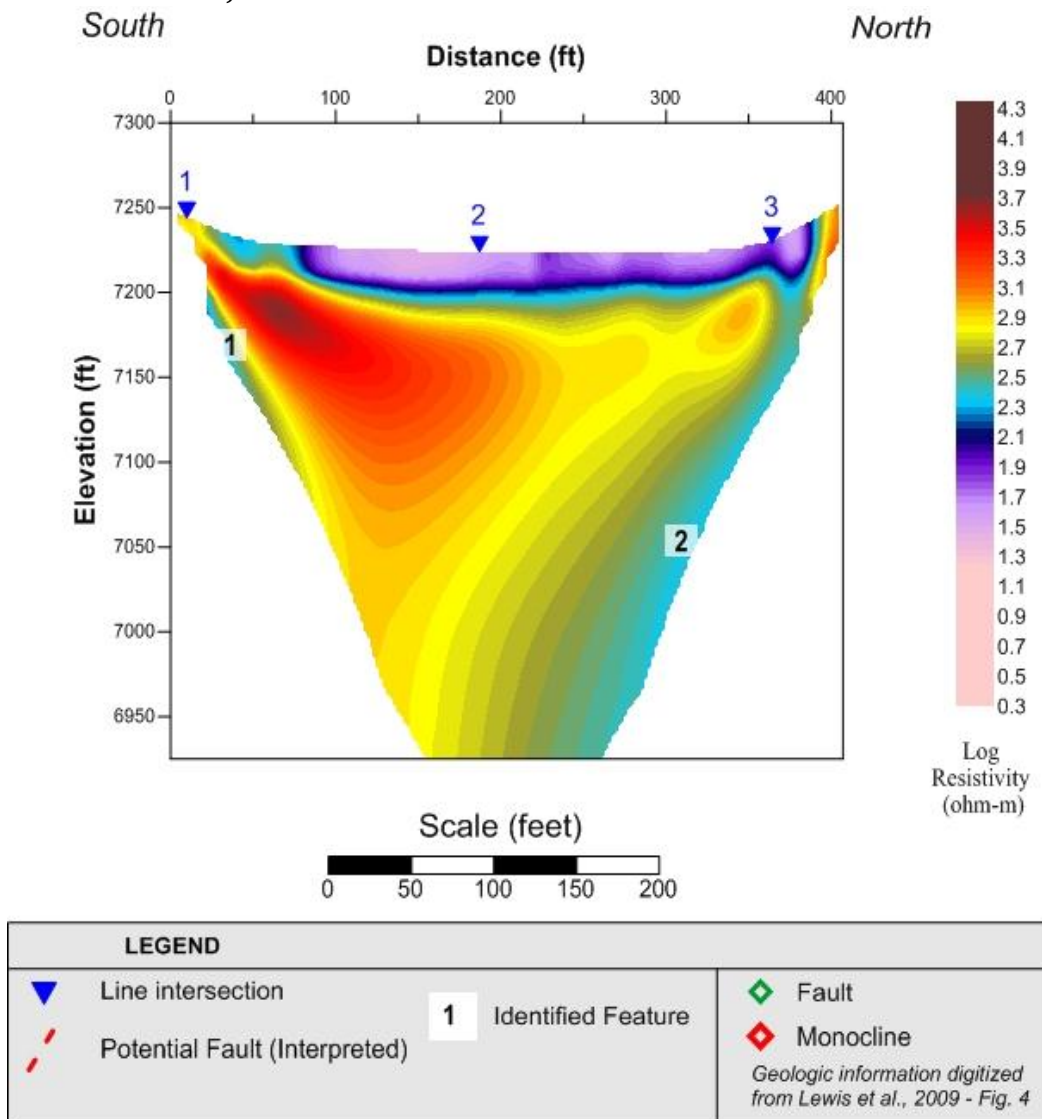


4.1.5 2D Resistivity Profile 5

Figure 8 displays the modeled resistivity results for profile 5, acquired perpendicular to profiles 1 through 4. The dominant feature in this profile is the near-surface conductive layer discussed previously, which extends across the majority of the profile with an average thickness of 20 feet. Although the wetland occurs between approximately 180 and 375 feet along the profile, the near-surface conductive layer is uniformly conductive as far south as about 75 feet along the profile. This may indicate that alluvial groundwater beneath the canyon floor floodplain extends south beneath the adjacent alluvial slope or that the near-surface conductive layer is mapping silt- and

clay-rich alluvial deposits. Deep resistivity values can be observed becoming more conductive at the edges of the model; between 7200 and 7100 feet elevation on the southern edge, labeled (1), and quite clearly at all depths on the northern edge, labeled (2). The feature on the southern edge of the model coincides well with the location of the conductive feature labeled (1) in profile 1, although unfortunately there is little overlap of these regions of the two models. These are regions of the model where we have the lowest sensitivity and hence it is difficult to draw any reasonable conclusions as to the origin of such features.

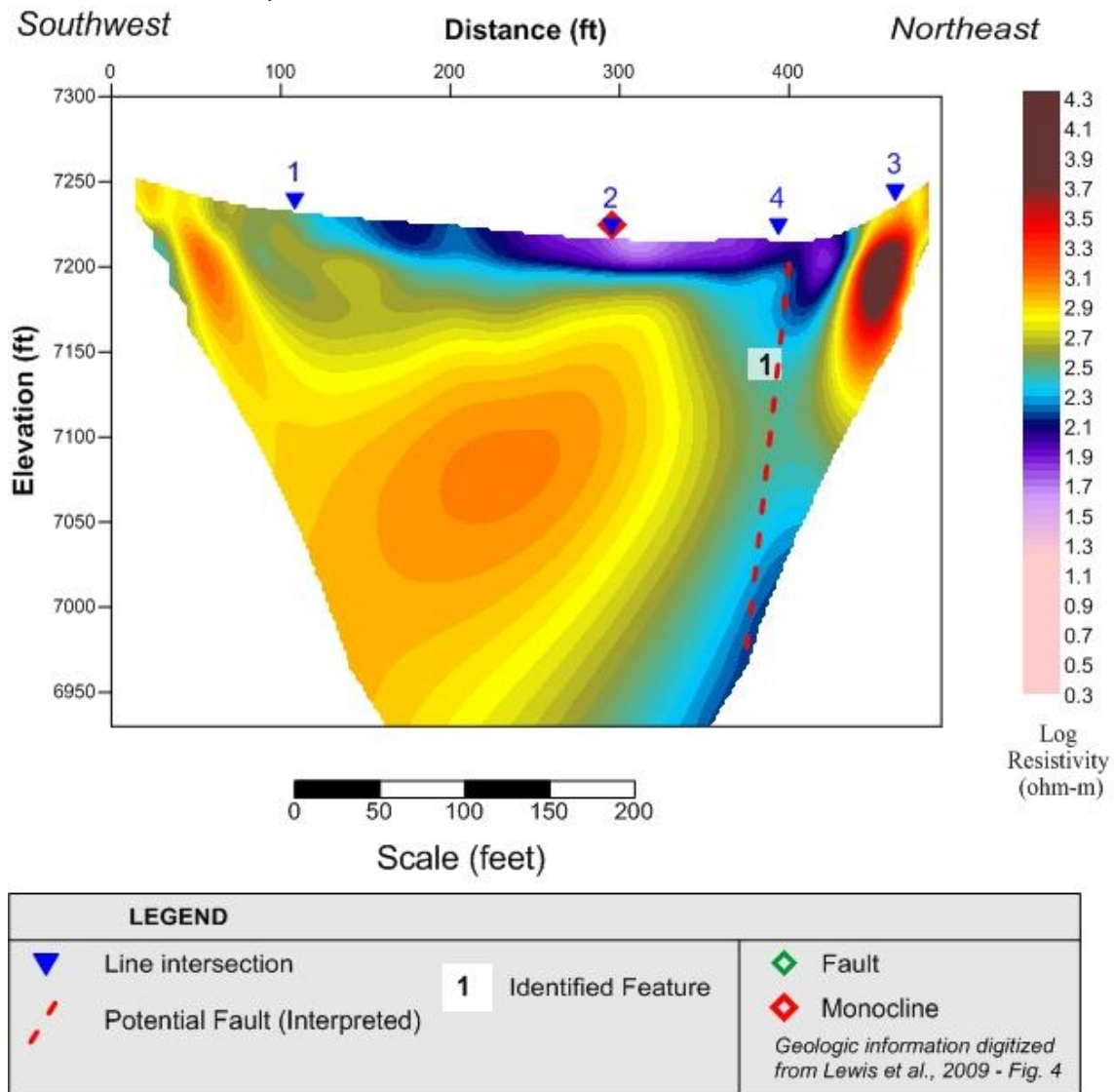
Figure 8. Profile 5 Model Resistivity Results - Identifying Electrical Resistivity Features of Interest, includes Visual Aids of Potential Structural Features.



4.1.6 2D Resistivity Profile 6

Figure 9 displays the modeled resistivity results for profile 6, acquired parallel to and to the southeast of profile 5. The near-surface conductive layer discussed previously extends between 100 and 450 feet along the profile, with an average thickness of 25 feet. Similar to profile 5, the wetland occurs between approximately 300 and 430 feet along the profile, but the near-surface conductive layer extends farther south to about 140 feet along the profile. Maximum conductivity values are somewhat less than that in profile 5. Beneath this layer we observe one significant conductive feature, labeled (1). This feature is located beneath the north margin of the wetland and is associated with an offset in the model resistivity contours which extends to the limit of the penetration depth for the model. This could potentially represent a fault running through this profile.

Figure 9. Profile 6 Model Resistivity Results - Identifying Electrical Resistivity Features of Interest, includes Visual Aids of Potential Structural Features.

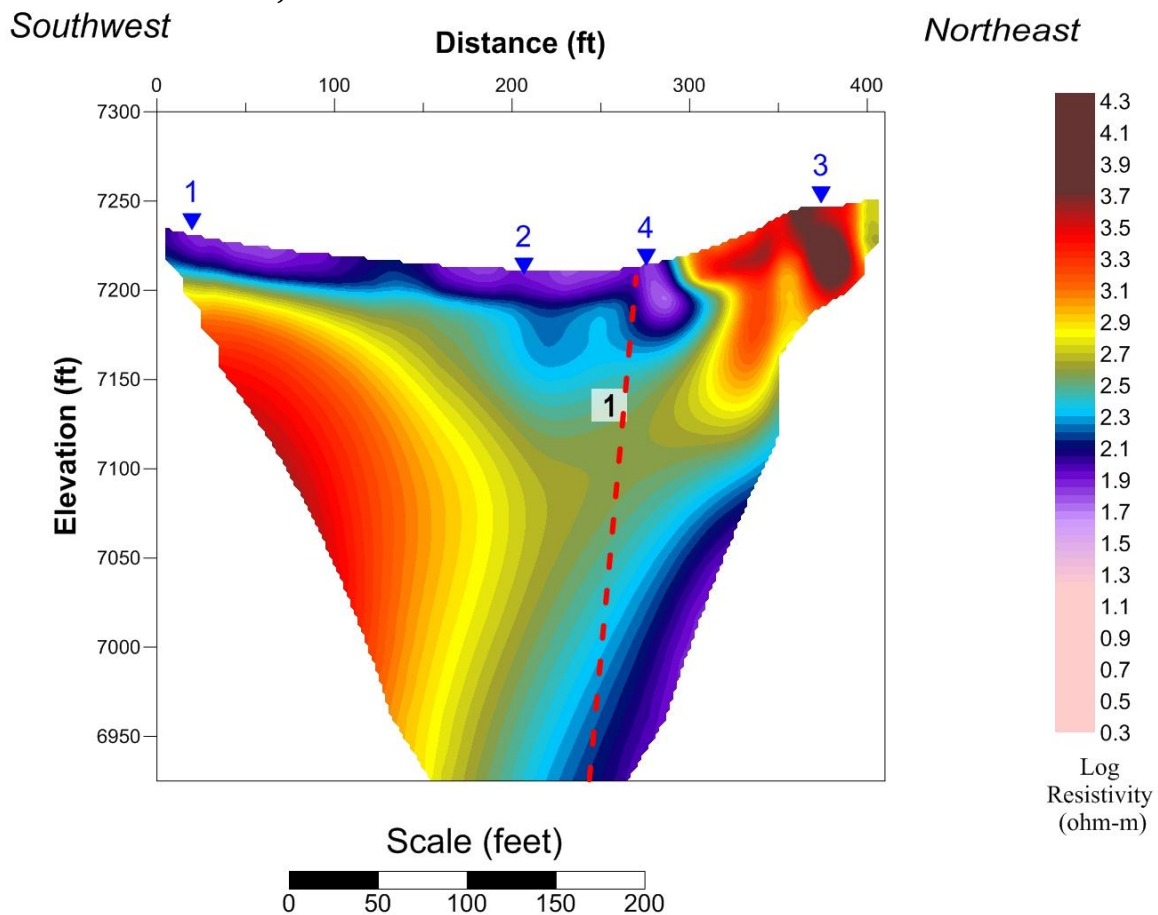


4.1.7 2D Resistivity Profile 7

Figure 10 displays the modeled resistivity results for profile 7, acquired parallel to and to the southeast of profile 6. The near-surface conductive layer discussed previously extends between 0 and 300 feet along the profile, with an average thickness of 25 feet. The wetland occurs between approximately 170 and 270 feet along the profile, corresponding to the north end of the near-surface conductive layer. As in profile 6, the near-surface conductive layer extends farther south than the wetlands and dips northward towards the canyon axis. At depth we observe one significant conductive feature, labeled (1), which may extend from the surface to the depth

penetration limit of the resistivity model. This feature is again associated with an offset in the model resistivity contours that may represent a fault running through this profile. This feature could also represent two separate features; an alluvium-filled (and possibly saturated) channel inset into the bedrock tuffs that corresponds to the base of the previously described near-surface conductive layer, and a deeper conductive feature existing beneath 7100 feet elevation. The latter feature is on the edge of the resistivity model in a region with the lowest model sensitivity, so confidence is low.

Figure 10. Profile 7 Model Resistivity Results - Identifying Electrical Resistivity Features of Interest, includes Visual Aids of Potential Structural Features.

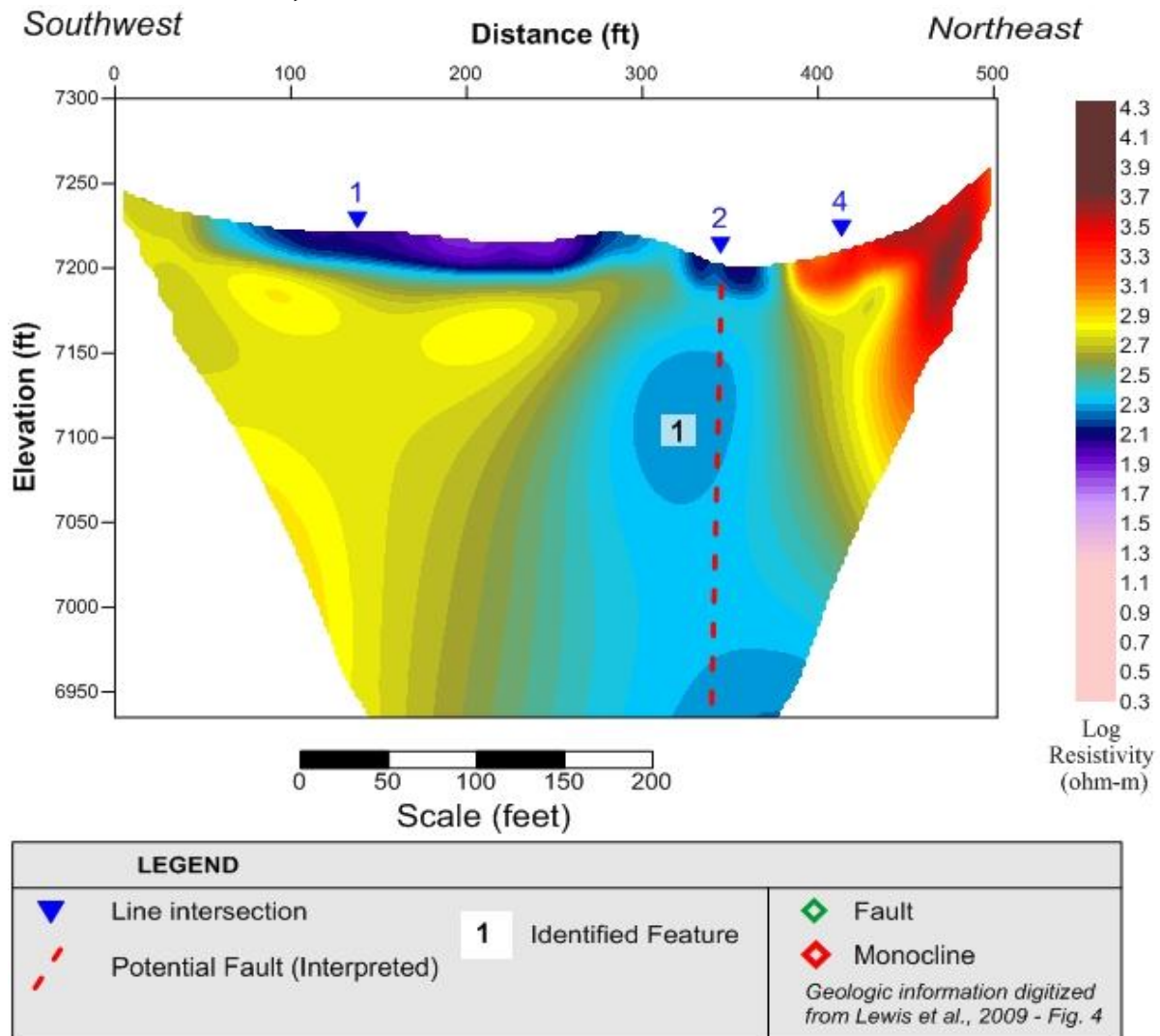


LEGEND		
	Line intersection	1 Identified Feature
	Potential Fault (Interpreted)	
	Fault	
	Monocline	
<i>Geologic information digitized from Lewis et al., 2009 - Fig. 4</i>		

4.1.8 2D Resistivity Profile 8

Figure 11 displays the modeled resistivity results for profile 8, acquired parallel to and to the southeast of profile 7. The near-surface conductive layer discussed previously extends between 50 and 380 feet along the profile, with an average thickness of 25 feet. The profile crosses the eastern end of the wetland, which occurs between approximately 310 and 365 feet along the profile. South of 310 feet, the near-surface conductive layer may represent silt- and clay-rich alluvial deposits. At depth we observe one significant conductive feature, labeled (1). This feature is centered under the wetlands and is associated with a clear offset in the model resistivity contours, with the conductive feature extending unbroken from the near-surface to the penetration depth limit of the resistivity model. The feature may represent a fault running through this profile.

Figure 11. Profile 8 Model Resistivity Results - Identifying Electrical Resistivity Features of Interest, includes Visual Aids of Potential Structural Features.

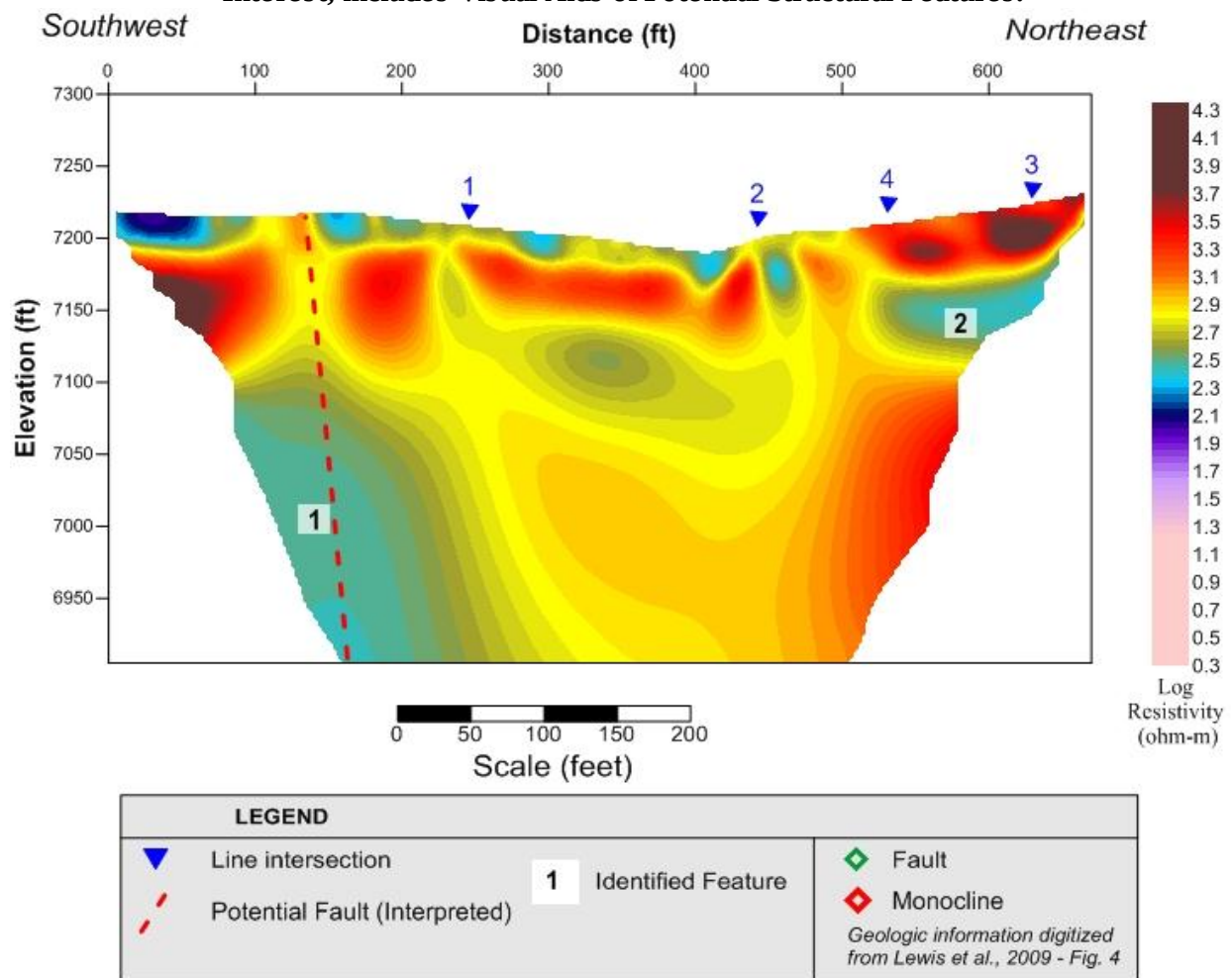


4.1.9 2D Resistivity Profile 9

Figure 12 displays the modeled resistivity results for profile 9, acquired parallel to and to the southeast of profile 8. This profile is located east of the wetlands in an area dominated by surface bedrock exposures and thin talus-slope deposits. The near-surface conductive layer discussed previously is absent in this profile. The stream, which incises a narrow bedrock channel into the welded tuffs approximately 400 feet along the profile, is a minor shallow conductive feature. Two conductive features are labeled within this profile; number (1) is located at 150 feet along the profile between approximately 7100 and 6900 feet elevation. This feature is located at the edge of the resistivity model so confidence is low based on the low

sensitivity in this region. An offset in the model resistivity contours is observed above this feature through the higher resistivity values, possibly indicating a fault in this location. The second conductive feature, labeled (2), is located between 520 and 630 feet along the profile at an elevation of approximately 7150 feet. This feature does not seem to be associated with any offset in the model resistivity contours and its horizontal nature is similar to feature (6) in profile 1 and feature (3) in profile 2, although it is about 100 feet higher in elevation. This feature occurs in bedrock and most likely represents strata with enhanced water and/or clay content.

Figure 12. Profile 9 Model Resistivity Results - Identifying Electrical Resistivity Features of Interest, includes Visual Aids of Potential Structural Features.



4.2 3D RESISTIVITY MODEL RESULTS

The results of the 3D inverse modeling are displayed in Figure 13, displayed as a series of slices at selected depths within the model domain. The elevations (depths) are indicated in the lower left corner of each subplot within the mosaic of different slices. The maximum and minimum values of model resistivity for the 3D inverse modeling are approximately an order of magnitude smaller and larger than the 2D results, reflecting the improved ability of the 3D modeling to cope with complex structure. This is to be expected since we are including the regions between the 2D profiles in the 3D modeling, rather than assuming them to be constant as was the case for the individual 2D profile models. Hence, we can expect improvements in the model resistivity values and resolution of the features.

Within Figure 13, for the top two depth slices (7210 and 7170 feet elevation) the main feature of interest is the electrically conductive region stretching from the upper northwest corner of the model grid down to the intersection with profile 8, labeled (1). This region is concentrated in the canyon bottom, and appears coincident with the wetland and floodplain areas of upper Sandia Canyon. This region could be reflecting more conductive sediments associated with the alluvium or low resistivity associated with an alluvial groundwater. The remainder of the model domains displays resistive values outside of this region.

The conductive region discussed above becomes more resistive by the depth slice at 7130 feet elevation, possibly reflecting a change from alluvial deposits to bedrock tuffs. There are several areas along the canyon that remain slightly more conductive than the background resistive values, labeled (2) and (3). The main feature at this level is the conductive bull's-eye located between profiles 7 and 8, labeled (4). Two more conductive features can be observed on the southeast edge of the model domain in this area, to the north and east of feature 4, labeled (5) and (6). As we proceed through the depth slices the region of the model domain with these three features remains consistently more conductive than the surrounding resistive background. A number of potential faults have been mapped in this region which are displayed on the base map of Figure 13 (taken from Lewis et al, 2009, faults are shown as black lines). These appear to coincide well with the location of these features and the area of conductive model values.

Another conductive feature, labeled (7), can be observed in the upper northeast corner of the model domain. This feature first becomes apparent at an elevation of 7050 feet and remains evident down to an elevation of 6650 feet. This feature is apparent in profiles 1 and 5 of the 2D resistivity models, with the 3D resistivity model appearing to confirm that this feature is confined to the southeast corner of the survey area. It is interesting to note that a northwest – southeast trending canyon-parallel fault was identified in Lewis et al (2009) on the plateau area just to the northwest of the resistivity survey area.

Below the depth slice at 6650 feet the majority of the model domain has become more conductive suggesting a change in lithology across the survey area of the canyon. The conductive features of interest are very difficult to distinguish from the background resistivity from this point.

Figure 13. Plan View Depth Slices of Three-dimensional Model Resistivity (2 sheets).

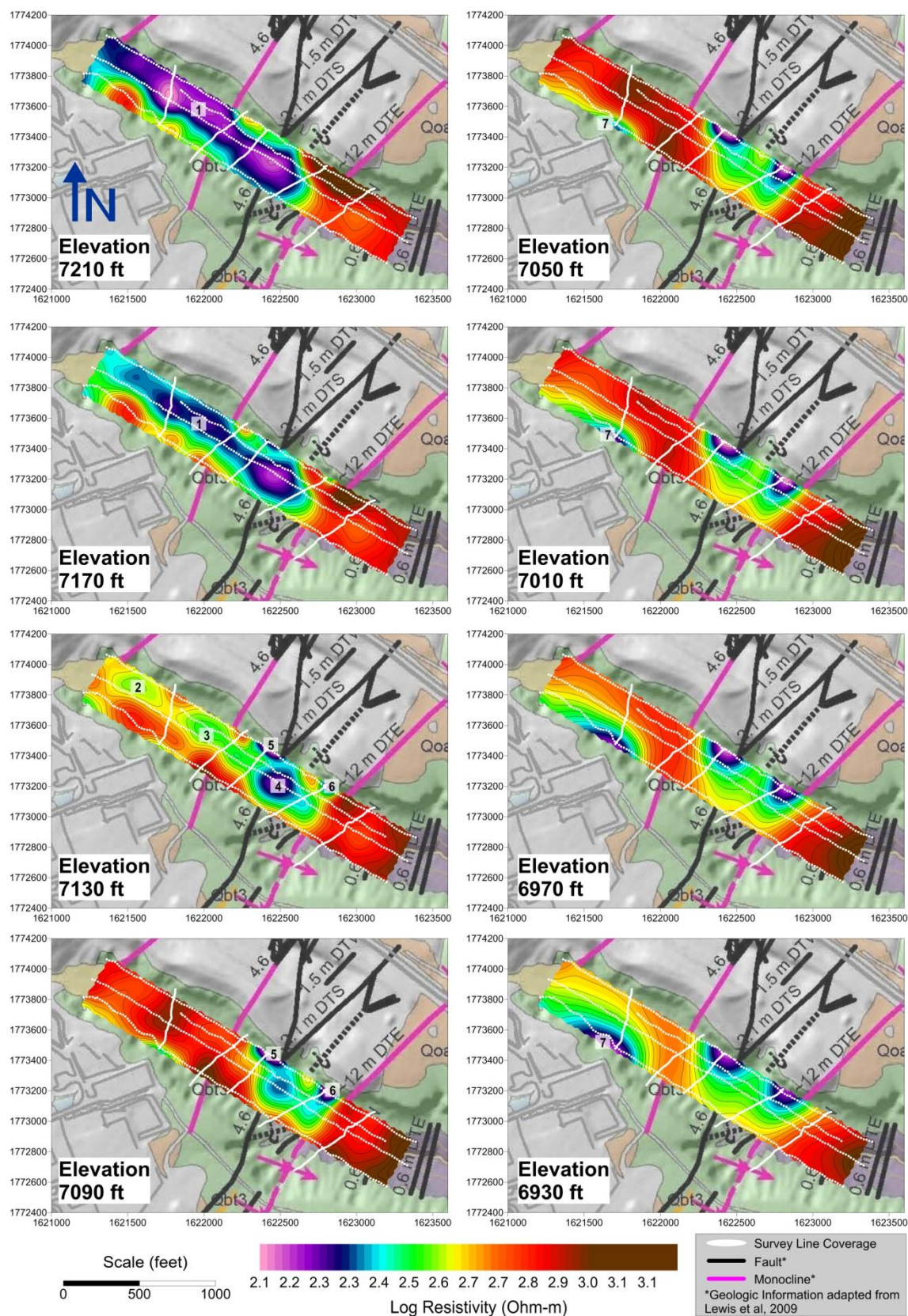


Figure 13 continued. Plan View Depth Slices of Three-dimensional Model Resistivity (2 sheets).

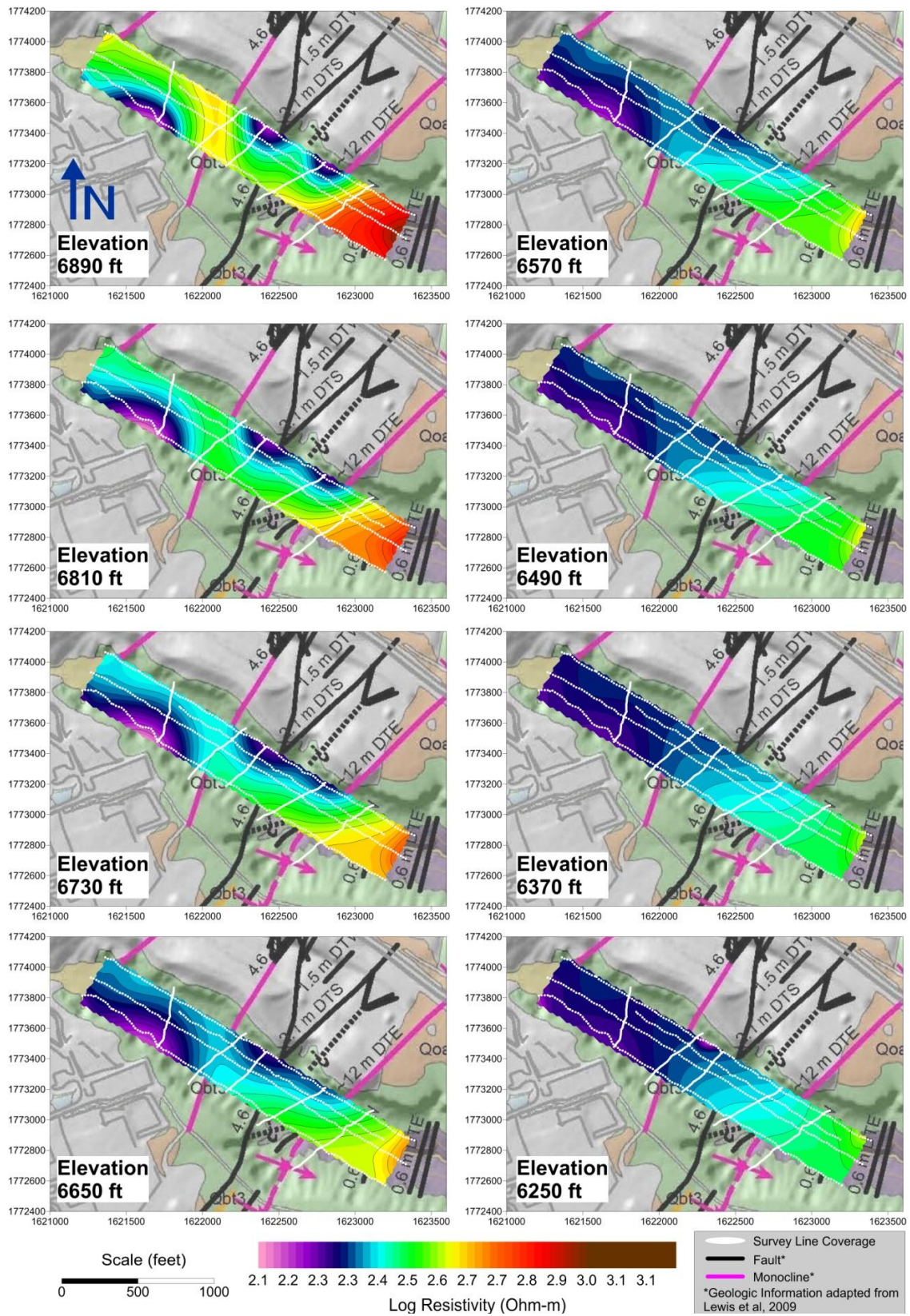
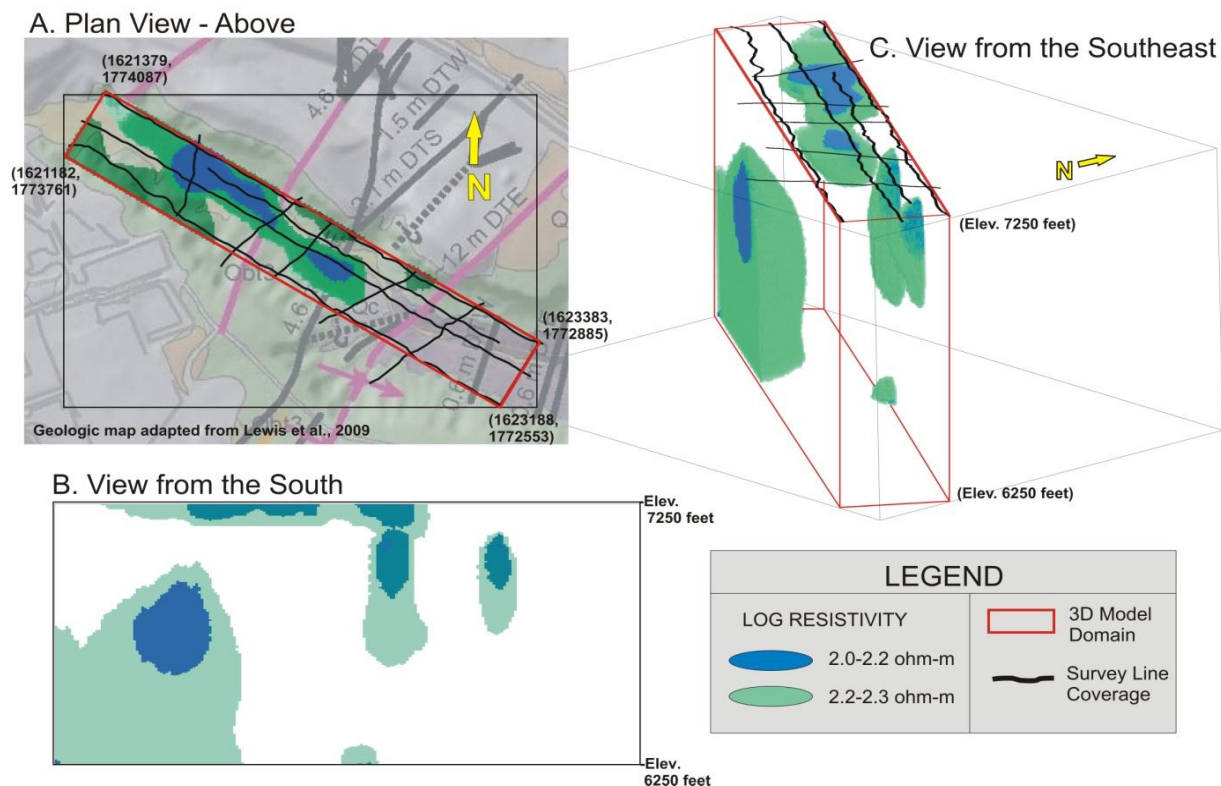


Figure 14 displays three-dimensional renderings of the low resistivity features along the Upper Sandia Canyon covered by the 3D inverse modeling. Figure 14(a) displays a plan view of the 3D model domain and results from above, figure 14(b) displays a profile view from the south (looking north), and figure 14(c) shows the isometric view along the long axis of the canyon, as viewed from the southeast (looking towards the northwest). Two levels of resistivity values are presented, with the small opaque resistivity body in blue (resistivity value of 100 to 150 ohm-m) and the larger transparent higher resistivity body in green (resistivity value between 150 and 200 ohm-m). The main regions of interest in the figure are the low resistivity feature in the near-surface, stretching downstream from the northwest corner of the model domain, labeled as feature (1) in Figure 13. In addition, there are several low resistivity regions, one approximately in the middle of the model domain and a second on the upper southwest corner of the model domain, which can be seen extending to depth. The feature in the middle of the model domain is coincident with an area of the upper Sandia Canyon where a number of potential faults have been mapped (Lewis *et al*, 2009).

Figure 14. Three-dimensional Renderings of the Low Resistivity Features Along the Upper Sandia Canyon.



5.0 CONCLUSIONS

Geophysical characterization activities, in the form of electrical resistivity, were completed in the wetland area of upper Sandia Canyon at the U.S. Department of Energy (DOE) Los Alamos National Laboratory in Los Alamos, New Mexico. Data were acquired between September 12 and September 20, 2011. Resistivity data were collected in two-dimensional (2D) profiles and inverted in both 2D and three-dimensional (3D) format, the latter producing a model that reduces distortions possibly seen in 2D profiles for complex 3D electrically conductive targets. The main conclusions of this study are:

- 2D and 3D inversions of DC resistivity data provide a model of electrical properties of subsurface materials of the region beneath and adjacent to the wetland in upper Sandia Canyon.
- Resistivity features are expected to correspond to, among other factors, variations in water content; ionic strength of pore water; and clay content.
- Numerous high- and low-resistivity features correspond to observed or reasonably inferred geological features. For example, a very conductive layer extending from the surface to 20-25 feet (6.1-7.6 m) below ground level in the upper Sandia Canyon wetland correlates well with an alluvial aquifer perched on a welded unit (Qbt₂) of the Bandelier Tuff.
- “Offsets” in horizontal resistive units may indicate structural features such as faults or zones of intense fracturing. The magnitudes of the offsets are much greater than displacements of mapped faults in the area and probably do not correspond to vertical offsets of rock units; rather, they may correspond to lateral differences in water or clay contents within units.
- Several areas of low resistivity correlate generally with mapped fault and/or fracture zones (as detailed in Lewis *et al*, 2009).
- In general, there is a widespread resistive layer beneath the wetland that may correspond to the near-surface welded Bandelier Tuff that lies below the wetland alluvium. This

resistive layer may represent an aquitard beneath much of the wetland. Several areas of subvertical low-resistivity structures that penetrate the potential Bandelier Tuff aquitard were identified in this survey; these low-resistivity structures may represent infiltration zones through the potential welded Bandelier Tuff aquitard, allowing moisture from the surface to reach depths of several hundred feet.

- At present, a significant limitation to the interpretation of these data is the ambiguity between the positive effects on electrical *conductivity* of clay and water content of rocks. For example, it is not possible to determine what values of resistivity might correspond to full saturation.
- These geophysical data provide important new information for the hydrogeologic model of the wetlands and will help inform future investigations.

6.0 REFERENCES

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- Oldenburg, D. W., and Li, Y., 1999, Estimating depth of investigation in DC resistivity and IP surveys: *Geophysics*, **64**, 403-416.

APPENDIX A

Plate 1 Profile 1 - Two-dimensional Model Resistivity Results

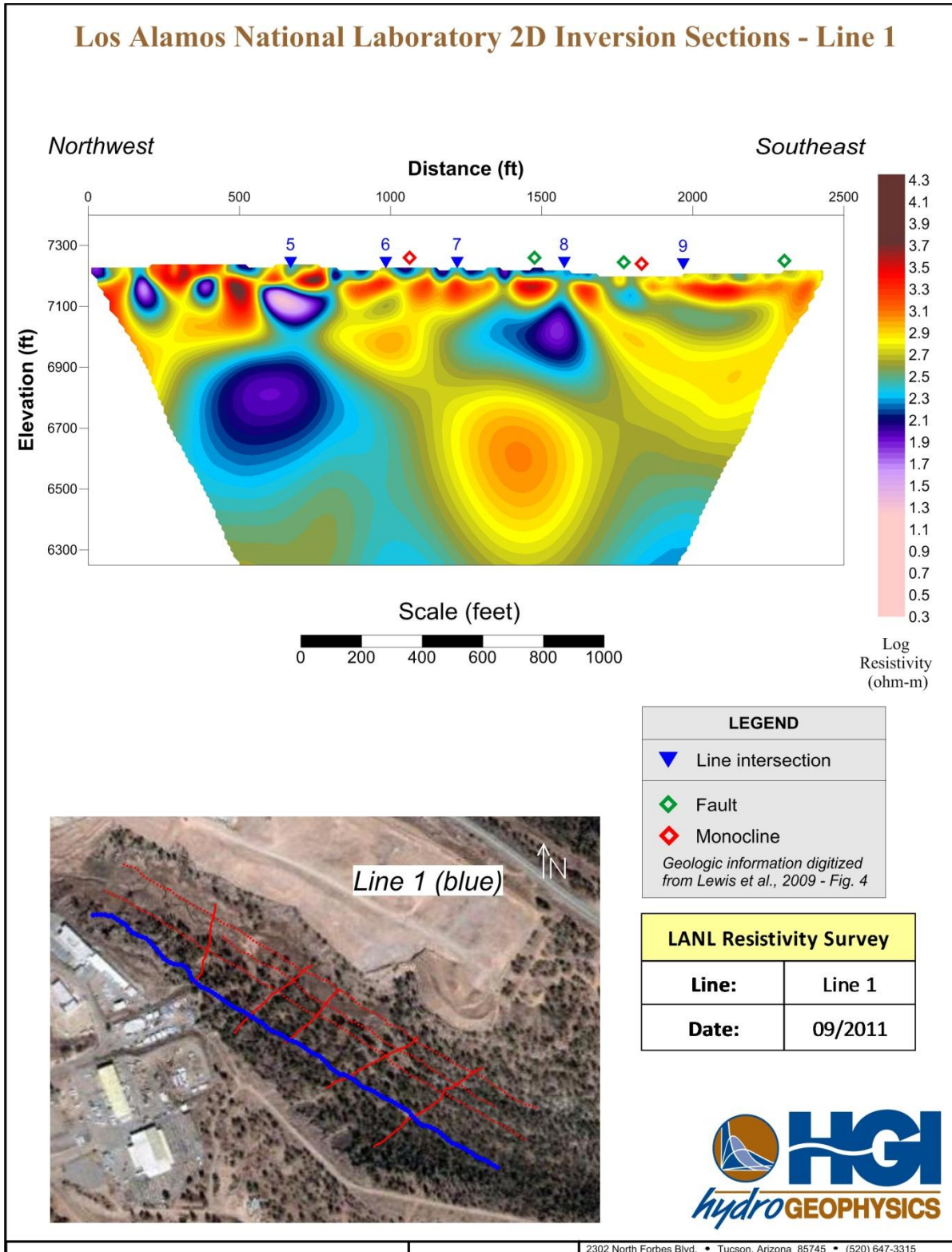


Plate 2Profile 2 - Two-dimensional Model Resistivity Results

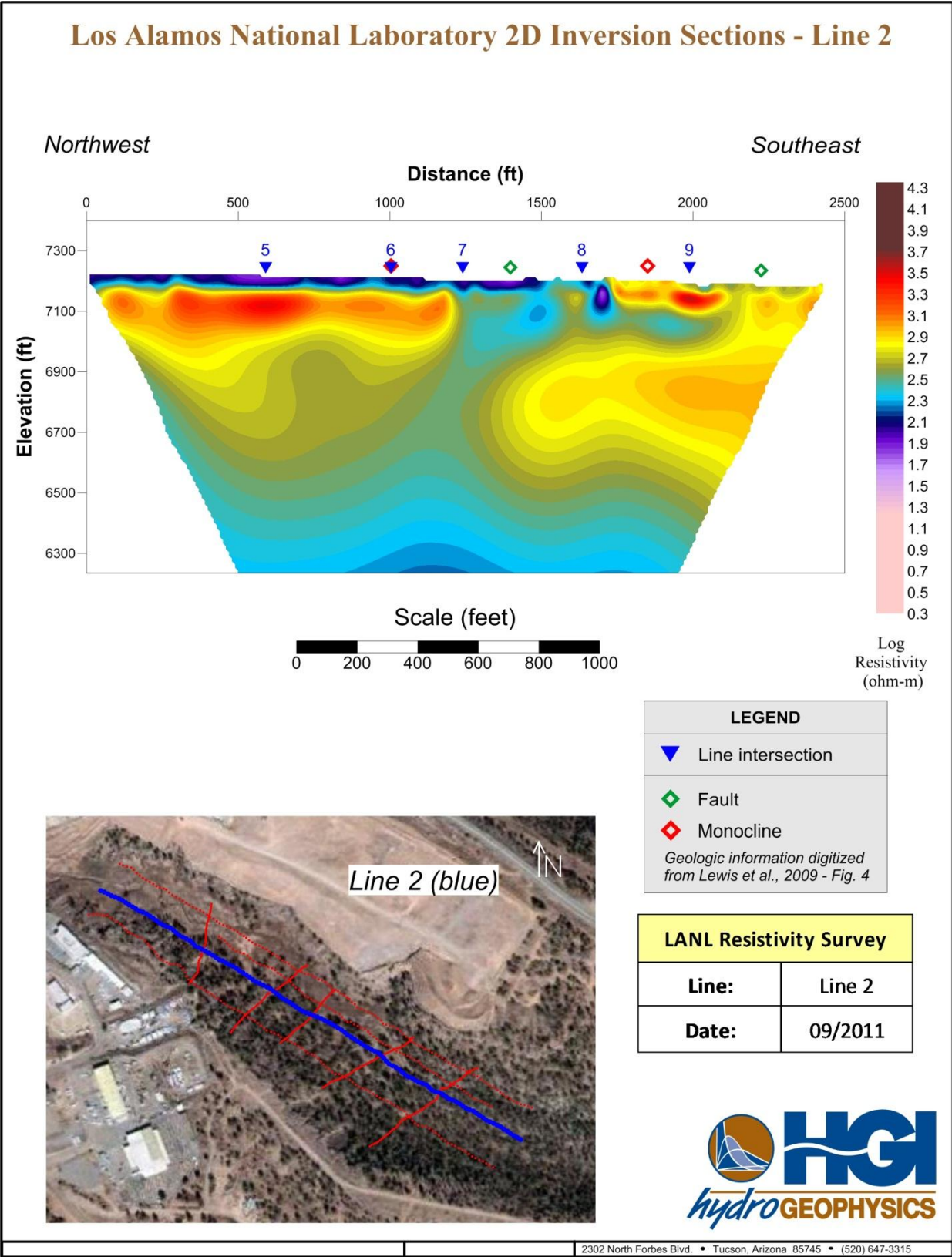
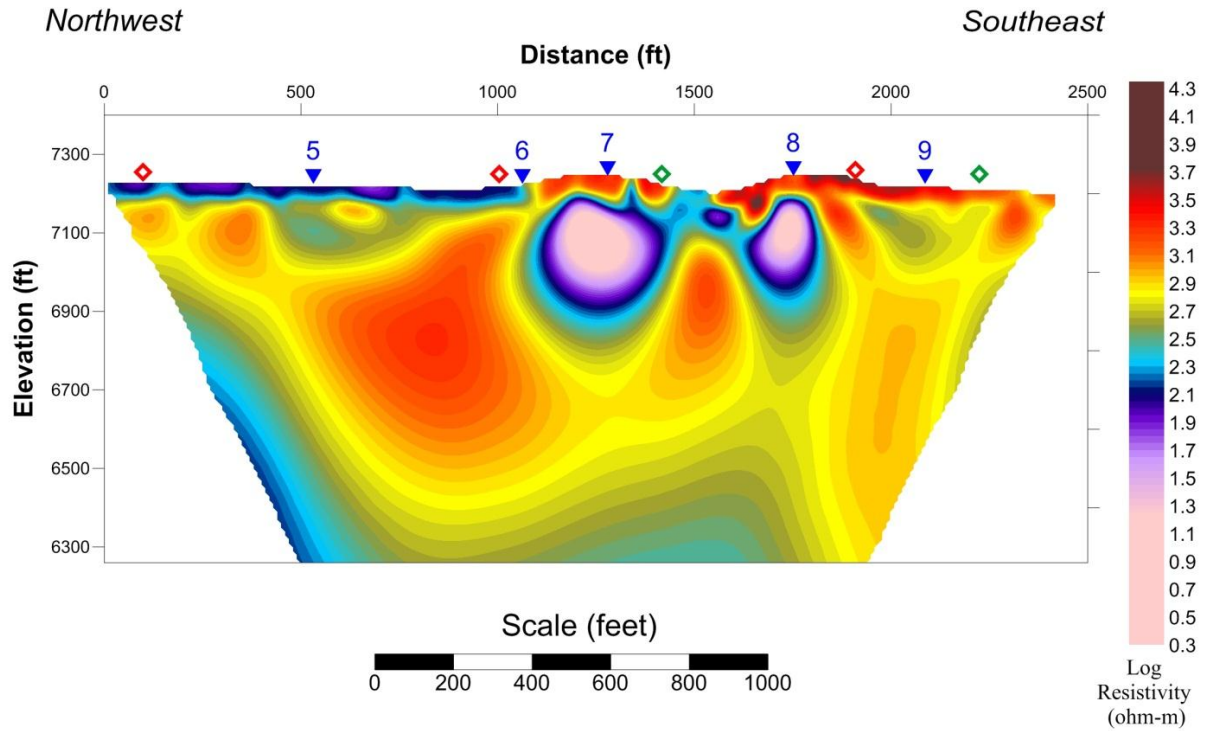
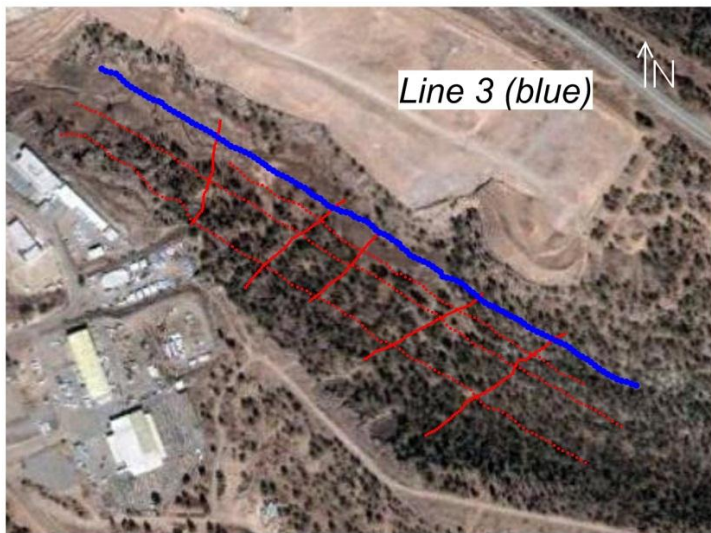


Plate 3 Profile 3 - Two-dimensional Model Resistivity Results

Los Alamos National Laboratory 2D Inversion Sections - Line 3



LEGEND	
	Line intersection
	Fault
	Monocline
<i>Geologic information digitized from Lewis et al., 2009 - Fig. 4</i>	



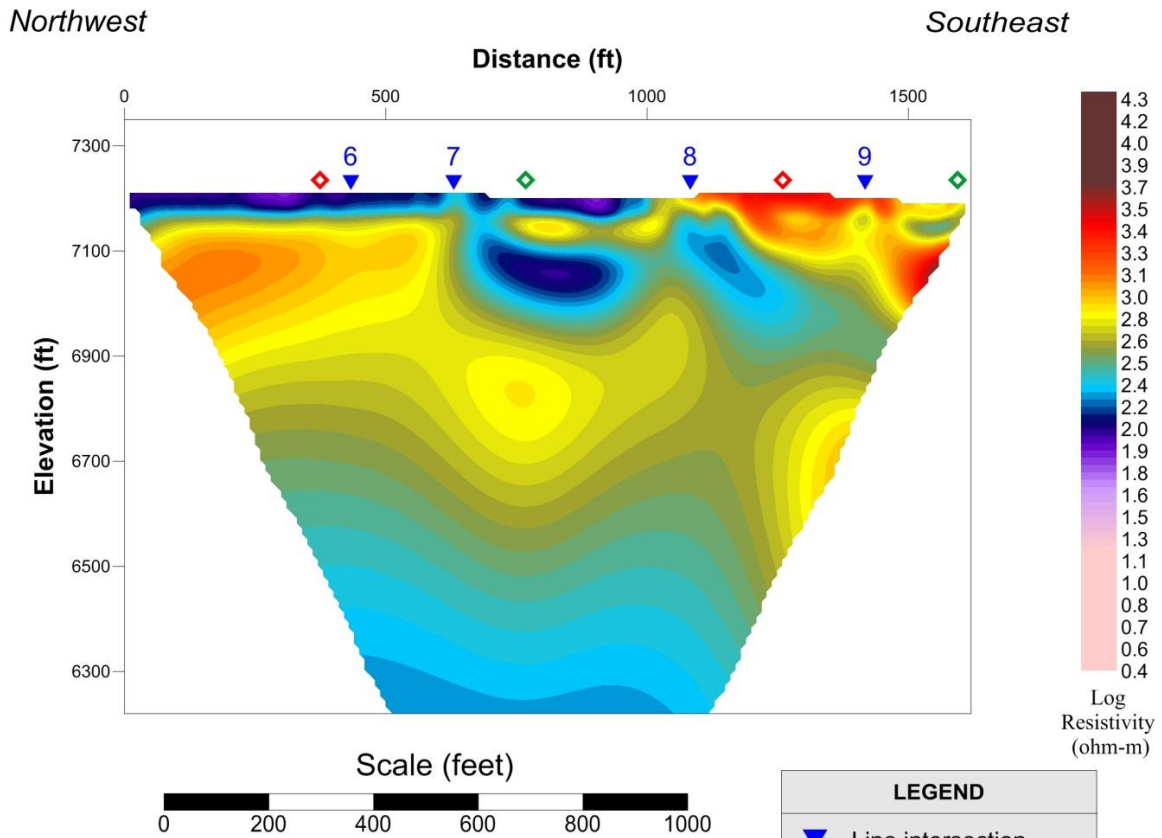
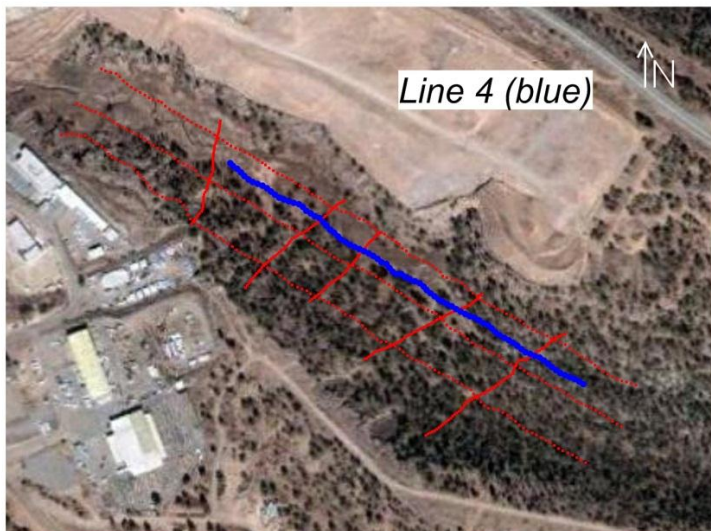
LANL Resistivity Survey	
Line:	Line 3
Date:	09/2011



2302 North Forbes Blvd. • Tucson, Arizona 85745 • (520) 647-3315

Plate 4 Profile 4 - Two-dimensional Model Resistivity Results

Los Alamos National Laboratory 2D Inversion Sections - Line 4



LEGEND	
▼	Line intersection
◆	Fault
◆	Monocline
Geologic information digitized from Lewis et al., 2009 - Fig. 4	

LANL Resistivity Survey	
Line:	Line 4
Date:	09/2011



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Plate 5 Profiles 1 through 4 Fence Plot - Two-dimensional Model Resistivity Results

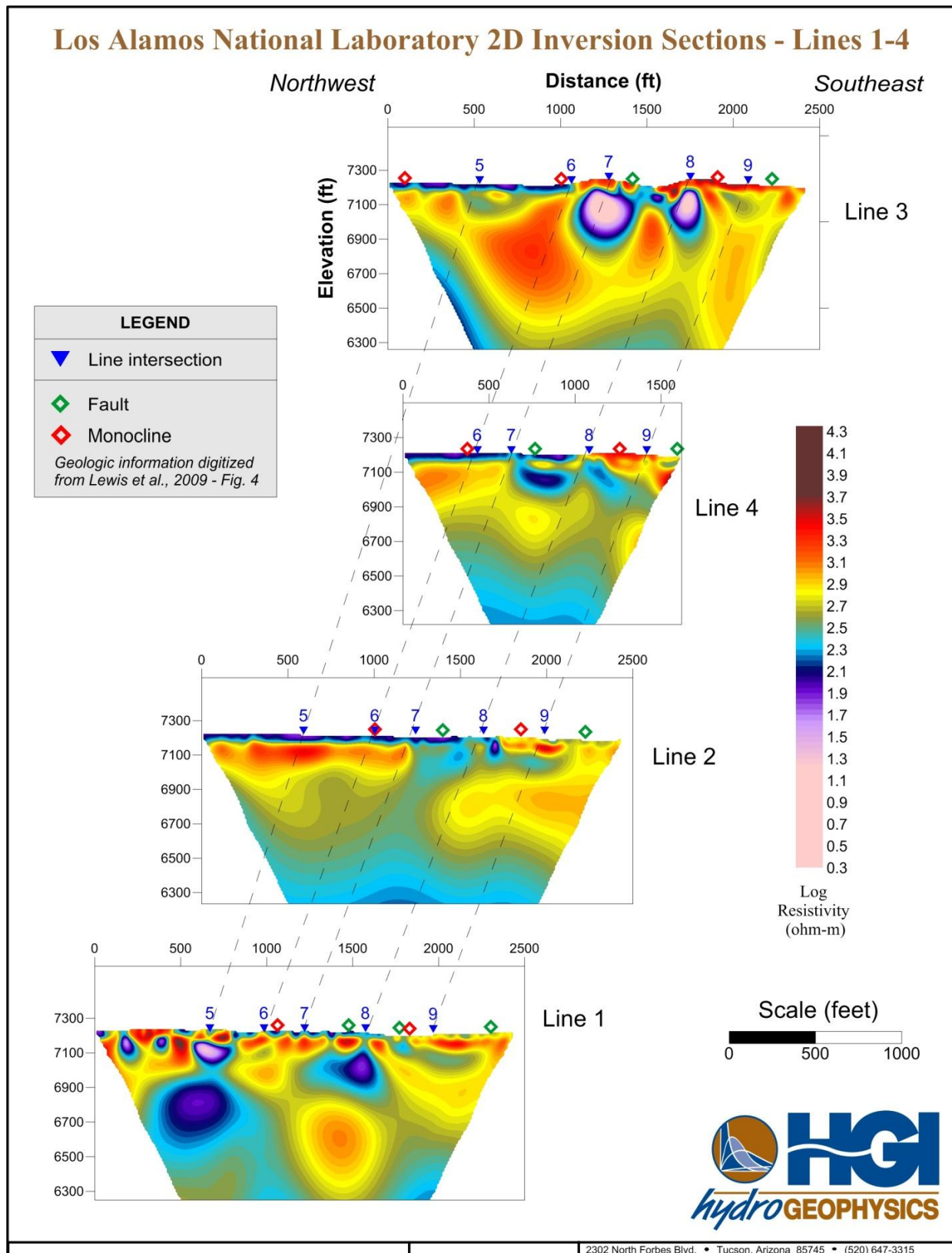
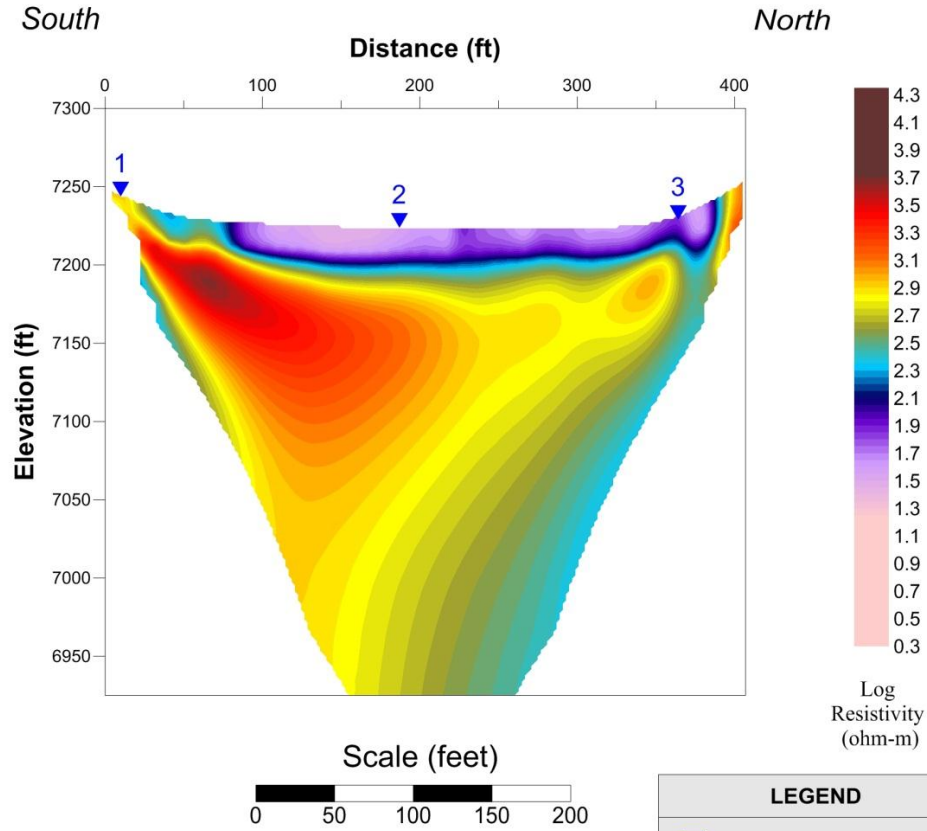
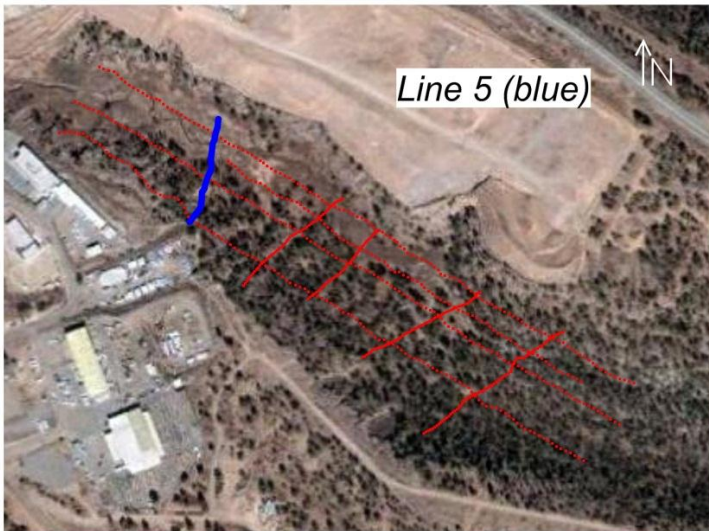


Plate 6 Profile 5 - Two-dimensional Model Resistivity Results

Los Alamos National Laboratory 2D Inversion Sections - Line 5



LEGEND	
▼	Line intersection
◇	Fault
◇	Monocline
Geologic information digitized from Lewis et al., 2009 - Fig. 4	

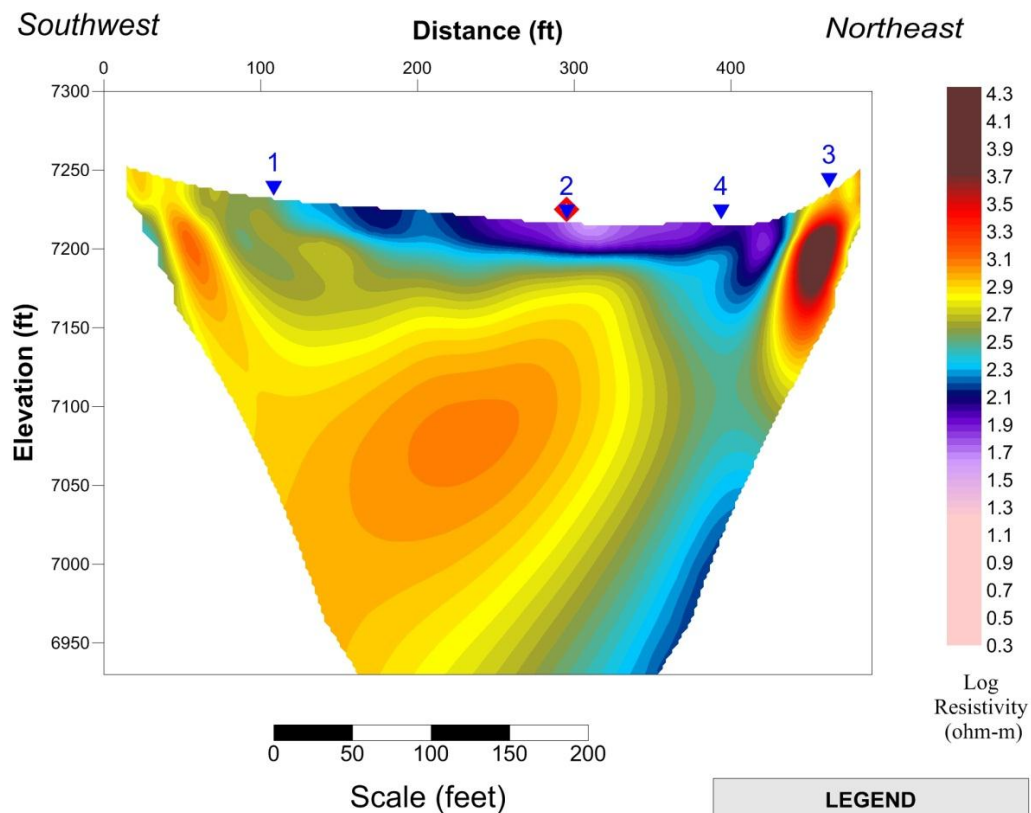
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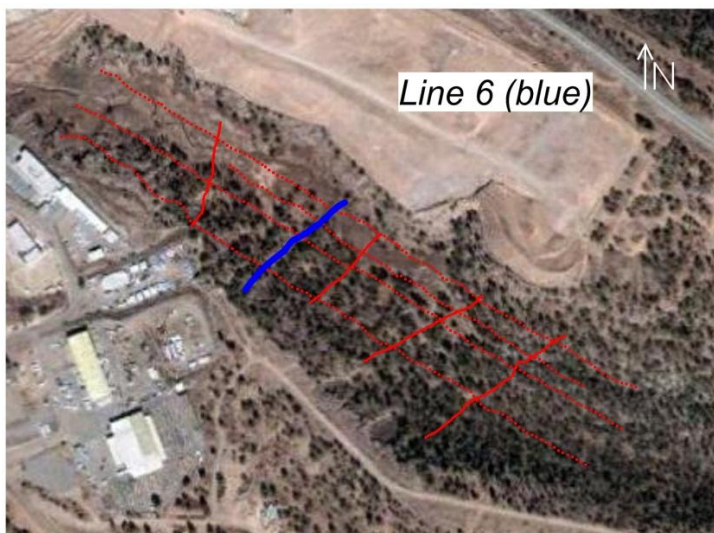
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Plate 7 Profile 6 - Two-dimensional Model Resistivity Results

Los Alamos National Laboratory 2D Inversion Sections - Line 6



LEGEND	
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◆	Fault
◆	Monocline
Geologic information digitized from Lewis et al., 2009 - Fig. 4	

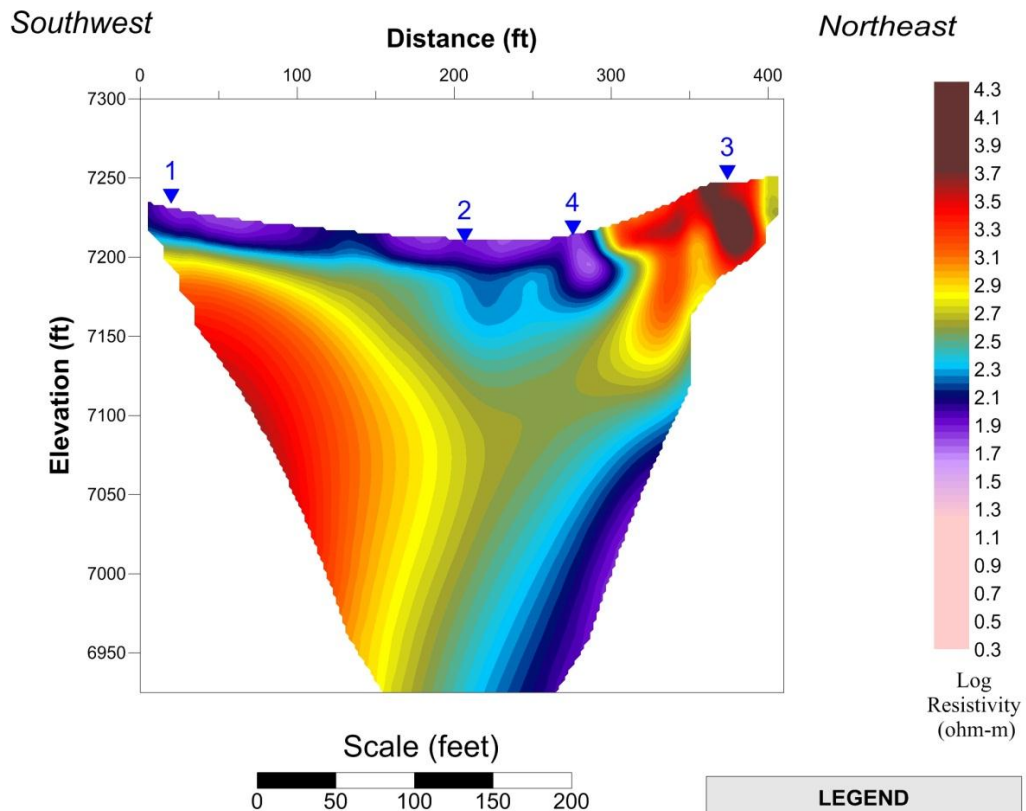
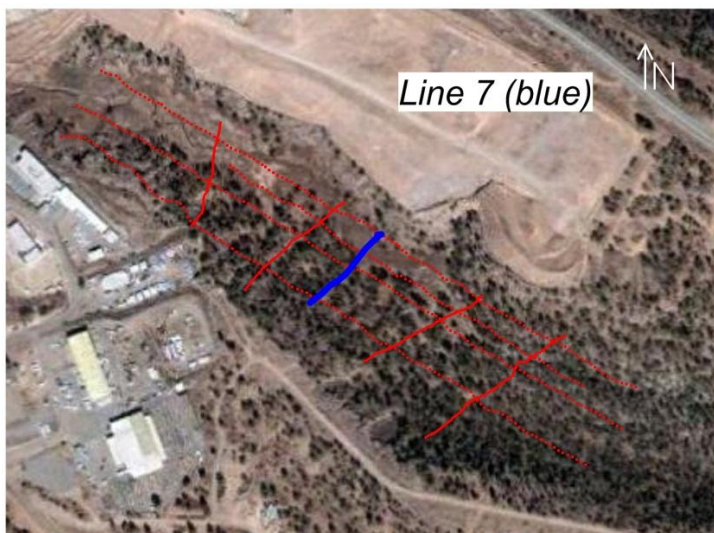


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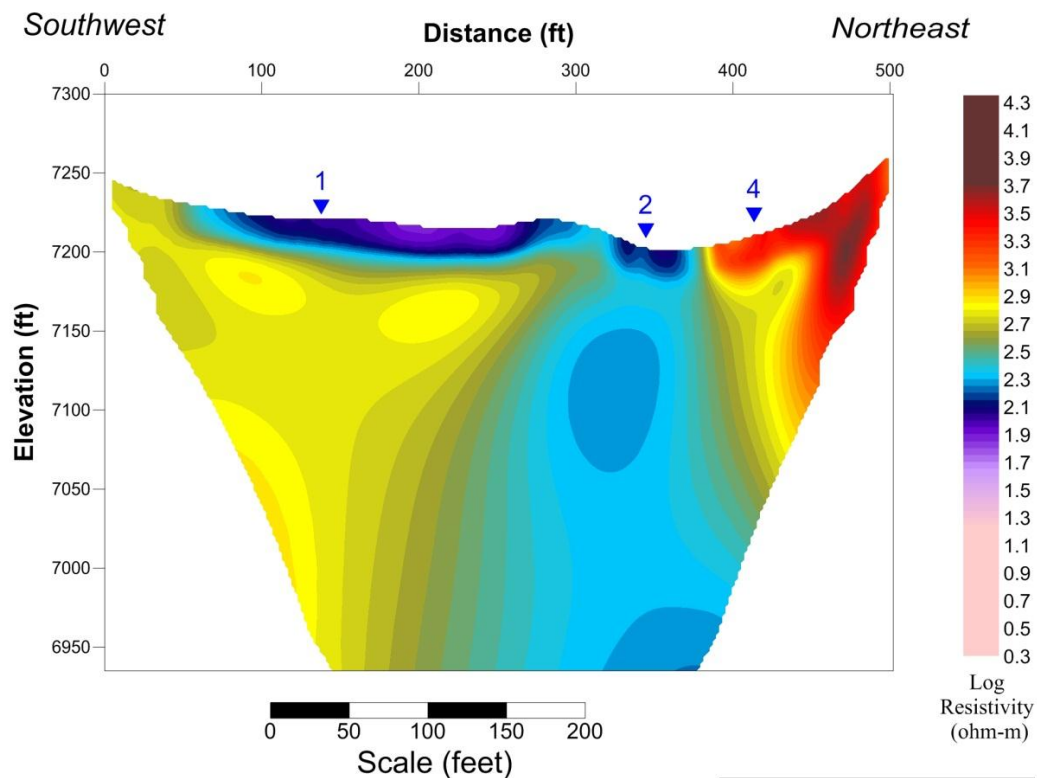
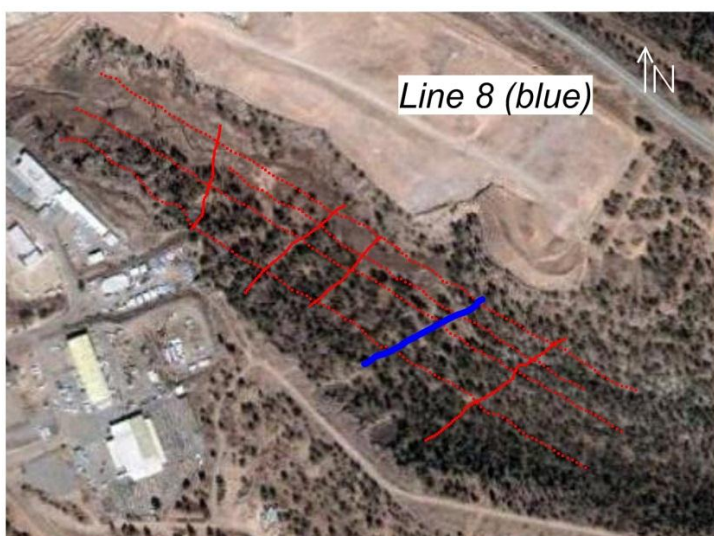
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Date:	09/2011



Los Alamos National Laboratory 2D Inversion Sections - Line 8

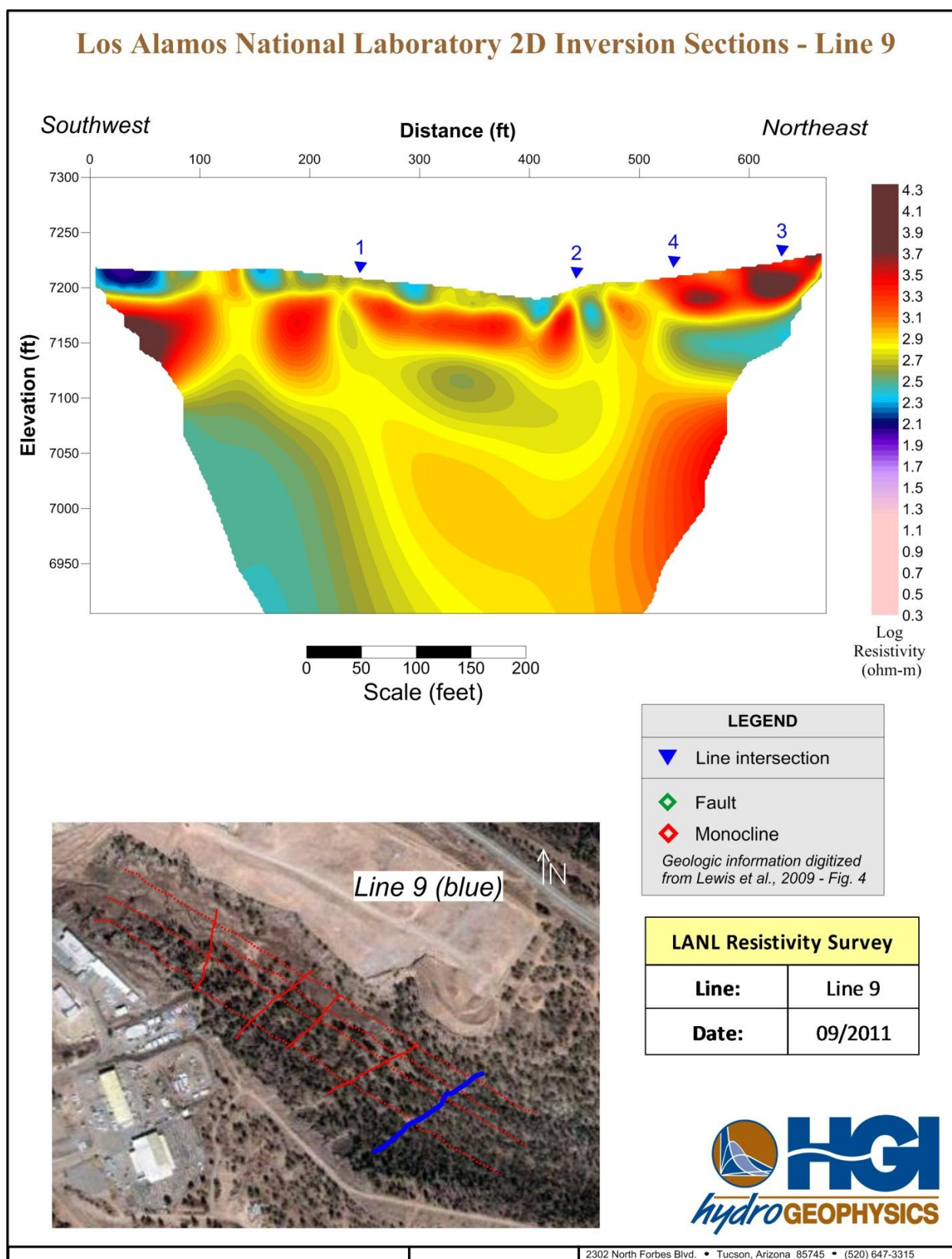


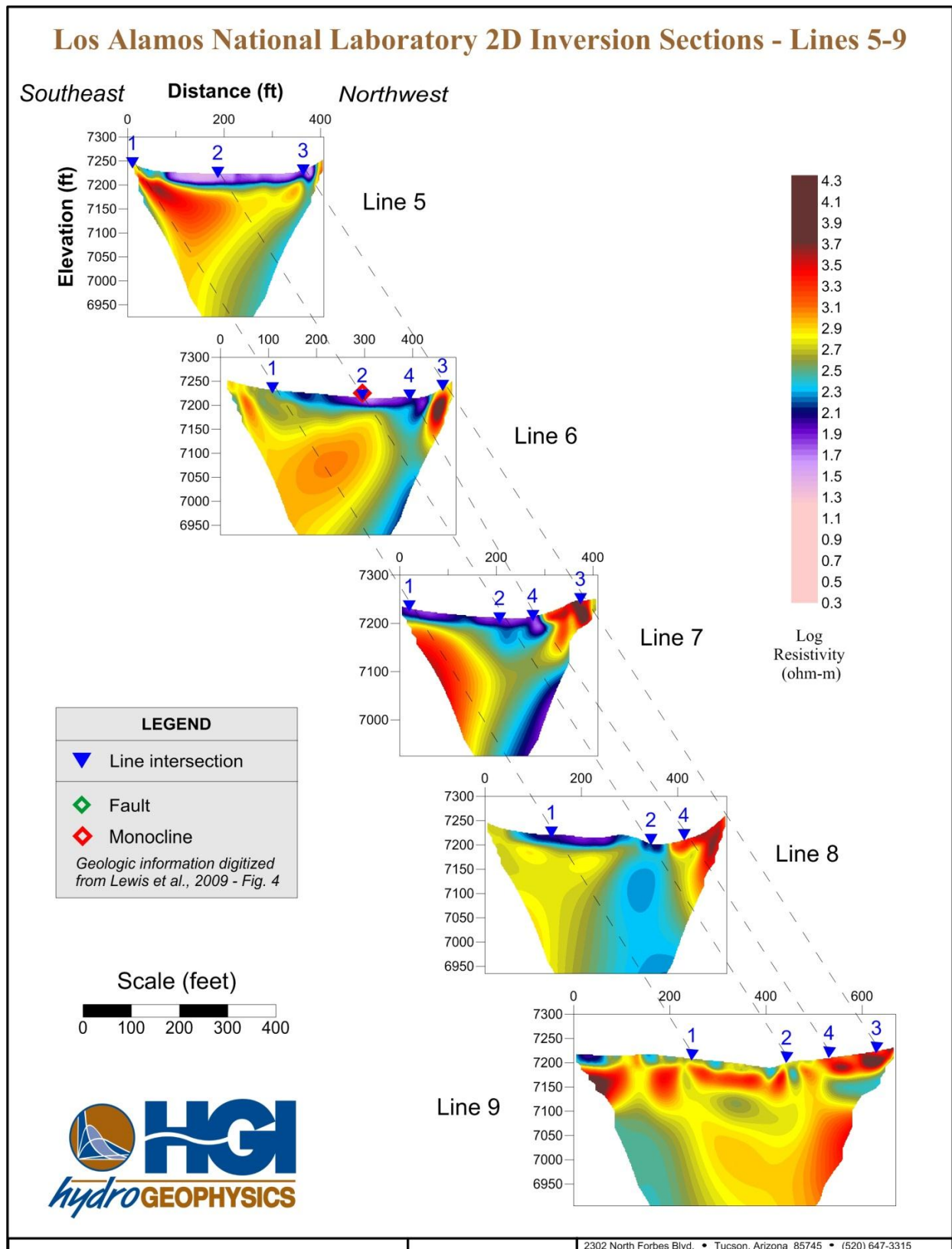
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◇	Monocline
Geologic information digitized from Lewis et al., 2009 - Fig. 4	

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Date:	09/2011



Plate 10 Profile 9 - Two-dimensional Model Resistivity Results





Appendix F

Perched-Intermediate Groundwater Level Responses

F-1.0 INTRODUCTION

Appendix F of the Sandia Canyon Investigation Report (hereafter the Phase I IR) summarized surface-water studies and established alluvial groundwater-level responses to surface-water flow in Sandia Canyon (LANL 2009, 107453). That appendix also examined perched-intermediate groundwater-level responses at wells SCI-1 and SCI-2. However, the period of record for water levels in those two intermediate wells was insufficient to determine whether the water levels responded to surface and alluvial processes. This appendix further examines perched-intermediate groundwater-level responses to surface water sources and alluvial groundwater levels at SCI-1 and SCI-2 by including additional water-level data collected since June 2009. In addition, water levels at intermediate wells MCOI-4, MCOI-5, and MCOI-6 in Mortandad Canyon are analyzed to determine whether there are hydrologic connections between the various groundwater zones beneath Sandia and Mortandad Canyons (see section 7.2). Groundwater temperatures are also examined as evidence of hydrologic connections in this study.

The hydrologic conceptual model, provided in section 7.2 of this report, describes surface water flows and infiltration patterns in Sandia Canyon. The analysis of available hydrogeological data indicates the primary zone of percolation to suballuvium bedrock units along Sandia Canyon occurs in the middle portion of the canyon, approximately between alluvial wells SCA-2 and SCA-4 where perched alluvial groundwater is present (Figures 3.2-1 and 7.0-1) (LANL 2009, 107453). Recharge to perched-intermediate zones located at wells SCI-1 and SCI-2 probably originates from this area. Similarly, in Mortandad Canyon, perched water is present in canyon-bottom alluvium. This perched water infiltrates the underlying bedrock, especially below the confluence of Mortandad and Ten Site Canyons (LANL 2006, 094161). Wells MCOI-4, MCOI-5, and MCOI-6 are located in this area, and recharge to those wells is probably derived from the perched alluvial groundwater in Mortandad Canyon.

F-2.0 SURFACE WATER SOURCES

National Pollutant Discharge Elimination System (NPDES) Outfall 001 in upper Sandia Canyon contributes much of the surface water that flows down Sandia Canyon. Figure F-2.0-1a shows daily and running-average outfall volumes recorded for NPDES Outfall 001 in upper Sandia Canyon (Plate 1) from October 1, 2006, to June 30, 2012. This outfall discharges effluent predominantly from Los Alamos National Laboratory's (the Laboratory's) Technical Area 46 (TA-46) Sanitary Wastewater Systems Consolidation plant and the TA-03 steam plant (TA-3-SM22) once daily. Effluent for cooling of the TA-03 power plant is also discharged here, but currently the power plant produces power only infrequently and adds little to the effluent volume. Outfall 001 is the main effluent source of water to Sandia Canyon, and average discharges were approximately 305,000 gal./d in 2011. Two other outfalls currently discharge to the head of Sandia Canyon, NPDES Outfalls 03A027 and 03A199 associated with facility cooling of the Strategic Computing Complex and the Laboratory Data Communications Center. Together, these outfalls contribute approximately 100,000 gal./d of cooling water effluent to the canyon with the highest effluent volumes in the summer. Figure F-2.0-1a also shows precipitation measured at the TA-06 weather station. A previous study showed that runoff contributes a significant volume of surface water as compared with effluent volume (LANL 2008, 102996). Together, the Outfall 001 and precipitation data in Figure F-2.0-1a provide information about surface water sources to Sandia Canyon.

NPDES Outfall 051 has historically released effluent from the Laboratory's Radioactive Liquid Waste Treatment Facility to Effluent Canyon, a tributary of Mortandad Canyon (section 2.1.2). This outfall has been a significant surface water source to Mortandad Canyon since 1963, but outfall volumes have declined steadily since the early 1980s (Figure F-2.0-2). No effluent has been released from Outfall 051 since November 2010.

It is noteworthy that large, fairly steady effluent volumes have been discharged continuously to Sandia Canyon since the early 1950s. In contrast, effluent volumes discharged to Mortandad Canyon have declined. This difference in the effluent histories of the two adjacent canyons is used to determine if long-term perched-intermediate water levels have responded to these distinct surface water sources.

F-3.0 PERCHED-INTERMEDIATE GROUNDWATER LEVELS

Perched-intermediate monitoring well SCI-1 (Figure 3.2-1 and Plate 1) is located on the north side of the road in Sandia Canyon between alluvial wells SCA-2 and SCA-3. SCI-1 is screened in the Puye Formation just above the contact with the Cerros del Rio basalt at approximately 300 ft depth below the base of the alluvium. Monitoring well SCI-2 is located about 270 ft south of SCA-3 and near regional well R-43; this well is screened in the Cerros del Rio basalt where the perched-intermediate groundwater is about 500 ft below the base of the alluvium. The mean daily groundwater levels at SCI-1 and SCI-2 are shown in Figure F-2.0-1b for the periods from February 2007 to June 2012 and from February 2009 to June 2012, respectively. Also shown are mean daily groundwater levels at nearby alluvial wells SCA-3 and SCA-4 and piezometers SCP-1c, SCP-2a and SCP-2b. This figure shows that alluvial water levels fluctuate at a much higher frequency than the intermediate-zone water levels. The groundwater level at SCI-1 has fluctuated approximately 7 ft over the period of record. The water-level fluctuation is smooth and shows a gradual groundwater rise from October 2007 to November 2010 and a gradual decline of about 3 ft from November 2010 to early 2012. Some inflections occur in the water-level curves for well SCI-1 (e.g., in late summer 2008 and fall 2010) that demonstrate potential responses to larger water-level changes in alluvial water levels. The groundwater level at SCI-2 has fluctuated approximately 5 ft over its period of record, showing a rising trend from 2008 to the end of 2011 of about 5 ft, followed by a decline of about 0.5 ft in 2012. There is no obvious water-level response to either surface water flows or alluvial water-level fluctuations at deeper well SCI-2.

Figure F-2.0-3 shows the relative groundwater-level fluctuations in the intermediate groundwater beneath Sandia Canyon at wells SCI-1 and SCI-2 and the intermediate groundwater beneath Mortandad Canyon at wells MCOI-4, MCOI-5, and MCOI-6. MCOI-4 is screened in Puye sediments at the top of the Cerros del Rio basalts, and MCOI-5 and MCOI-6 are screened in the basalt. Also shown in the figure are the more recent monthly discharge volumes from Outfall 051 that enter Mortandad Canyon. No discharges from this outfall have occurred since November 2010. The perched-intermediate groundwater level at MCOI-4 declined about 2 ft between 2008 and the middle of 2010. Water levels have been steady since late 2010, but there is some uncertainty about the accuracy of these later data, which may represent water in the sump. The perched-intermediate groundwater at MCOI-5 and MCOI-6 shows similar long-term trends: a gradual rise of about 10 ft from 2006 to 2008, relatively steady water levels from 2008 to 2011, followed by gradual decline of about 5 ft from 2011 to 2012. There is no obvious water-level response at the perched-intermediate wells MCOI-4, MCOI-5, and MCOI-6 because of the long-term decline in effluent volumes released at Outfall 051 (Figure F-2.0-2) because water levels at those wells gradually rise and fall. However, while the water levels at wells MCOI-5 and MCOI-6 have been steady or declining, the levels at well SCI-2 have risen. Given that outfall discharges have declined in Mortandad Canyon while remaining essentially steady in Sandia Canyon and that intermediate water levels within the basalt in Mortandad Canyon (i.e., at MCOI-5 and MCOI-6) have declined since early 2010 while those in Sandia Canyon have risen (i.e., at SCI-2), the data do not preclude that recent intermediate groundwater decline at MCOI-5 and MCOI-6 could be related to the decline and subsequent cessation of discharges from Outfall 051.

The intermediate groundwater beneath Sandia and Mortandad Canyons does not clearly indicate a correlation with runoff events or alluvial groundwater fluctuations in Sandia or Mortandad Canyons. A longer period of groundwater-level data for both SCI and MCOI wells and a more formal analysis of the data might better illustrate such correlations.

F-4.0 GROUNDWATER TEMPERATURE

The alluvial and intermediate groundwater temperature time series for the period from October 2006 to June 2012 is presented in Table F-4.0-1 and Figure F-4.0-1. Temperature variations in the alluvial wells are described in Appendix F of the Phase I report (LANL 2009, 107453). Here, the longer temperature records are used to determine whether connections between alluvial groundwater and perched-intermediate groundwater can be established.

The groundwater temperature at intermediate monitoring well SCI-1 is approximately 11 °C. This is warmer than at alluvial wells SCA-2 and SCA-3, which have temperatures near 8 °C, but is similar to that of alluvial well SCA-4. The groundwater temperature at SCI-1 does not show an apparent seasonal trend but has shown a temperature decline of about 0.5 °C from 2007 to 2012 while its groundwater level has risen (Figure F-2.0-1b). The SCI-1 groundwater level is approximately 300 ft lower than at wells SCA-3 and SCA-4. Based on a local geothermal gradient of 33°C/km (1 °C/100 ft) (Kron and Heiken 1980, 097415), SCI-1 would be approximately 3 °C warmer than SCA-3 or SCA-4 if the geothermal gradient controlled its temperature. This difference exists between wells SCA-3 and SCI-1, which indicates the geothermal gradient controls the temperature of water at SCI-1 and that the flow path is slow enough to allow for temperature equilibrium. The similarity in the groundwater temperatures at SCI-1 and SCA-4 may indicate the intermediate groundwater is sourced from the alluvium in middle Sandia Canyon with faster recharge. Because SCI-1 is located closer to SCA-3 than to SCA-4 (Figure 3.2-1), the former is more likely to be the case.

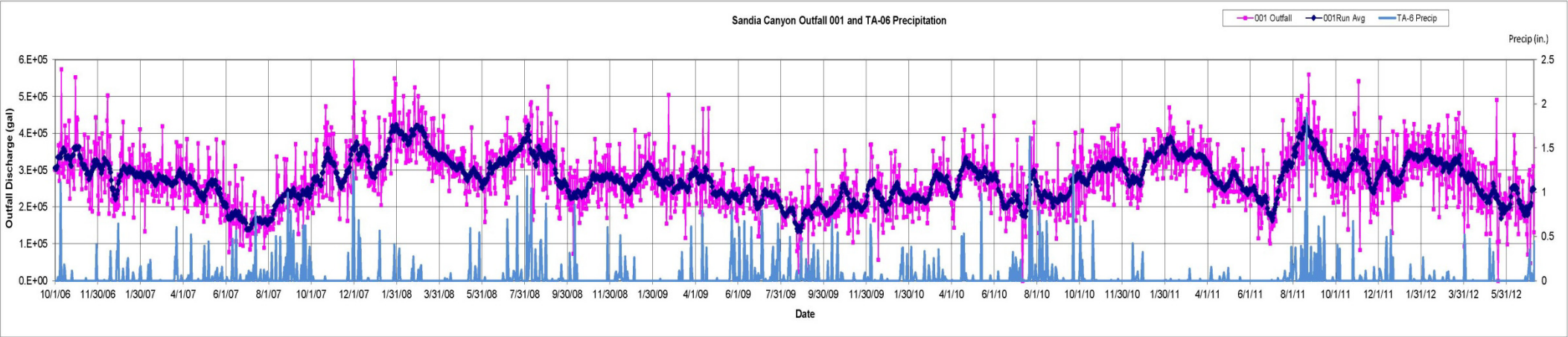
The intermediate groundwater temperature in the Cerros del Rio basalt at SCI-2 is about 16 °C, similar to that of MCOI-5 and MCOI-6 in Mortandad Canyon, and about 5 °C higher than at SCI-1 and SCA-4; the groundwater at SCI-2 is about 160 ft deeper than at SCI-1 and 460 ft deeper than at SCA-4. The temperature at SCI-2 was relatively constant from 2008 to early 2010, after which the temperature has steadily declined about 0.15 degrees. The difference in temperature between SCA-4 and SCI-2 is very close to the 4.6 °C dictated by the geothermal gradient, implying the temperature of the perched-intermediate groundwater at SCI-2 is in thermal equilibrium with the surrounding rock and that this groundwater is not actively recharged by alluvial water. The same conclusion can be drawn by analogy at wells MCOI-5 and MCOI-6.

F-3.0 REFERENCES

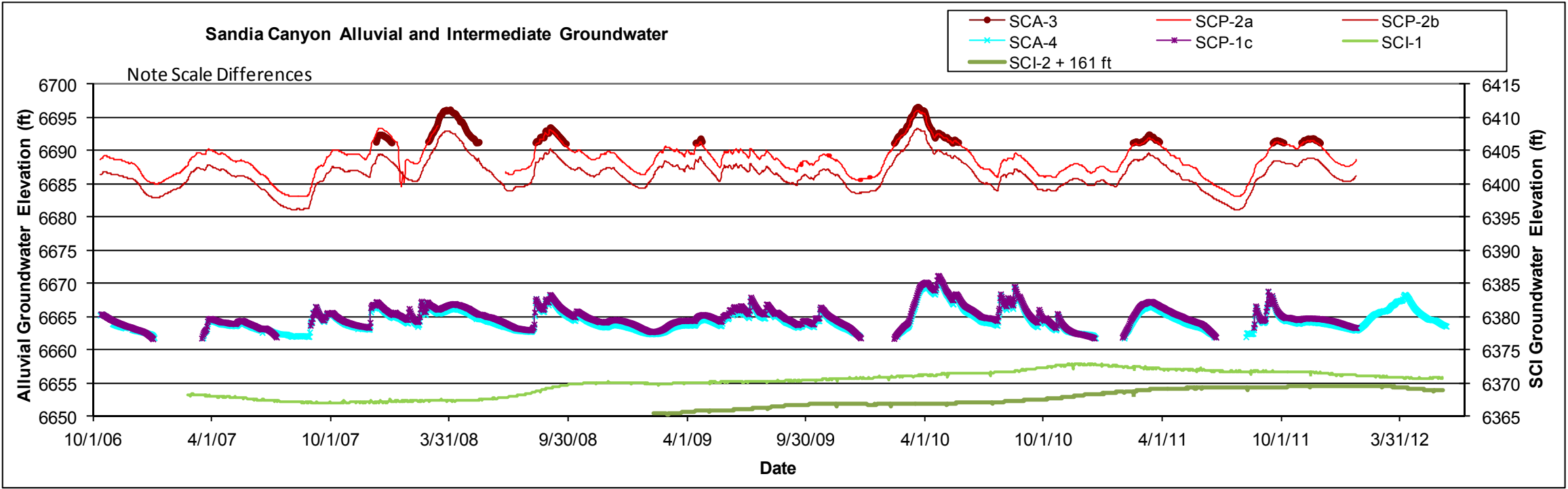
The following list includes all documents cited in this appendix. Parenthetical information following each reference provides the author(s), publication date, and ER ID. This information is also included in text citations. ER IDs are assigned by the Environmental Programs Directorate's Records Processing Facility (RPF) and are used to locate the document at the RPF and, where applicable, in the master reference set.

Copies of the master reference set are maintained at the New Mexico Environment Department Hazardous Waste Bureau and the Directorate. The set was developed to ensure that the administrative authority has all material needed to review this document, and it is updated with every document submitted to the administrative authority. Documents previously submitted to the administrative authority are not included.

- Kron, A., and G. Heiken, 1980. "Geothermal Gradient Map of the Conterminous United States," Los Alamos Scientific Laboratory map number LA-8476-MAP, Los Alamos, New Mexico. (Kron and Heiken 1980, 097415)
- LANL (Los Alamos National Laboratory), October 2006. "Mortandad Canyon Investigation Report," Los Alamos National Laboratory document LA-UR-06-6752, Los Alamos, New Mexico. (LANL 2006, 094161)
- LANL (Los Alamos National Laboratory), July 2008. "Fate and Transport Investigations Update for Chromium Contamination from Sandia Canyon," Los Alamos National Laboratory document LA-UR-08-4702, Los Alamos, New Mexico. (LANL 2008, 102996)
- LANL (Los Alamos National Laboratory), October 2009. "Investigation Report for Sandia Canyon," Los Alamos National Laboratory document LA-UR-09-6450, Los Alamos, New Mexico. (LANL 2009, 107453)



a.



b.

Figure F-2.0-1 Sandia Canyon outfall volumes and TA-06 precipitation records. Also shown are mean daily water levels measured in alluvial wells SCA-3 and SCA-4, alluvial piezometers SCP-1c and SCP-2a,b and intermediate wells SCI-1 and SCI-2, for the period of record, October 2006 to May 2012.

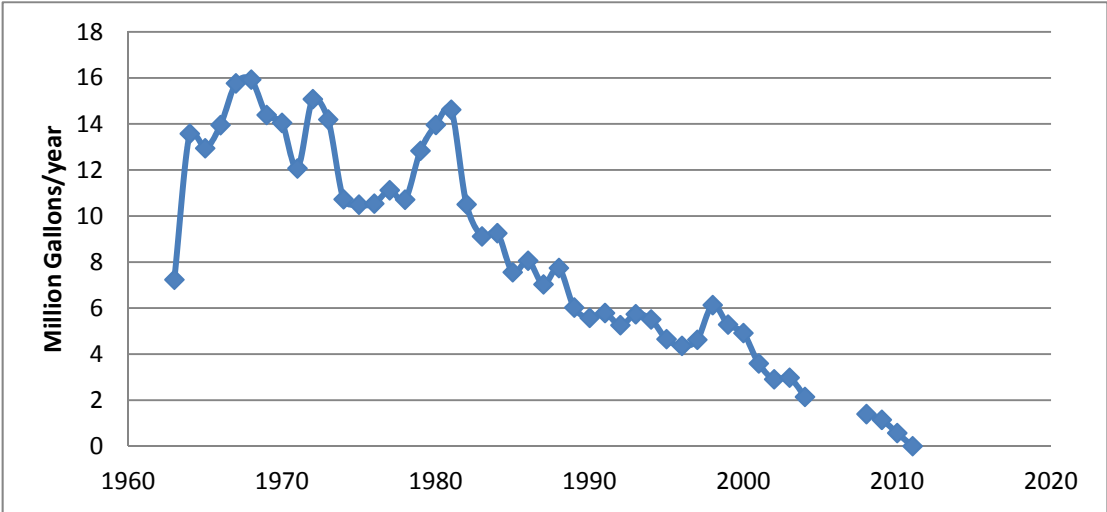


Figure F-2.0-2 Annual outfall volumes released from Outfall 051

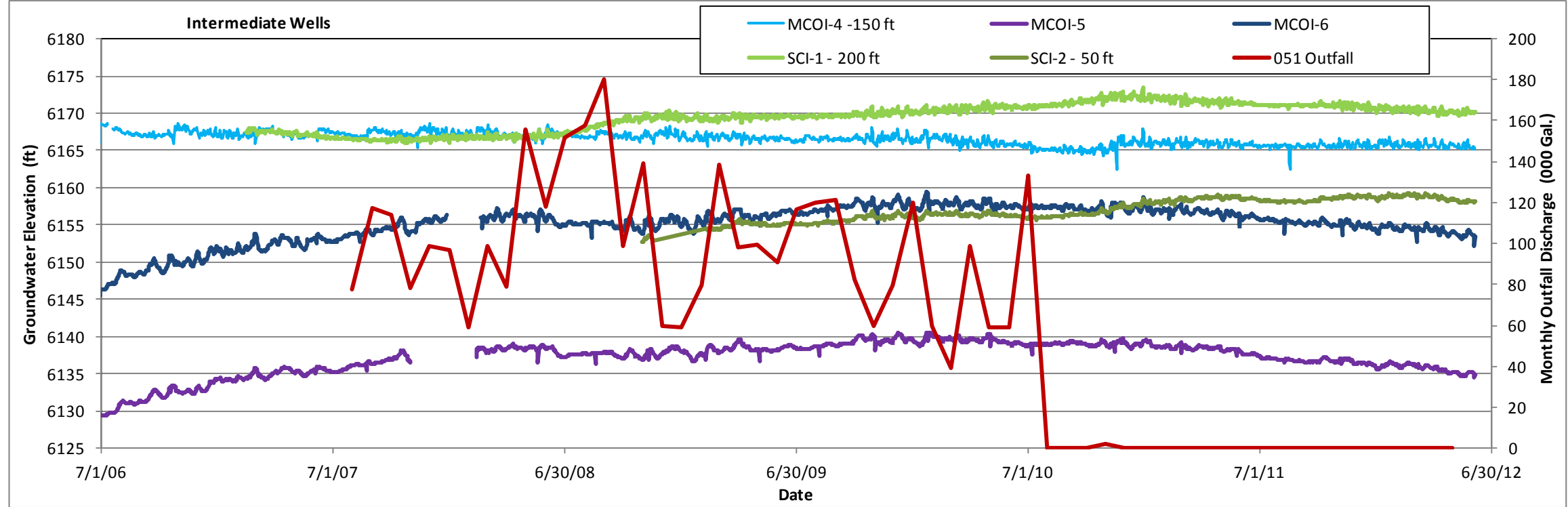


Figure F-2.0-3 Mean daily alluvial water levels measured in intermediate wells SCI-1, SCI-2, MCOI-4, MCOI-5, and MCOI-6. Also shown are monthly discharge volumes for Mortandad Canyon Outfall 051.

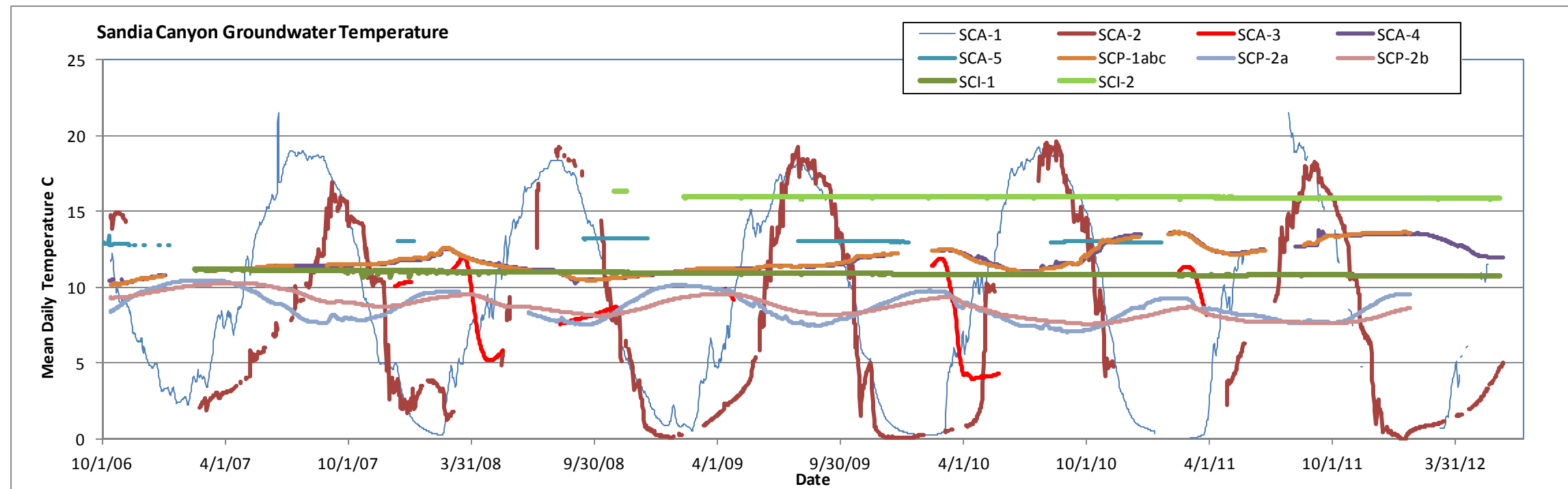


Figure F-4.0-1 Temperature fluctuations in Sandia Canyon alluvial and intermediate groundwater

Table F-4.0-1
Summary of Alluvial and Intermediate
Groundwater Temperature Data in Sandia Canyon

Well Name	Port Description	Avg T (C)	Min T (C)	Max T (C)	Std Dev (C)	Count
SCA-1	SINGLE COMPLETION	9.36	0.04	21.73	6.35	41442
SCA-2	SINGLE COMPLETION	7.79	-0.06	22.52	6.46	27713
SCA-3	SINGLE COMPLETION	8.22	3.93	11.98	2.45	9150
SCA-4	SINGLE COMPLETION	11.84	0.25	22.26	0.88	43688
SCA-5	SINGLE COMPLETION	13.03	12.71	17.86	0.11	14886
SCP-1abc	SCP-1a	11.90	10.37	13.89	0.85	15543
SCP-1abc	SCP-1b	11.76	10.11	13.79	0.87	33735
SCP-1abc	SCP-1c	11.68	9.98	13.58	0.85	39708
SCP-2a	SINGLE COMPLETION	8.68	7.06	10.47	0.93	43714
SCP-2b	SINGLE COMPLETION	8.73	7.59	10.31	0.75	46307
SCI-1	SINGLE COMPLETION	10.81	9.77	10.89	0.04	21294
SCI-2	SINGLE COMPLETION	15.93	15.00	15.99	0.04	21294
MCOI-4	SINGLE COMPLETION	14.57	14.25	14.63	0.03	20616
MCOI-5	SINGLE COMPLETION	15.98	15.81	16.04	0.02	21267
MCOI-6	SINGLE COMPLETION	14.92	14.88	16.34	0.05	21267

Appendix G

*Analysis of Regional Aquifer Water Levels
Observed at Monitoring Wells Near Sandia Canyon*

G-1.0 MAPS OF THE REGIONAL AQUIFER WATER-TABLE NEAR SANDIA CANYON

This appendix presents two different analyses of the shape of the regional water table based on the available water-level data. First, the large-scale analysis incorporates data from all the regional wells on the Pajarito Plateau (section G-1.1) using monthly averages for February 2011; a complete set of water-level data for all the regional wells was not available for the first months of 2012 at the time this appendix was prepared. January 2012 monthly-averaged water-level data are applied for small-scale analysis of the regional water table near Sandia Canyon (section G-1.2).

G-1.1 REGIONAL WATER-TABLE MAP

The regional aquifer beneath Los Alamos National Laboratory (LANL or the Laboratory) is a complex hydrogeological system. The top of the aquifer is predominantly under phreatic (water-table) conditions. However, areas of local confinement are also caused by local hydrogeological conditions. In general, the top of the regional aquifer is defined by the elevation of the regional water table. In the areas of local confinement, a regional piezometric surface represents the elevation of hydraulic heads in the confined zones. In general, the regional piezometric surface can be considered to represent a spatial continuation of the water table in the confined areas. Because the aquifer is predominantly under phreatic conditions, the term “regional water table” is used even though in some areas of the aquifer the term “regional piezometric surface” is more appropriate.

The general shape of the regional water table is predominantly controlled by the areas of regional recharge to the west (flanks of Sierra de los Valles) and discharge to the east (the Rio Grande and the White Rock Canyon springs). The structure of the regional phreatic flow is also expected to be impacted by (1) local infiltration zones (e.g., beneath wet canyons); (2) heterogeneity of aquifer properties; and (3) discharge zones (water-supply wells and springs).

Information about the elevation of the regional water table is provided by existing data from monitoring wells (water levels) and selected springs (discharge elevations). Well data are used primarily to map the elevation of the regional water table; spring discharge elevations are used only in the vicinity of White Rock Canyon to provide additional constraints on the water-table elevation.

Water-table elevations vary in time because of transient effects that include pumping of the water-supply wells and large- and small-scale variability in aquifer recharge. Therefore, water-level maps represent specific periods of time. Averaged water levels for February 2011 are computed for the regional aquifer wells and presented in Figure G-1.1-1. For abandoned wells TW-2 and TW-3, historical water-level data that are considered to be uncertain but important for constraining the water-table map in the northern portion of the Laboratory are used. February 2011 measurements also were not available for CdV-R-37-2. Because this well is important for characterizing the groundwater flow directions near the Pajarito fault zone, July 2010 data are used for this well. The analysis also includes more recent water-level data for newly installed wells: July 2011 for well R-64, May 2011 for R-61, and November 2011 for R-62.

In addition to the transients, many other factors complicated the contouring of the regional water table. For example, differences in well-screen placements and local hydrogeologic conditions complicate the interpretation of the water-level data.

1. Some screens are substantially below the top of regional saturation (more than 60 ft); as a result, the water-level data collected may not represent actual water-table elevations (e.g., R-10a, R-13, R-18, R-20, R-21, R-26, R-28, R-32, and R-34).

2. Some screens are long (more than 50 ft) and may represent composite water levels within the aquifer (DT wells, R-8, R-13, and R-15, a total of six wells).
3. Some screens are under confined conditions and represent piezometric surface elevations (e.g., R-4 and R-24).
4. Well R-25 is drilled in a complicated hydrogeological setting, and it is uncertain which of two R-25 screens (screen 4 or 5) provides information about the water-table elevation.
5. Well R-9 is screened in a zone (basalts within Santa Fe Group, Tb2) that is potentially disconnected from the regional aquifer.

Water-table screens are located in various hydrostratigraphic units, including sedimentary and volcanic rocks with contrasting hydrogeologic properties; it is expected the structure of the regional water table is impacted by groundwater flow through hydrostratigraphic units with contrasting properties.

The process of water-table contouring is theoretically constrained by conformity rules (Freeze and Cherry 1979, 088742): (1) the contour lines should be perpendicular to the flow paths and (2) the length and the width of the flownet cells formed by the contour lines between two adjacent flow paths should have the same ratios. These rules are theoretically valid only for the case of a uniform isotropic aquifer with no recharge/discharge sources within flownet cells. Deviations from the conformity rules are caused by aquifer heterogeneity and anisotropy as well as by recharge/discharge sources within flownet cells.

The regional water table is contoured by attempting to achieve three goals simultaneously: (1) match the water-level data at the monitoring wells, (2) account for issues of data representativeness, and (3) preserve flownet conformity. Figure G-1.1-1 is a final contour map of the regional water table that attempts to satisfy those three goals. The actual contouring is performed using a combination of manual and automated techniques. The automated contouring is performed using the minimum curvature method (Smith and Wessel 1990, 107000). Analysis of numerical model simulations (similar to the one presented in Appendix K) representing the large-scale groundwater flow in the aquifer beneath the Pajarito Plateau are also taken into account in the process of water-level contouring.

The water-level data presented in the contoured map (Figure G-1.1-1) suggest potential mounding of the regional water table near R-42, R-8, and R-36. The mounding at R-8 may result from local recharge of the regional aquifer along Los Alamos Canyon. The water level at R-36 is slightly higher than the water levels at R-28, R-45, R-11, R-13, and R-34. The mounding at R-36 may result from local recharge of the regional aquifer along Los Alamos and Sandia Canyons. The water level at R-42 is slightly higher than the water levels at R-43, northwest of R-42. Based on the general shape of the water table, R-43 is supposed to be upgradient of R-42; however, the lower water levels at R-43 suggest a flow from R-42 toward R-43 because of mounding. The mounding at R-42 may result from local recharge of the regional aquifer along and south of Sandia Canyon and may be related to the elevated chromium concentrations in this well.

Figure G-1.1-2 shows a zoom in of the map presented in Figure G-1.1-1 for the area near the chromium plume in the regional aquifer beneath Sandia and Mortandad Canyons. Figure G-1.1-2 shows clearly the mounding near R-8 and R-36. The water-level contours suggest the predominant groundwater flow direction downgradient from R-42 is directed east-southeast towards R-28 and R-45. The difference in water level between R-42 and R-43 is only 0.1 ft, so the 2-ft contours in Figure G-1.1-2 do not show the slight gradient north of R-42.

G-1.2 Local-Scale Water-Table Map Near Sandia Canyon

Figure G-1.2-1 shows small-scale analysis of the regional water-table map near Sandia Canyon. The water-level data represent averages of the January 2012 water levels. The data for R-61 and R-62 are somewhat preliminary because the relatively short records (since the summer of 2011) do not provide sufficient information to characterize hydrogeologic conditions near these wells. It is important to note the water-level data presented in Figure G-1.2-1 suggest a predominantly east-southeast groundwater flow direction in the area around R-42 and R-28, with potential diversion to the north and south. Related to analyses presented in Appendixes J and K of this investigation report, it is important to note currently groundwater flow directions are uncertain. The hydraulic gradient near R-42 and R-28 is substantially flatter than across the rest of the Pajarito Plateau (Figure G-1.1-1); it is on the order of 0.001 with an uncertainty range from 0.0005 to 0.002. The flattening is potentially caused by the high aquifer permeability in this area (see Appendix L for further details).

Figure G-1.1-2 again shows clearly the mounding near R-8 and R-36. The water-level contours suggest the groundwater flow direction downgradient of R-42 is directed towards R-28 and R-45. The mounding near R-42 is not represented on the map because of water-level variability that is smaller (0.3 ft for the July 2012 data) than the contour intervals. Nevertheless, the R-42 water level is higher than the R-43 water level, suggesting local groundwater flow from R-42 toward R-43.

G-2.0 ANALYSIS OF TRANSIENT WATER LEVELS OBSERVED AT REGIONAL AQUIFER MONITORING WELLS NEAR SANDIA CANYON

Analysis of transient water levels observed in the regional aquifer at the monitoring wells near Sandia Canyon provides information about the magnitude of pumping drawdowns caused by the water-supply wells in the vicinity. The analysis also provides information about the hydrogeologic properties of the regional aquifer, the potential effect of local infiltration recharging the aquifer beneath Sandia Canyon, the influence of water-supply pumping on groundwater flow directions, and long-term groundwater-level elevation trends. The complex hydrogeology beneath the Laboratory, coupled with the relatively small magnitude of the observed water-level transients in the shallow portion of the regional aquifer, presents particular challenges for this analysis. Appendix G in Sandia Canyon investigation report (LANL 2009, 107453) discusses a hydraulic survey of transient water levels observed at 16 monitoring wells (or 19 observation locations, including multiple screens for some monitoring wells) using an analytical flow model and linear regression analysis. Here the same analysis is extended to include 7 new monitoring wells (R-42, R-43, R-44, R-45, R-50, R-61, and R-62) or 12 new monitoring screens.

G-2.1 Water-Level Data

The monitoring wells in and near Sandia Canyon monitor groundwater-level elevations in the shallow portion of the regional aquifer, which is predominantly under phreatic (unconfined) conditions. Water-supply wells in the vicinity pump from the deeper portion of the aquifer, which is primarily under confined conditions. The drawdown at the supply wells varies from 10 m to 25 m. The gradients and flow directions in the phreatic zone exhibit a predominant influence from ambient flow, with a less-pronounced influence from water-supply pumping. The ambient flow is controlled by areas of mountain-front and canyon-bottom recharge and discharge at the river and springs to the east. Maps of the regional water table are presented and discussed in section G-1.0.

Figure G-2.1-1 presents groundwater levels (as absolute water-level elevations above sea level) for the new observation wells near Sandia Canyon (R-42, R-43, R-44, R-45, R-50, R-61, and R-62). The total fluctuation in groundwater levels over the observation period presented is small, approximately ~0.25 m.

Figure G-2.1-2 presents the daily pumping (production) volumes from wells in the vicinity (PM-1, PM-2, PM-3, PM-4, PM-5, and O-4). Note that the pumping at all the wells, except at PM-4, is cycled on a daily basis. PM-4 is pumped continuously during the summer season. PM-2 was recently brought back online after a long-term maintenance problem.

The water-level transients are impacted by (1) municipal water-supply pumping, (2) variability in the ambient flux, (3) variability in local recharge beneath Sandia Canyon or other canyons (identification of such transients typically requires much longer observation periods than the existing 3-yr water-level record), (4) barometric effects, and (5) subsidence (pore-elastic effects) from water-supply pumping.

A visual comparison between the fluctuations in the groundwater levels and in the pumping volumes does not show clear correlations; the water levels in most of the monitoring wells are potentially impacted by the continuous pumping of PM-4 in the summer 2011. A correlation between general seasonal trends in water levels and pumping rates can be observed at many of the monitoring wells, suggesting these water-level changes are probably caused by water-supply pumping, with greater levels of pumping in the summer causing lower summer water levels.

The following analysis includes the modeling of transient water-level responses at monitoring wells by estimating pumping drawdown using simple analytical techniques that account for pumping influences. This approach allows “fingerprinting” of pumping influences at observation well locations, given contrasting pumping records, estimation of potential drawdown effects associated with individual pumping wells, and estimation of effective hydraulic properties of the aquifer between pumping and observation wells. While the use of a simple analytical model does not allow the accurate estimation of the spatial properties of aquifer heterogeneity, it can provide information about the aquifer properties, for example, nonuniform aquifer properties or aquifer anisotropy. A linear regression analysis is used to provide estimates of the rate of groundwater-level elevation decline in the monitoring wells.

G-2.2 Analytical Estimation of Potential Pumping Effects

Pumping drawdown effects have been simulated using the Theis solution (Freeze and Cherry 1979, 088742, p. 317) defined as

$$s = \frac{Q}{4\pi T} W(u) = \frac{Q}{4\pi T} W\left(\frac{r^2 S}{4Tt}\right),$$

where s is the transient drawdown (L), Q is the discharge from the well (L^3T^{-1}), and T is the transmissivity (L^2T^{-1}). $W(u)$ is the well function where $u = r^2 S / 4Tt$, and r is the distance to the pumping well (L), S is the specific storage coefficient, and t is time since pumping commenced (T). The Theis solution is intended for homogeneous formations, precluding its ability to characterize spatial variation of hydraulic properties. Nevertheless, the equation can provide estimates for the pumping effects in heterogeneous formations if the effective properties of the aquifer are known.

The principle of superposition is used to represent transient effects in pumping rates and to combine drawdown contributions from multiple water-supply wells to predict observed drawdown at a given monitoring well. In this way, the predicted drawdown at a monitoring well is a sum of drawdowns created by each production well during each pumping period:

$$s = \sum_{i=1}^N \sum_{j=1}^{M_i} \frac{Q_{ij} - Q_{ij-1}}{4\pi T_i} W\left(\frac{r_i^2 S_i}{4T_i(t - t_{Qij})}\right),$$

where N is the number of pumping wells; M_i is the number of pumping periods (i.e., number of pumping rate changes); Q_{ij} is the pumping rate of well i during pumping period j ; and t_{Qij} is the time when the pumping rate changed at well i during pumping period j . In these analyses, seven pumping wells are considered, and the maximum number of pumping rate changes (M_i) is 2035 (for O-4). The principle of superposition allows for different effective hydraulic properties between different water-supply/observation well pairs (T_i, S_i), referred to as cross-hole effective hydraulic properties. In this way, it is possible to estimate the extent the heterogeneity affects the observed drawdowns in the monitoring wells. Furthermore, discrepancies between simulated and observed pressures may suggest additional transients or heterogeneities currently not included in this model (e.g., transients in the ambient fluxes).

Inverse modeling is employed to identify effective hydraulic properties (transmissivity T and specific storage S), resulting in model predictions that are consistent with observed water-level elevations (calibration targets). The daily variations in the water-supply production record, which include the daily pumping and recovery periods, are explicitly represented in the model.

This inverse analysis is similar to the analysis of pumping tests. However, in this case, the pumping test includes multiple pumping wells that have transient pumping records. The benefits of this approach are that (1) specially designed field tests are not needed (testing should include a prolonged cessation of pumping at all the production wells before the test, although this might not be feasible), (2) the effects of measurement errors may be mitigated given long water-level and pumping records, and (3) information regarding aquifer heterogeneity can be obtained.

Rates of decline in the groundwater-level elevations are estimated using a linear regression analysis performed using a least-squares Levenberg-Marquardt algorithm to fit a straight line to the observed water levels. The slope of the line provides an optimal estimate of the water-level trend in a least-squares sense.

The simulation of the water-level transients is performed using the code WELLS (<http://wells.lanl.gov>) (Mishra et al. 2011, 227708). The calibration of the water-level transients to the water-supply pumping records and estimation of the aquifer properties is performed using the code MADS (<http://mads.lanl.gov>) (Vesselinov and Harp 2011, 227709).

The code WELLS is able to solve not only the confined aquifer flow represented by the Theis equation. It can be applied to simulate (1) unconfined (phreatic) conditions, (2) leaky conditions, (3) partial penetration of the pumping and observations wells, (4) multiple aquifer layers with different hydrogeologic properties, etc. (<http://wells.lanl.gov>). In the past, analyses have been performed of R-28, R-15, and R-11 water-level data accounting for partial penetration and phreatic conditions (the results are not shown here). However, Theis and more complicated analyses provided similar results for estimated transmissivity and storativity, and similar matches between observed and simulated drawdowns. Thus, the analyses presented herein are based on Theis, which is also consistent with the analyses presented in Sandia Canyon investigation report (LANL 2009, 107453).

G-2.3 Results and Discussion

Figure G-2.3-1 presents plots of the observed (plotted in red) and simulated groundwater-level elevations (plotted in black) at all the monitoring wells (except at R-61 and R-62 where the water-level records are relatively low and are not sufficient for this analysis). By inspecting the plots, it is apparent the water-level transients observed in each well can be accurately simulated with the analytical model. It is also obvious that all the wells analyzed exhibit very similar transient behaviors. The analyses demonstrated that because of the relatively short water-level records, only PM-4 could be definitively identified as a pumping well impacting the observed transients. Also most of the wells seem to be influenced by the pumping at

PM-3, which started to work in the beginning of 2012; however, the record is not sufficient to identify the apparent aquifer properties characterizing PM-3 pumping effects. The analyses also suggest the water levels are influenced by some of the other water-supply wells as well. However, the influences are small, and the limited data set is not sufficient to accurately fingerprint the pumping influences.

For each inversion model, the apparent (effective) cross-hole transmissivities and storativities between the observation wells and PM-4 are estimated (Tables G-2.3-1 and G-2.3-2). It is important to note the various transmissivity estimates listed in Table G-2.3-1 are within 0.5 orders of magnitude of each other, indicating a degree of consistency in the estimates of this effective property. Some of the variation in this parameter may be attributed to early-time behavior of Theis solution parameters (Wu et al. 2005, 106998). The specific storage estimates vary by more than 0.5 orders of magnitude (Table G-2.3-2), indicating various degrees of interwell connectivity between pumping/monitoring well pairs (Meier et al. 1998, 106999). As with the transmissivity estimates, some of this variability may be attributed to early-time behavior of Theis solution parameters.

Aquifer estimates in Tables G-2.3-1 and G-2.3-2 represent the apparent large-scale aquifer properties of the aquifer between the pumping and observations wells; the estimated aquifer properties characterize aquifer properties along the pathway through which most of the pumping drawdown propagates. These estimates do not represent the properties of the shallow aquifer where the monitoring screens are located. The transmissivity estimates range from 4000 to 9000 m²/d. The estimated large-scale aquifer transmissivity is about an order of magnitude higher than the transmissivity estimated during the R-28 pumping test (500 m²/d; Appendix L). This is consistent with the expected order of magnitude difference in the transmissivity for the aquifer thickness interrogated by the pumping at wells PM-4 and R-28.

Table G-2.3-3 summarizes the results of the calibrations by indicating the pumping wells that the model identified as influencing the water-level fluctuations at each monitoring well.

Table G-2.3-4 presents the rate of groundwater-level change at the monitoring wells near Sandia Canyon. It is apparent a declining trend in water levels occurs near Sandia Canyon, with an average decline of approximately 0.177 m/yr with a standard deviation of 0.104 m/yr about this average. While it is clear water levels are declining, the rate of decline varies spatially. High rates of decline are observed at R-8 and R-6, and the lowest rates are observed at R-1, R-5 screen 4, and R-14 (Table G-2.3-4). The water-level declines are observed at screens located at various depths below the regional aquifer water table; therefore, the data do not provide direct observation of the decline of the regional water table in the study area.

G-2.4 Summary of Pumping Effects

A simple analytical model was used to extract groundwater information from production and water-level records about the properties of the regional aquifer beneath the Sandia Canyon area. The inverse analysis of pressure responses from pumping suggests there may be large-scale hydrogeologic structures with properties that are different from the rest of the aquifer. Fingerprinting of water-supply pumping influences at the monitoring wells indicates the complicated connections within the aquifer resulting from large-scale heterogeneities. The water levels at the monitoring wells are declining in a nonuniform manner within the area. Currently, the transient water-level records for wells R-61 and R-62 are not sufficient to perform the analyses presented here.

The presented analyses are important because they provide information about (1) effective hydrogeological properties of the aquifer (in a manner similar to standard pumping tests), (2) hydraulic connections between water-supply and monitoring wells (as well as the hydrostratigraphic sections screened by these wells), and (3) potential impact of water-level transients on directions of groundwater flow and contaminant transport in the area.

G-3.0 TRANSIENTS IN WATER LEVELS AND CONCENTRATIONS OF GEOCHEMICAL CONSTITUENTS OBSERVED AT R-28

Figure G-3.0-1 compares transients in concentrations of key geochemical constituents with the water-level elevations observed at R-28. The figure suggests some correlation exists between the water levels and the chromium concentrations: low chromium concentrations are correlated with seasonal water-level increases, while high chromium concentrations are correlated with seasonal water-level decreases. This correlation could indicate fluctuations of the regional water table affect the contaminant fate and transport. If true, this behavior may be caused by various hydrogeological and geochemical processes; it may also indicate chromium is arriving through the vadose zone at the regional aquifer very close to R-28 because the phreatic water level impacts the concentration. It is also possible the observed correlation between the water levels and the chromium concentrations is coincidental.

G-4.0 REFERENCES

The following list includes all documents cited in this appendix. Parenthetical information following each reference provides the author(s), publication date, and ER ID. This information is also included in text citations. ER IDs are assigned by the Environmental Programs Directorate's Records Processing Facility (RPF) and are used to locate the document at the RPF and, where applicable, in the master reference set.

Copies of the master reference set are maintained at the New Mexico Environment Department Hazardous Waste Bureau and the Directorate. The set was developed to ensure that the administrative authority has all material needed to review this document, and it is updated with every document submitted to the administrative authority. Documents previously submitted to the administrative authority are not included.

Freeze, R.A., and J.A. Cherry, January 1979. *Groundwater*, Prentice-Hall, Inc., Englewood Cliffs, New Jersey. (Freeze and Cherry 1979, 088742)

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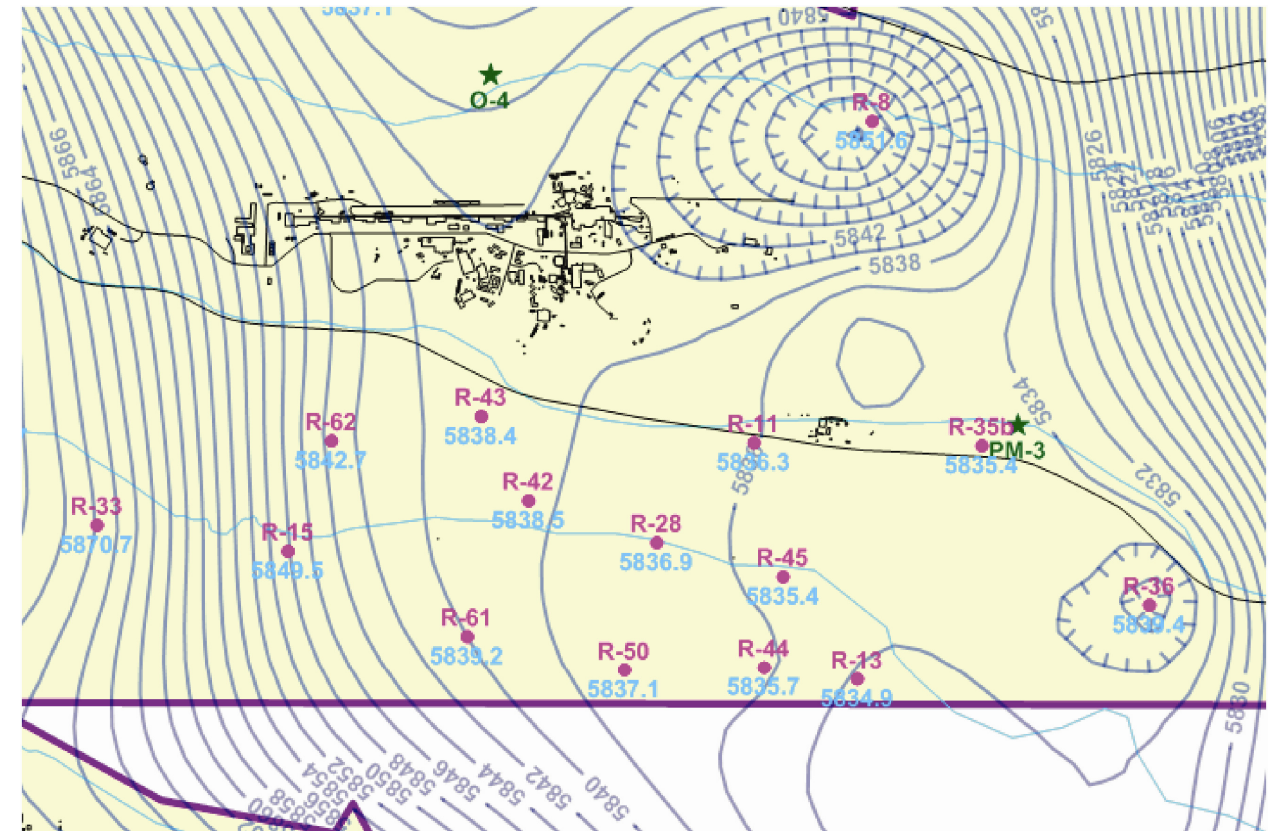
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Wu, C.-M., T.-C. Yeh, J. Zhu, T.H. Lee, N.-S. Hsu, C.-H. Chen, and A.F. Sancho, 2005. "Traditional Analysis of Aquifer Tests: Comparing Apples to Oranges?," *Water Resources Research*, Vol. 41, W09402, 12 pp. (Wu et al. 2005, 106998)

Figure G-1.1-1 Regional water-table map representing the average regional water levels observed in February 2011



Note: Water levels are shown in feet above mean sea level.

Figure G-1.1-2 Regional water-table map representing the average regional water levels in the chromium plume area observed in February 2011

Figure G-1.2-1 Water-table map representing the general trend in the water levels near Sandia Canyon based on observations made in January 2012

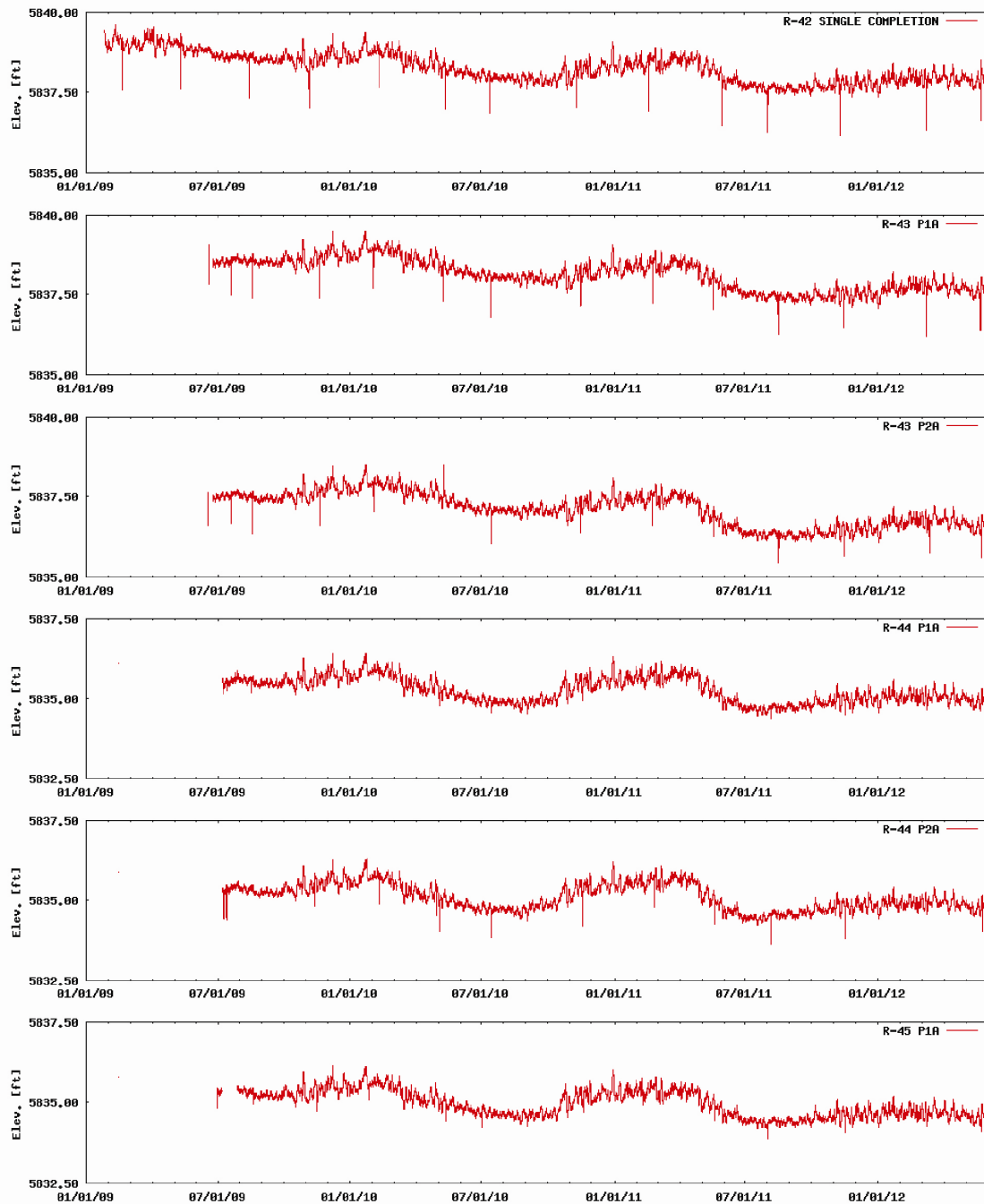


Figure G-2.1-1 Groundwater-level elevations at observation wells near Sandia Canyon

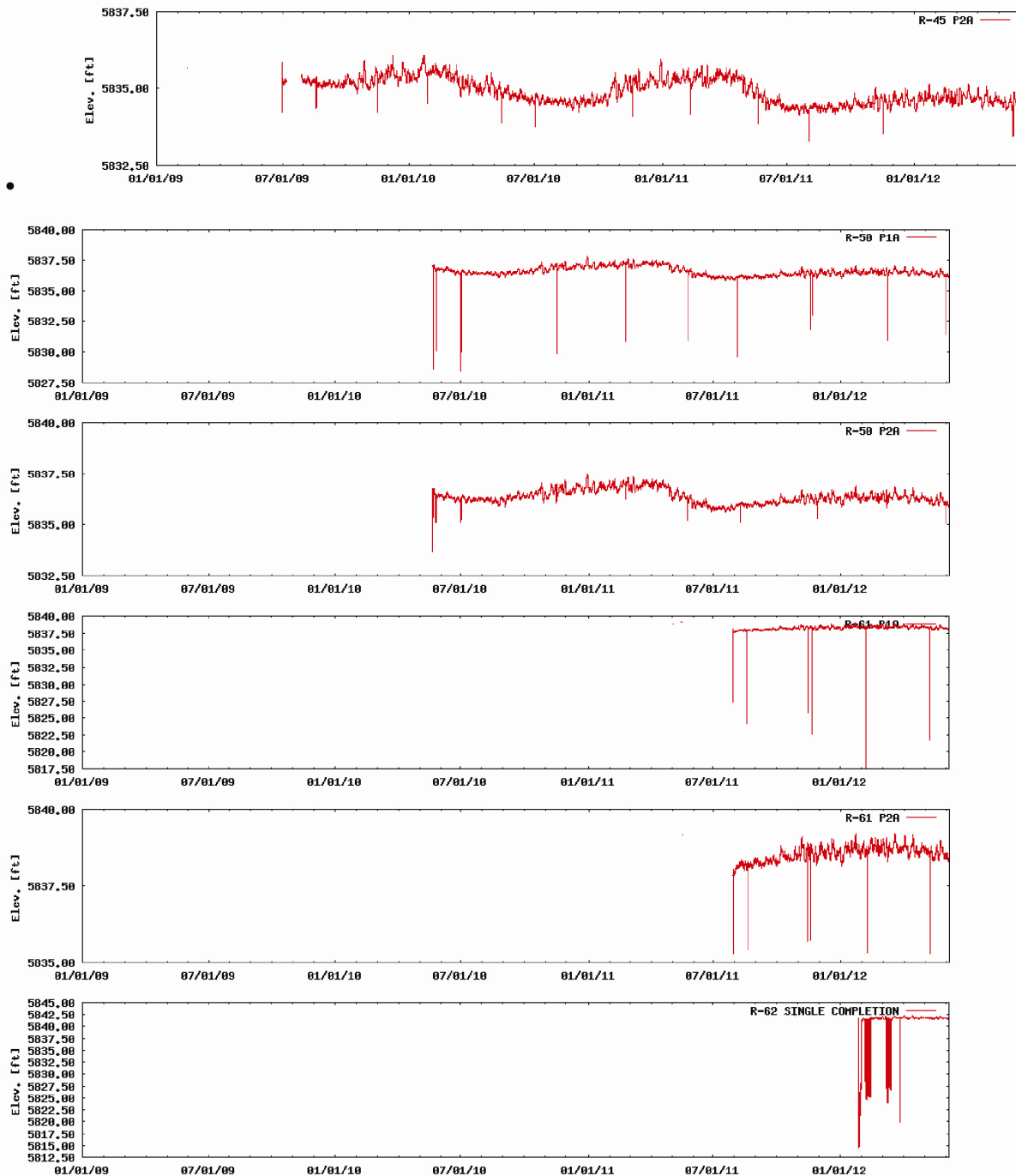


Figure G-2.1-1 (continued) Groundwater-level elevations at observation wells near Sandia Canyon

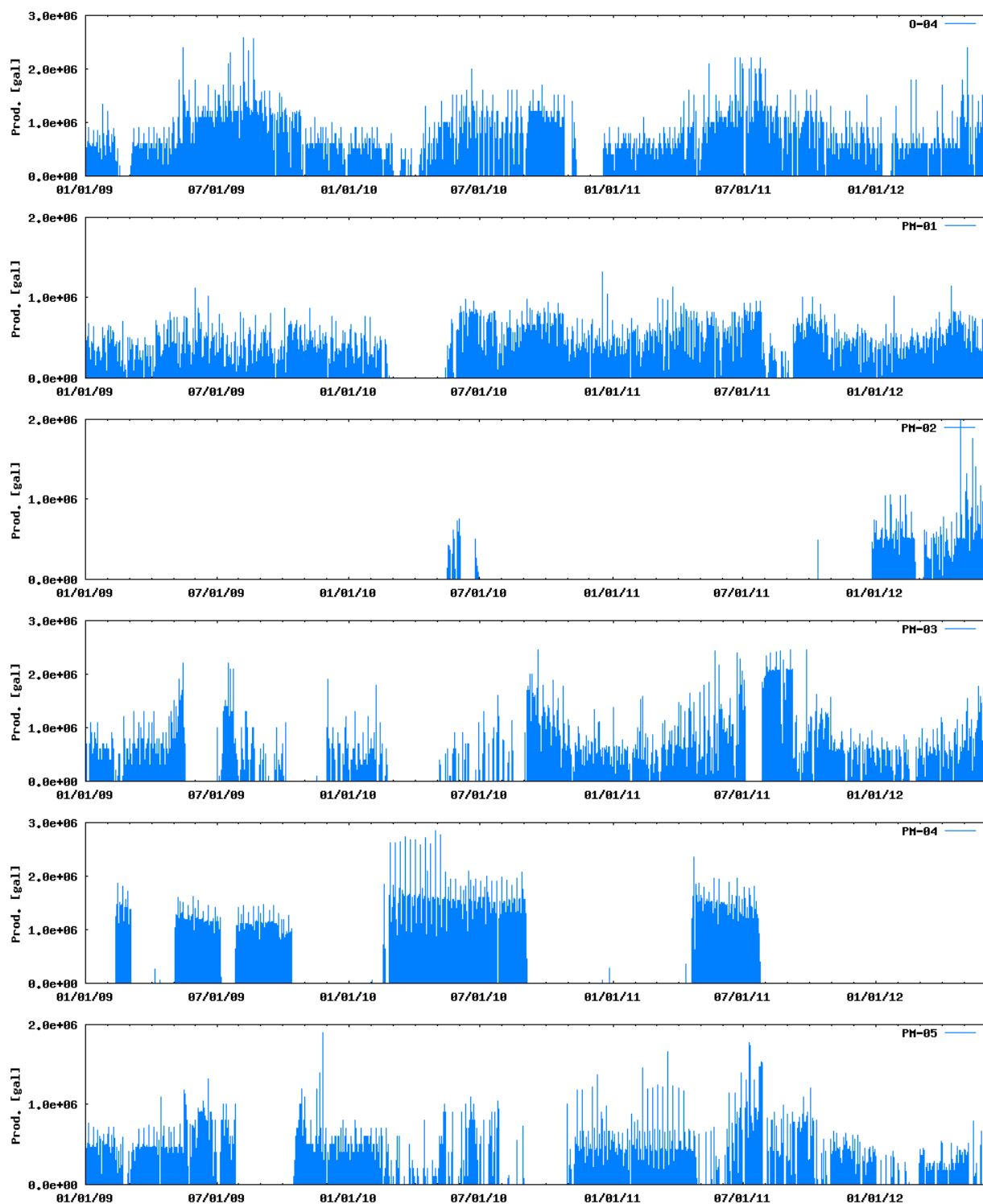
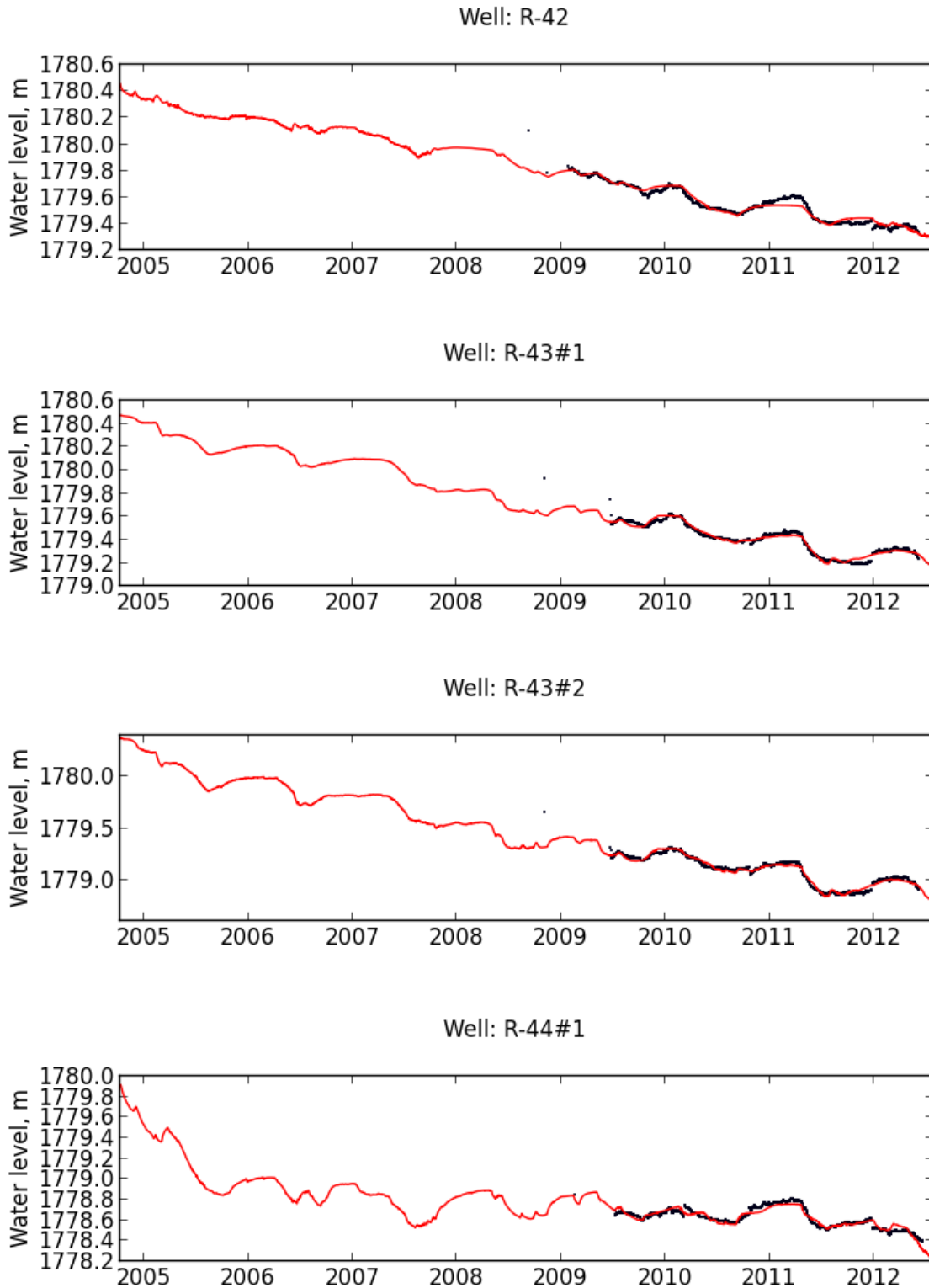
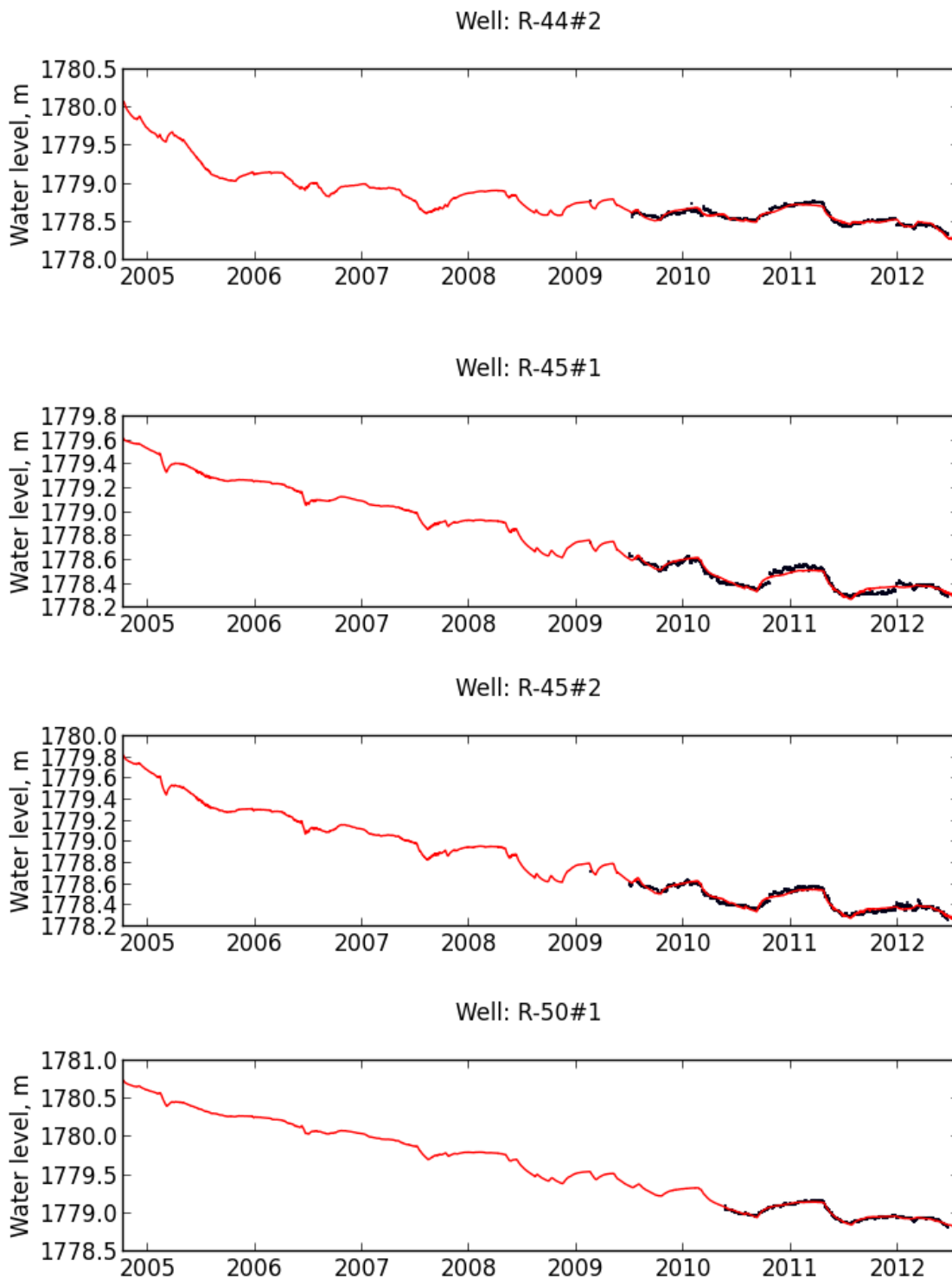


Figure G-2.1-2 Supply-well pumping volumes for production wells near Sandia Canyon



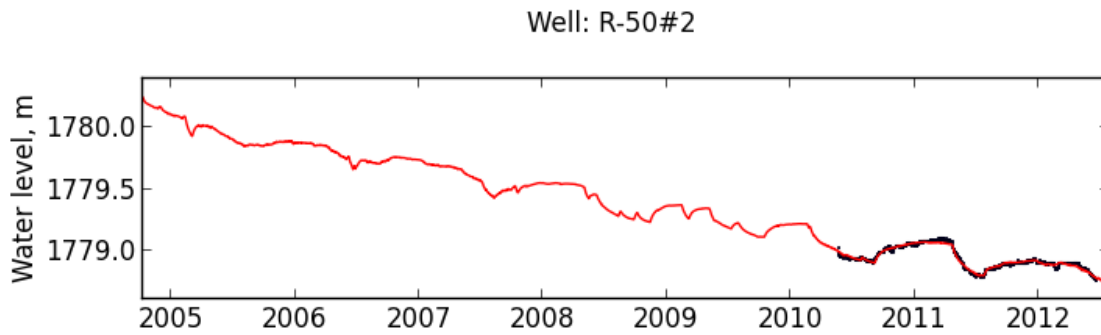
Notes: Each plot presents the results from a separate model inversion. In each case, the model simulates water elevations at a single observation well using pumping records for all seven water-supply wells. Note differences in the y-axis scales on each plot.

Figure G-2.3-1 Barometrically corrected observed (red line) and model-simulated (black line) water levels at individual monitoring wells



Notes: Each plot presents the results from a separate model inversion. In each case, the model simulates water elevations at a single observation well using pumping records for all seven water-supply wells. Note differences in the y-axis scales on each plot.

Figure G-2.3-1 (continued) Barometrically corrected observed (red line) and model-simulated (black line) water levels at individual monitoring wells



Notes: Each plot presents the results from a separate model inversion. In each case, the model simulates water elevations at a single observation well using pumping records for all seven water-supply wells. Note differences in the y-axis scales on each plot.

Figure G-2.3-1 (continued) Barometrically corrected observed (red line) and model-simulated (black line) water levels at individual monitoring wells

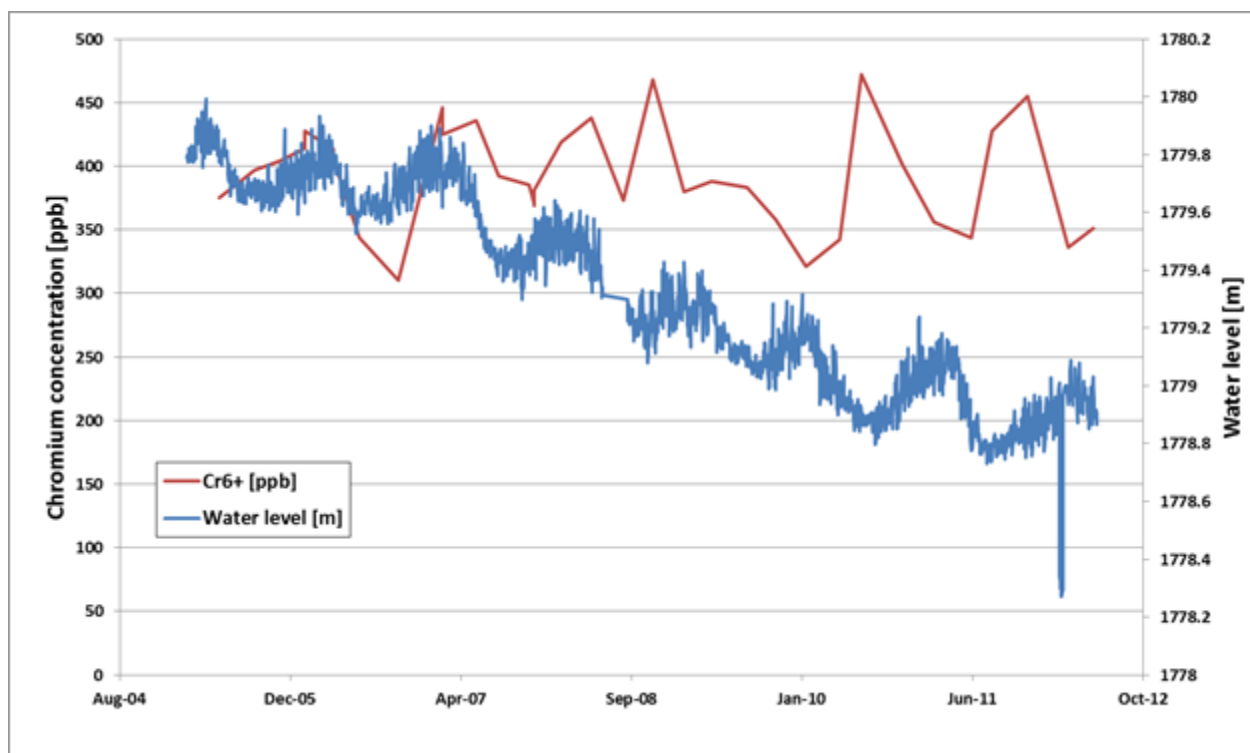


Figure G-3.0-1 Transients in concentrations of key geochemical constituents and water-level elevation observed at well R-28

Table G-2.3-1
Estimates of Apparent Cross-Hole
Transmissivity (m²/d) between Pumping Wells
and Monitoring Wells Based on Model Calibration

Well	Screen	PM-4
R-42	Single	5.38E+03
R-43	1	4.47E+03
R-43	2	6.09E+03
R-44	1	9.26E+03
R-44	2	9.06E+03
R-45	1	5.61E+03
R-45	2	5.74E+03
R-50	1	3.80E+03
R-50	2	6.19E+03

Table G-2.3-2
Estimates of Apparent Cross-Hole
Storativity (Unitless) between Pumping Wells
and Monitoring Wells Based on Model Calibration

Well	Screen	PM-4
R-42	Single	0.153
R-43	1	0.072
R-43	2	0.043
R-44	1	0.023
R-44	2	0.022
R-45	1	0.031
R-45	2	0.022
R-50	1	0.069
R-50	2	0.044

Table G-2.3-3
Identification of the Influence of Pumping Wells (Columns)
on Monitoring Wells (Rows) Water Levels Near Sandia Canyon

Well	Screen	PM-1	PM-2	PM-3	PM-4	PM-5	O-4
R-42	Single	No	?	?	Yes	?	?
R-43	1	No	?	?	Yes	?	?
R-43	2	No	?	?	Yes	?	?
R-44	1	No	?	?	Yes	?	?
R-44	2	No	?	?	Yes	?	?
R-45	1	No	?	?	Yes	?	?
R-45	2	No	?	?	Yes	?	?
R-50	1	No	?	?	Yes	?	?
R-50	2	No	?	?	Yes	?	?

Notes: "Yes" indicates a positive identification of the ability of the model to simulate a component of the water-level fluctuations at a well. "No" indicates the model was not able to attribute a component of the water-level fluctuations to the pumping well. A question mark indicates the results are inconclusive.

Table G-2.3-4
Estimated Rate of Groundwater-Level Elevation Decline Based on Available Water-level Records

Well	Screen	Rate of Water-Level Decline (m/yr)	Comment
R-1	Single	0.051	Water-level fluctuations influenced by municipal water-supply pumping
R-5	4	0.028	None
R-6	Single	0.240	None
R-7	3	0.172	No pumping influences identified
R-8	1	0.239	Water-level fluctuations influenced by municipal water-supply pumping
R-8	2	0.390	Water-level fluctuations influenced by municipal water-supply pumping
R-9	Single	0.083	No pumping influences identified
R-11	Single	0.181	Water-level fluctuations influenced by municipal water-supply pumping
R-13	Single	0.171	None
R-14	1	0.046	Water-level fluctuations influenced by municipal water-supply pumping
R-14	2	0.051	Water-level fluctuations influenced by municipal water-supply pumping
R-15	Single	0.102	Water-level fluctuations influenced by municipal water-supply pumping
R-28	Single	0.128	Water-level fluctuations influenced by municipal water-supply pumping
R-33	1	0.092	Water-level fluctuations influenced by municipal water-supply pumping
R-33	2	0.092	Pronounced water-level fluctuations influenced by municipal water-supply pumping at PM-5
R-34	Single	0.159	Very small seasonal water-level fluctuations with not apparent correlation to municipal water-supply pumping
R-35a	Single	0.305	Pronounced water-level fluctuations influenced by municipal water-supply pumping at PM-3

Table G-2.3-4 (continued)

Well	Screen	Rate of Water-Level Decline (m/yr)	Comment
R-35b	Single	0.169	Very small seasonal water-level fluctuations potentially influenced by municipal water-supply pumping
R-36	Single	0.165	Very small seasonal water-level fluctuations potentially influenced by municipal water-supply pumping
R-42	Single	0.116	Seasonal water-level fluctuations influenced by municipal water-supply pumping
R-43	1	0.102	Seasonal water-level fluctuations influenced by municipal water-supply pumping
R-43	2	0.098	Seasonal water-level fluctuations influenced by municipal water-supply pumping
R-44	1	0.122	Seasonal water-level fluctuations influenced by municipal water-supply pumping
R-44	2	0.122	Seasonal water-level fluctuations influenced by municipal water-supply pumping
R-45	1	0.152	Seasonal water-level fluctuations influenced by municipal water-supply pumping
R-45	2	0.152	Seasonal water-level fluctuations influenced by municipal water-supply pumping
R-50	1	0.078	Seasonal water-level fluctuations influenced by municipal water-supply pumping
R-50	2	0.092	Seasonal water-level fluctuations influenced by municipal water-supply pumping
R-61	1	—*	Short record not sufficient for analysis of water level transients
R-61	2	—	Short record not sufficient for analysis of water level transients
R-62	Single	—	Short record not sufficient for analysis of water level transients

* — = No estimate for the water level decline.

Appendix H

Chromium Isotope Investigation

H-1.0 INTRODUCTION

Chromium isotope results for groundwater from Sandia and Mortandad Canyon were presented as part of the Sandia Canyon Investigation Report (Phase I SCIR) (LANL 2009, 107453). Initial data were consistent with reduction of chromium(VI) to chromium(III), primarily in the Cerros del Rio basalt. Herein, updated chromium isotope values for groundwater are presented along with a more detailed conceptual model explaining chromium(VI) isotopic and concentration variation as a function of mixing of contaminant chromium(VI) with background chromium(VI), dilution/sorption, and reduction of chromium(VI) to chromium(III).

H-2.0 CHROMIUM ISOTOPE FRACTIONATION

Chromium has four stable isotopes: chromium-50 (4.35%), chromium-52 (83.8%), chromium-53 (9.50%), and chromium-54 (2.37%), where the percentage given is the approximate relative abundance of each isotope in terrestrial samples. The chromium isotope analysis uses the relative abundance of the two most common chromium isotopes, chromium-52 and chromium-53.

The delta (δ) notation is as follows:

$$\delta^{53}\text{Cr} = \{[(^{53}\text{Cr}/^{52}\text{Cr}_{\text{sample}})/(^{53}\text{Cr}/^{52}\text{Cr}_{\text{standard}})-1]*1000\} \quad \text{Equation H-1}$$

in units of per mil (‰) or parts per thousand. This notation is often used in isotope analyses to show the difference in isotope ratios between a sample and an isotopic standard.

The standard used in this study was National Institute of Standards and Technology (NIST) SRM 979, a chromium nitrate compound sold by the NIST as an isotopic standard.

Ratios of chromium-53 to chromium-52 have been demonstrated to reflect the degree of reduction of dissolved chromium(VI) to chromium(III) along surface water and groundwater flow paths (Berna et al. 2010, 226764; Raddatz et al. 2011, 226766). During both abiotic and biotic reduction of chromium(VI) to chromium(III), a kinetic isotope effect occurs in which the lighter isotope, chromium-52, reacts preferentially, leaving the remaining dissolved chromium(VI) enriched in the heavier isotope, chromium-53.

This process is represented mathematically (Ellis et al. 2002, 098081) as follows:

$$\delta^{53}\text{Cr} = [(\delta^{53}\text{Cr}_{\text{ini}} + 10^3)f^{(\alpha-1)}]-10^3 \quad \text{Equation H-2}$$

where $\delta^{53}\text{Cr}$ is the isotopic composition of residual dissolved chromium(VI), and f is the fraction of chromium(VI) remaining. In Equation H-2, α is the instantaneous fractionation factor, defined as $R_{\text{product}}/R_{\text{reactant}}$ where R_{product} and R_{reactant} are the chromium-53/ chromium-52 ratios of the instantaneous product and reactant pools, respectively. Before any reduction of chromium(VI) takes place, f is equal to 1, and $\delta^{53}\text{Cr}$ is equal to $\delta^{53}\text{Cr}_{\text{ini}}$. Equation H-2 can be used to calculate f , the fraction of chromium(VI) remaining. This value, in turn, can be subtracted from unity and converted to a percentage to calculate the percentage of chromium(VI) reduction occurring along a flow path.

For simplicity, the magnitude of the fractionation factors are expressed as $\varepsilon = 1 - \alpha$. ε values of 2.1‰ to 4.3‰ have been observed in laboratory experiments resulting from both biotic and abiotic reduction processes (Ellis et al. 2002, 098081; Kitchen et al. 2004, 098088; Johnson and Berna 2008, 102464; Sikora et al. 2008, 102411; Jamieson-Hanes et al. 2012, 226765). Fractionation factors do not appear to vary with chromium(VI) concentration, at least in the case of microbial reduction (Sikora et al. 2008,

102411). Recent work suggests the weathering of mafic rocks results in the production of chromium(VI) with elevated $\delta^{53}\text{Cr}$ (Izbicki et al. 2008, 102412). Weathering can produce chromium(VI) with elevated $\delta^{53}\text{Cr}$, or alternatively the increase in $\delta^{53}\text{Cr}$ occurs after chromium(VI) “is delivered to the water, via partial reduction by Fe(II)-bearing solids or bacteria” (Raddatz et al. 2011, 226766). Chromium isotopes are not fractionated significantly by adsorption processes (Ellis et al. 2004, 098086).

The initial chromium isotope composition of dissolved chromate before reduction is $\delta^{53}\text{Cr}_{\text{ini}}$. Chromite ores, from which industrial chromium is derived, have an average $\delta^{53}\text{Cr}$ of -0.082 ± 0.058 ‰ (2 σ) (Schoenberg et al. 2008, 102413). Because of the high temperature and efficiency of extraction, industrial chromium should have very similar $\delta^{53}\text{Cr}$ values to chromite ores (Ellis et al. 2002, 098081; Schoenberg et al. 2008, 102413). The highest value measured for industrial reagent chromium is 0.37 ‰ (Ellis et al. 2002, 098081). Herein, a value of 0 ‰ for $\delta^{53}\text{Cr}_{\text{ini}}$ of contaminant chromium(VI) is assumed.

H-3.0 SAMPLE COLLECTION AND PRESERVATION

Surface and groundwater samples were collected in 1-L high-density polypropylene bottles for chromium isotope analyses. Before November 2008, the nonacidified samples were filtered through 0.45-micrometer membranes. During the course of chromium investigations it was recognized that, for some samples, colloidal chromium(III) passed through 0.45 and 0.22-micrometer membranes. Even though colloidal chromium(III) appears to have no effect on $\delta^{53}\text{Cr}$ of chromium(VI), samples collected from November 2008 onwards were filtered through 0.02-micrometer membranes as a best practice (LANL 2009, 107453).

H-4.0 ANALYTICAL METHODOLOGY

All samples were measured by multicollector inductively coupled plasma mass spectrometer at the University of Illinois–Urbana Champaign (UIUC). For a description of sample preparation and analytical techniques see Appendix H of the Phase I SCIR (LANL, 2009, 107453). The absolute difference between duplicate pairs of field samples was always less than 0.2 ‰, except for one sample from R-35a where the difference in duplicates was 0.23 ‰. Two times the root-mean-square difference for 16 pairs of duplicate samples was ± 0.13 ‰ (95% confidence). UIUC also measured the chromium(VI) concentrations of the water samples by isotope dilution.

H-5.0 RESULTS AND DISCUSSION

Results for chromium(VI) concentrations and $\delta^{53}\text{Cr}$ of groundwater samples are presented in Table H-5.0-1, with all isotope data rounded to 1 decimal place. Spatial variability in results is shown in Figure H-5.0-1. Because the wells sampled were installed over many years, with some wells put in place relatively recently, most recent data are shown in Figure H-5.0-1 (as opposed to averages). This ensures that patterns being compared come from wells providing representative groundwater chemistry data. Note that for the majority of wells, particularly those completed in the regional aquifer, $\delta^{53}\text{Cr}$ is relatively consistent over time. One notable exception is the shallow screen at R-43, which will be discussed in more detail below in context of the conceptual model for chromium isotope variation.

It is not the intention here to discuss in detail isotopic signatures at each individual well but rather to recognize overall patterns that allow for understanding of where chromium(VI) reduction to chromium(III) occurs along the transport pathways in the groundwater system. Several patterns emerge from Figure H-5.0-1. All wells considered background with respect to chromium(VI) (based on location relative

to the main plume, occurrence of cocontaminants, and flow and transport considerations) have chromium(VI) concentrations less than 6 ppb and have $\delta^{53}\text{Cr}$ values in the range of 1‰–2‰. These values are similar to those detected at background locations associated with basalts at Idaho National Laboratory (Raddatz et al. 2011, 226766) and in the recharge areas of flow paths in alluvial aquifers associated with ultramafic rocks in the western Mojave Desert of California (Izbicki et al. 2008, 102412). As such, it appears natural background chromium(VI) in this system has a higher $\delta^{53}\text{Cr}$ signature than industrial sources. The deep screens at all dual screened wells, except for well R-45, have chromium(VI) concentrations and $\delta^{53}\text{Cr}$ in the background range.

For wells that show evidence of chromium(VI) contamination, it is interesting to consider the position of the screened interval within the stratigraphic column, particularly for perched-intermediate wells. Of all the units present, the basalts have the greatest potential to reduce chromium(VI) to chromium(III) because of the abundant iron(II)-bearing minerals such as olivine, pyroxene, and magnetite. When iron(II) is oxidized to iron(III), chromium(VI) can be simultaneously reduced to chromium(III). Raddatz et al. (2011, 226766) state, “Fe(II)-bearing minerals and glass in the basalts provide ample reducing potential, and laboratory studies have shown that Cr(VI) reduction by Fe(II)-bearing minerals is rapid and can occur in oxygen-bearing solutions.” It is often assumed reduction occurs at dissolved oxygen levels of less than 6 mg/L, although it can also occur in reducing microenvironments within oxidizing settings or through the metabolic activity of aerobic microbes (Raddatz et al. 2011, 226766). In the samples analyzed, dissolved oxygen ranged from ~2 mg/L to 10 mg/L. Batch and column experiments have demonstrated reduction of chromium(VI) associated with Cerros del Rio basalt (LANL 2009, 107453). Other units, including the Puye Formation, also showed evidence of reduction in these experiments, although to lesser degrees than in the Cerros del Rio basalts, presumably because of the presence of iron(II)-bearing minerals.

Only intermediate wells SCI-1 and MCOI-4 are completed in perched layers on top of the Cerros del Rio basalt. All other intermediate and regional aquifer wells are completed in or below the basalt (or adjacent dacite lava). Well SCI-1 is along the infiltration pathway from the primary chromium(VI) release associated with Sandia Canyon. This well has the lowest $\delta^{53}\text{Cr}$ values (0.3‰–0.5‰), suggesting little reduction of chromium(VI) to chromium(III), consistent with its location above the basalts, though some reduction may have occurred in overlying Bandelier Tuff (significant chromium mass exists in the tuff, likely primarily as adsorbed phases). This also implies that despite the large chromium inventories in the upstream Sandia wetland, waters at SCI-1 experienced little reduction of chromium(VI) in the wetland. This apparent discrepancy can be resolved by considering that effectively all chromium(VI) interacting with the wetland sediments was likely reduced to chromium(III), leaving no residual chromium(VI) with a higher $\delta^{53}\text{Cr}$ signature. Studies of chromium(III) in wetland sediments could verify this assumption. The chromium(VI) detected at well SCI-1 is likely from surface waters that passed over the Sandia wetland with very short residence times and little interaction with wetland sediments.

Well MCOI-4 is also completed on top of the basalts but does not follow the same pattern as well SCI-1, having some of the highest $\delta^{53}\text{Cr}$ values observed in this study and a chromium(VI) concentration that is currently just slightly above background. Chromium(VI) in this well may be the result of a small quantity of chromium(VI) that transported laterally in perched zones from Sandia Canyon along a minor pathway with a long residence time that allowed for significant reduction of chromium(VI). Alternatively, the chromium(VI) may be at least partially derived from a volumetrically less important chromate source in Mortandad Canyon with a flow and transport history quite different from many of the wells associated with the main plume. This Mortandad Canyon chromium source is uncertain, but chromium is present in sediment reach E-1E in upper Effluent Canyon (potentially from cooling-tower releases) and was discharged at Outfall 051 into Effluent Canyon, indicating some release into that tributary canyon (LANL 2006, 094161). In addition, chromium plating operations occurred on Sigma Mesa near the headwaters of Mortandad Canyon. This is a less likely and poorly constrained chromium source, but chromium(VI) from

plating baths can be slightly enriched in chromium-53 relative to other anthropogenic sources resulting from fractionation associated with the plating process (Berna et al. 2010, 226764). Regardless of the source, significant reduction of chromium(VI) somewhere along the flow path to the location of this well (for example, in overlying Puye Formation sediments) may have occurred, leading to the higher observed $\delta^{53}\text{Cr}$. Intermediate-depth well MCOI-5 is also likely associated, at least in part, with a Mortandad source of chromium(VI) and has the highest recent $\delta^{53}\text{Cr}$ and lowest chromium(VI) concentration, at a level considered to be less than background. This well is completed in basalt, which would provide the reducing capacity necessary to produce the observed $\delta^{53}\text{Cr}$ and low concentrations. Wells SCI-2 and MCOI-6 are also completed in basalt but probably contain a higher proportion of waters derived from Sandia Canyon and the primary chromium plume that derived from Sandia Canyon (see section D-3.2). It is unlikely the isotopic composition of industrial chromate was significantly different for a Mortandad Canyon versus a Sandia Canyon source. The isotopic variation seen in intermediate wells SCI-2, MCOI-6, MCOI-4, and MCOI-5 is more likely a function of the position in the plume (or plumes in the case of mixing between a Mortandad Canyon and Sandia Canyon source). Well SCI-2 is near the centroid of the Sandia Canyon chromium(VI) plume where chromium(VI) concentrations presumably overwhelmed the reducing capacity of the basalts, leading to modest increases in $\delta^{53}\text{Cr}$. The other intermediate wells are thought to be closer to plume margins where more extensive reduction of chromium(VI), with associated increases in $\delta^{53}\text{Cr}$, are likely to occur because the reductive capacity has not been depleted. Plume mixing could confuse interpretation of $\delta^{53}\text{Cr}$ signatures in the sense of averaging out the degree of reduction that has occurred from different sources and along different flow paths converging in a mixed zone.

All of the regional aquifer wells showing evidence of chromium(VI) contamination have $\delta^{53}\text{Cr}$ values that fall in a narrow range, similar to 1‰. Figure H-5.0-2 shows the processes, including dilution, mixing with background waters, and reduction, that could lead to the observed values close to unity. This figure is useful for illustrating the combined effects of these processes on chromium(VI) concentrations and $\delta^{53}\text{Cr}$ values. Because well R-42 is the most contaminated well studied, the most recent $\delta^{53}\text{Cr}$ value and chromium(VI) concentration from this well were used to calculate a hypothetical high chromium(VI) concentration end-member that had not undergone reduction in basalts. The isotopic composition of well SCI-1 was assumed for this hypothetical end-member. The isotopic values detected at well SCI-1 either represent the chromate source isotopic composition or minor reduction in the upgradient wetland or in the overlying Bandelier Tuff. Equation H-2 was used to calculate the fraction of chromium(VI) remaining after reduction along the flow path to well R-42, and from there an initial concentration for the original source entering the vadose zone was estimated. Higher initial chromium(VI) concentrations may have occurred, but this end-member is sufficient to illustrate the processes occurring that explain the observed chromium isotopic variation in the data set.

It is clear that reduction (process 1 on Figure H-5.0-2) somewhere along the individual flow paths has affected all wells with the possible exception of well SCI-1. (It is important to note that chromium isotope measurements do not imply reduction has occurred at the location being sampled but rather somewhere along the flow path to that location.) Except for samples from deep-screened wells that appear to be background with respect to chromium(VI), all nonbackground points plot above the mixing line defined by the presumed high chromium(VI) source that had not undergone reduction and the background location with the highest $\delta^{53}\text{Cr}$. All such points must have experienced some degree of chromium(VI) reduction as they cannot be explained by mixing alone (cf. Raddatz et al. 2011, 226766). It is also clear from comparison of results from the perched-intermediate zone wells that some of the reduction has occurred in the Cerros del Rio basalts, consistent with the presence of abundant iron(II)-bearing minerals in that unit, and potentially in the overlying Puye Formation in the case of MCOI-4. Additional reduction in other units, including in the regional aquifer, cannot be ruled out. It is also apparent that although background concentrations are low, mixing with background could explain part of the observed chromium isotope variation. Many of the points fall along the upper mixing line between R-42 (where evidence for reduction

is seen) and the background end-member (process 2 on Figure H-5.0-2). Waters at these locations have likely experienced a combination of reduction and mixing with background. Wells near the centroid of mass (e.g., the shallow screens at wells R-42, R-28, and R-50) are less affected by mixing with background than wells closer to the periphery of the plume. In addition, dilution has to occur as waters from the vadose zone enter the regional aquifer. Dilution, along with sorption, will lower chromium(VI) concentrations but will not affect $\delta^{53}\text{Cr}$, except by mixing with background chromium(VI). Dilution (process 3 on Figure H-5.0-2), therefore is partly responsible for the spread of concentration values seen in the regional aquifer. Attenuation by sorption in the vadose zone likely also occurs, also having no effect on $\delta^{53}\text{Cr}$.

Increasing chromium(VI) concentration trends with decreasing $\delta^{53}\text{Cr}$ in the shallow screen at well R-43 are consistent with a chromium(VI) plume recently arriving at this location. As concentrations increase, more contaminant chromium(VI) with a lower $\delta^{53}\text{Cr}$ signature relative to background chromium(VI) is present (Figure H-5.0-3). It is also possible the observed trends indicate the reductive capacity along the flow-path to R-43 is being progressively overwhelmed such that a less-reduced isotopic signature is being observed over time. If this is the case, the reductive capacity along a flow path can be overwhelmed on very short time frames given the length of time this well has been monitored. A similar pattern may be emerging in the data from the deep screen at R-45 (Table H-5.0-1). Verification of the trends observed at this well will be possible with further sampling and analysis.

The isotopic results are consistent with a conceptual model in which contaminant chromium(VI) undergoes reduction in the vadose zone, primarily in the basalts, mixes with background chromium(VI) produced by weathering, and then “drips” into the regional aquifer from multiple arrival points. While reduction occurs in the vadose zone, the reduction capacity (or kinetics of reduction) of the basalts can decrease in time and even become overwhelmed, as demonstrated by high concentrations at wells such as R-42 and the R-43 time series. Using Equation H-2 and assuming $\delta^{53}\text{Cr}_{\text{ini}}$ of 0 ‰ and $\varepsilon = 3.4$ ‰, it can be estimated that only about 25% reduction of initial chromium(VI) has occurred along the entire flow path to R-42. Mass balance calculations presented in the Phase I SCIR (LANL, 2009, 107453) suggest that higher levels of reduction have occurred. Several reasons may exist for this apparent discrepancy. For example, it would be beneficial if $\delta^{53}\text{Cr}_{\text{ini}}$ and ε could be better defined for this system. Unfortunately, no samples of the potassium dichromate used in the cooling towers are available, so $\delta^{53}\text{Cr}_{\text{ini}}$ will remain an estimated parameter. In addition, the fractionation factor could be better constrained through experimental batch studies of chromium(VI) reduction using a variety of aquifer materials. Raddatz et al. (2011, 226766) have also reviewed other reasons why reduction may be underestimated. For example, Rayleigh models may underestimate reduction by several percent because of the assumption of closed system behavior (Abe and Hunkeler 2006, 226763). Also, the effective, field-relevant value of ε may be a factor of 2 or more less than that derived from laboratory batch experiments because of reservoir effects associated with the fact that chromium(VI) may have to diffuse into reducing microenvironments, which could cause significant underestimation of reduction (Berna et al. 2010, 226764; Raddatz et al. 2011, 226766). Perhaps most important, however, is that the results presented represent a snapshot in time. In the past, the basalts may have been more reactive before fracture filling and modification such as armoring with chromium hydroxides. The reductive capacity of the system clearly is currently incapable of complete reduction of chromium(VI). This may be a function of (1) slow kinetics of chromium(VI) reduction in the aquifer materials, (2) decrease in reduction capacity through time as reductants are consumed, and (3) isolation of reduction capacity from groundwater (e.g., armoring or preferential flow bypassing reduction sites).

Puye Formation sediments in the regional aquifer contain iron(II)-bearing minerals that could lead to additional reduction potential. The distribution of regional aquifer wells relative to the centroid of mass in the chromium plume is such that the chromium isotope data are more useful for comparing isotopic signatures near the center of the mass with those near plume margins than to seeking evidence for progressive enrichment in $\delta^{53}\text{Cr}$ with decreasing chromium(VI) concentration along a plume gradient. Two regional aquifer wells, R-42 and R-28, have chromium(VI) concentrations approximately an order of magnitude above the groundwater standard, whereas the remaining regional aquifer wells have much lower chromium(VI) concentrations. The reduction capacity along the flow pathways to the former wells is clearly overwhelmed by the high chromium(VI) concentrations (Figure H-5.0-1). As such, it is difficult to seek patterns indicative of the potential for additional chromium(VI) reduction in the regional aquifer with these data. One exception may be in comparing data from the lower screen at R-50 to R-42 (n.b., this comparison is only meaningful assuming these screens are hydrologically connected along a flow path). The highest $\delta^{53}\text{Cr}$ value at the R-50 lower screen is 1.9 ‰, while the lowest $\delta^{53}\text{Cr}$ value at R-42 is 1.0 ‰. This isotopic difference corresponds to chromium(VI) reduction of approximately 20%. Even though chromium isotope and concentration values at the lower screen of R-50 appear to be background, it is possible a combination of reduction, dilution, and mixing with true background along the flow path could effectively mask a small anthropogenic component. Furthermore, taking into the account the analytical uncertainty in the chromium isotope measurements and using equation H-2, it can be seen that approximately 10% reduction could occur but be effectively hidden within analytical error. As such, small but significant reduction in the regional aquifer cannot be ruled out.

H-6.0 SUMMARY

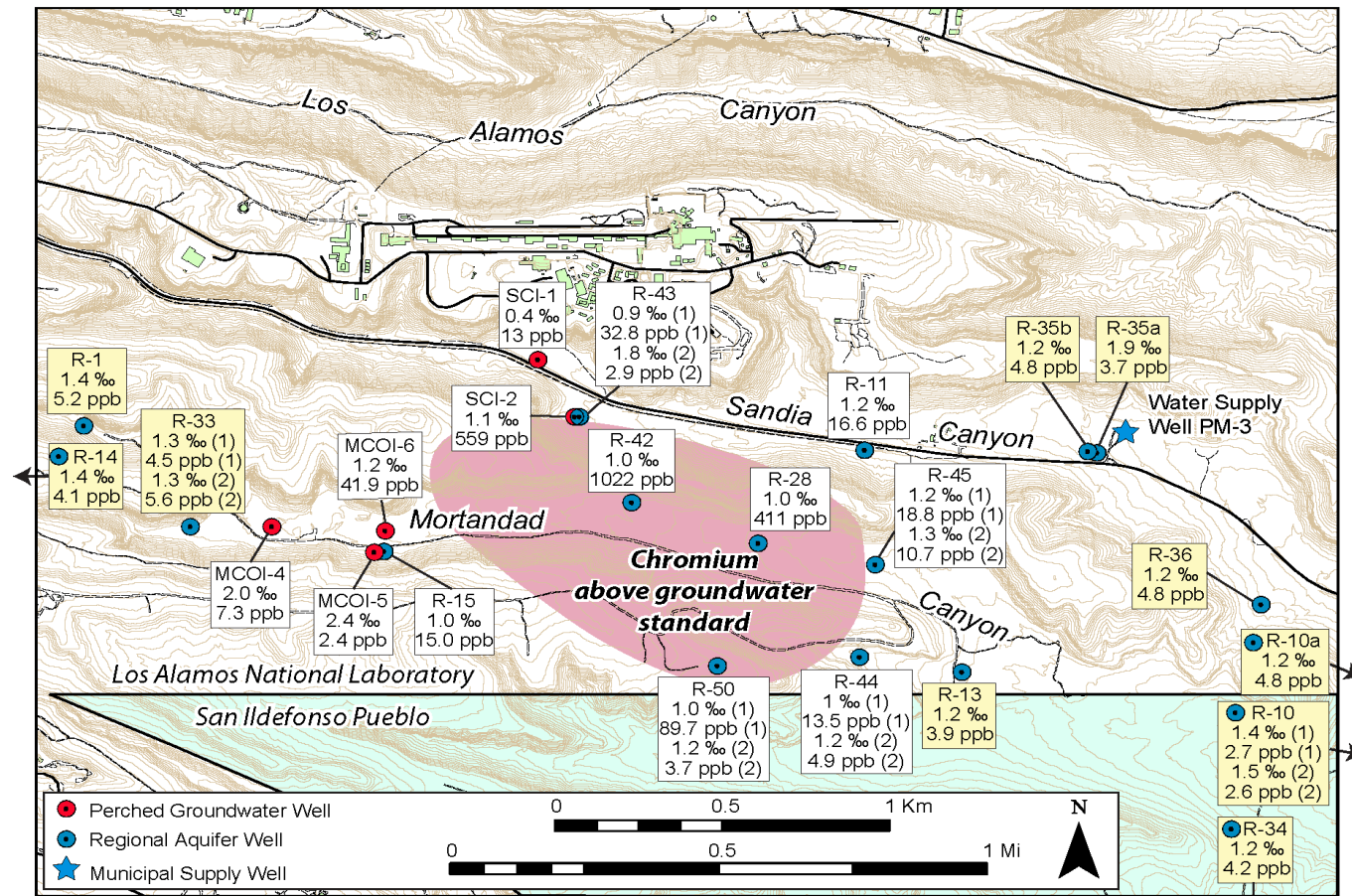
Chromium isotopes provide strong evidence for reduction of chromium(VI) in vadose zone basalts, and possibly in other stratigraphic units such as the Puye Formation, beneath Sandia Canyon and Mortandad Canyon. Reduction, mixing with background chromium(VI) and dilution/sorption are all important processes leading to the observed chromium isotopic variation. Though the reducing capacity of the basalts is significant, evidence indicates that either the kinetics of reduction are relatively slow or the reduction capacity has been overwhelmed along predominant flow paths by the large mass and potentially high historic concentrations of chromium(VI) that passed through the basalt. The results presented herein demonstrate where in the system chromium(VI) reduction currently occurs and provide semiquantitative estimates of the degree of reduction, estimates which may underestimate the true magnitude of reduction of chromium(VI) to chromium(III) that has occurred.

H-7.0 REFERENCES

The following list includes all documents cited in this appendix. Parenthetical information following each reference provides the author(s), publication date, and ER ID. This information is also included in text citations. ER IDs are assigned by the Environmental Programs Directorate's Records Processing Facility (RPF) and are used to locate the document at the RPF and, where applicable, in the master reference set.

Copies of the master reference set are maintained at the New Mexico Environment Department Hazardous Waste Bureau and the Directorate. The set was developed to ensure that the administrative authority has all material needed to review this document, and it is updated with every document submitted to the administrative authority. Documents previously submitted to the administrative authority are not included.

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Note: Some regional aquifer wells have two well screens separated by packers. Screens near the water table are designated with (1) and screens set 100 ft or more below the water table are designated with a (2).

Figure H-5.0-1 Most recent chromium(VI) concentrations and $\delta^{53}\text{Cr}$ for perched-intermediate and regional aquifer wells in Sandia Canyon and Mortandad Canyon. Where two values are given for each parameter, those followed by (1) are from the upper screen and those followed by (2) from the lower screen of the particular well (see Table 5.0-1 for screen depths). Text boxes shaded in yellow represent wells with only natural background chromate present. The pink-shaded plume represents that area of the groundwater system where chromium(VI) concentrations above the New Mexico groundwater standard of 50 ppb are believed to occur.

H-10

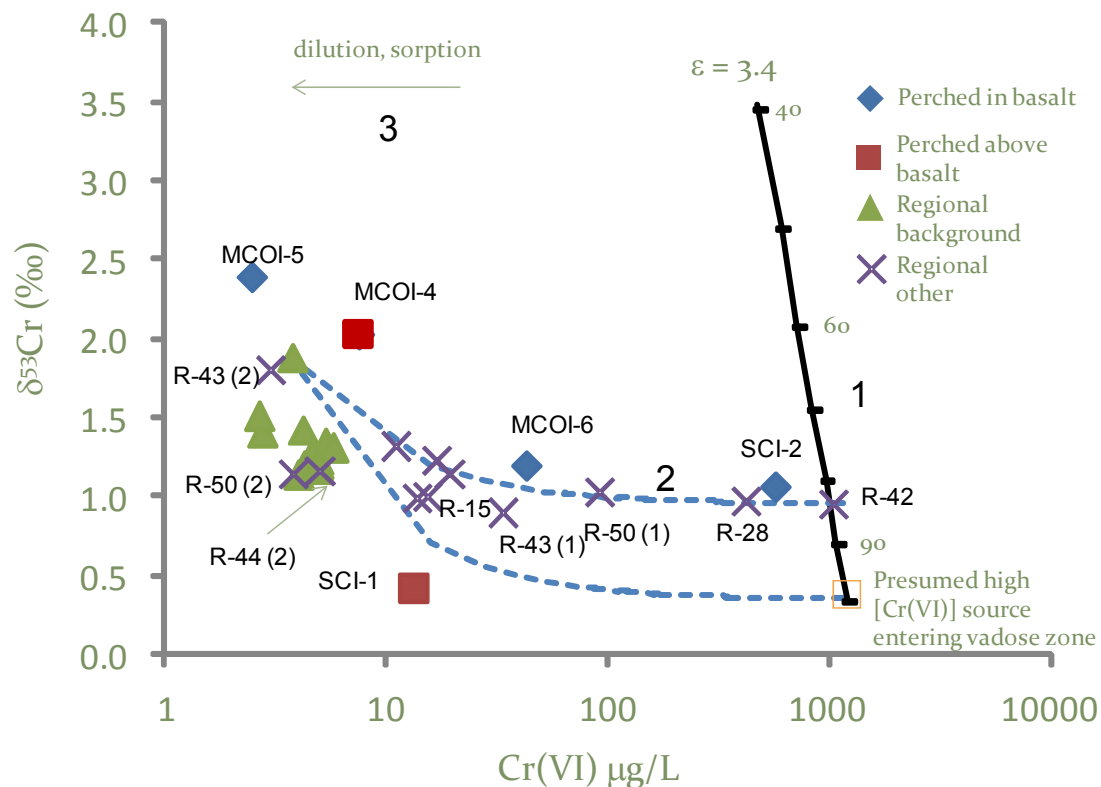


Figure H-5.0-2 $\delta^{53}\text{Cr}$ versus chromium(VI) concentration for most recent data from each well. Lower blue dashed line is a mixing line between a background water and a highly chromium(VI)-contaminated water (open orange box; estimated from the chromium(VI) concentration and $\delta^{53}\text{Cr}$ at well R-42; see text for explanation) that has not undergone reduction. Upper dashed line is a mixing line between well R-42 (shows isotopic evidence for chromium(VI) reduction) and background. The isotopic trend associated with reduction for $\epsilon = 3.4$ ‰ is shown, along with percentage chromium(VI) remaining as reduction proceeds. The value of 3.4 ‰ was chosen to be intermediate within the range of experimentally observed fractionation factors. The lack of isotopic fractionation associated with dilution and sorption is also shown. Numbers 1, 2, and 3 refer to processes of reduction, mixing, and dilution/sorption, respectively. These processes likely occur concurrently, at least to some degree. Not all data points are labeled to prevent cluttering of the diagram.

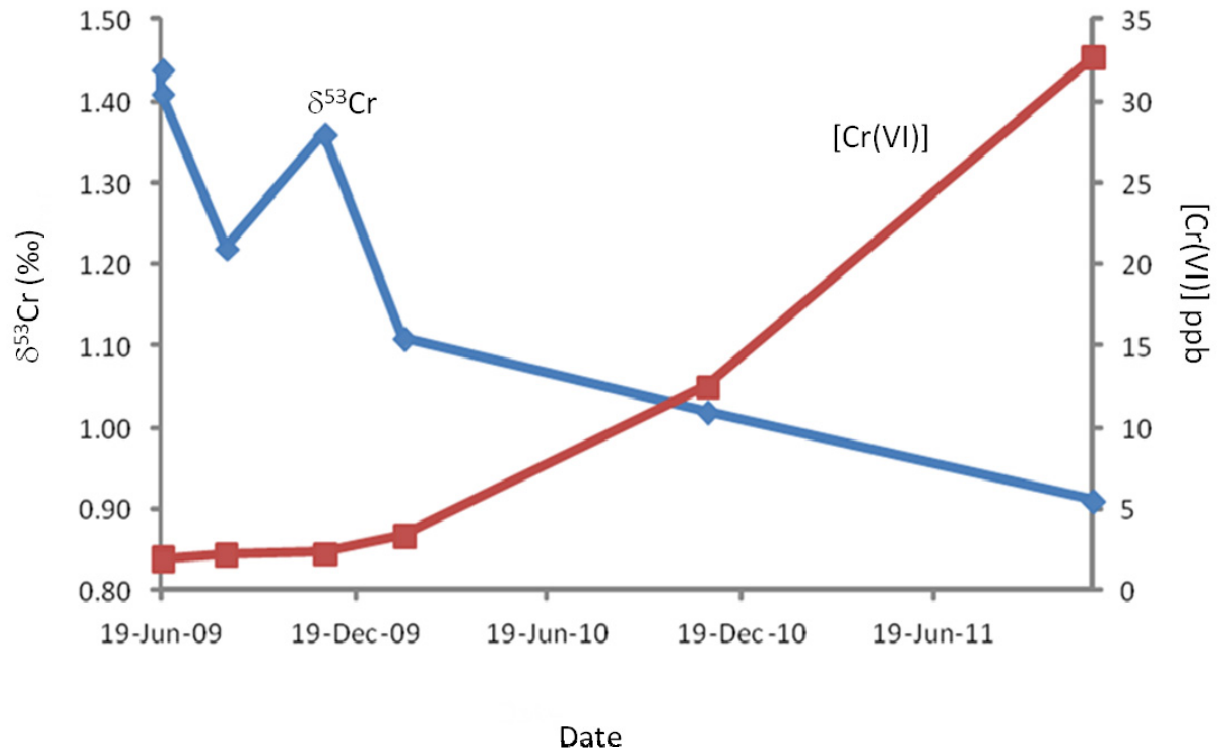


Figure H-5.0-3 Time series of $\delta^{53}\text{Cr}$ and chromium(VI) concentration at the shallow screen of well R-43

Table H-5.0-1
Chromium Isotope Results from Sandia and Mortandad Groundwater

Canyon	Location	Aquifer Type	Collection Date	Sample ID	UIUC Cr(VI)	$\delta^{53}\text{Cr}$ (‰)
Mortandad	MCOI-4	Intermediate	11/12/07	CAMO-08-8619	n/a ^a	1.9
	MCOI-4	Intermediate	05/29/08	CAMO-08-12733	5.6	1.8
	MCOI-4	Intermediate	08/19/08	CAMO-08-14494	7.5	1.9
	MCOI-4	Intermediate	11/18/08	CAMO-09-778	7.3	2.0
	MCOI-5	Intermediate	03/05/07	UF070200GMC501	n/a	2.9
	MCOI-5	Intermediate	11/12/07	CAMO-08-8625	n/a	2.0
	MCOI-5	Intermediate	02/13/08	CAMO-08-10422	1.6	2.8
	MCOI-5	Intermediate	05/20/08	CAMO-08-12738	1.8	2.4
	MCOI-5	Intermediate	08/18/08	CAMO-08-14499	2.4	2.2
	MCOI-5	Intermediate	11/11/08	CAMO-09-781	2.3	2.2
	MCOI-5	Intermediate	04/05/09	CAMO-09-8162	2.5	2.1
	MCOI-5	Intermediate	08/06/09	CAMO-09-9531	3.4	1.5
	MCOI-5	Intermediate	11/03/09	CAMO-10-3898	2.79	2.1
	MCOI-5	Intermediate	01/25/10	CAMO-10-9737	2.4	2.4
	MCOI-6	Intermediate	02/26/07	UF070200GMC601	n/a	1.6
	MCOI-6	Intermediate	11/09/07	CASA-08-7612	n/a	1.6
	MCOI-6	Intermediate	02/22/08	CAMO-08-10425	35.1	1.0
	MCOI-6	Intermediate	05/20/08	CAMO-08-12741	38.4	1.0
	MCOI-6	Intermediate	08/12/08	CAMO-08-14501	39.5	1.0
	MCOI-6	Intermediate	11/10/08	CAMO-09-785	40.7	1.2
	MCOI-6	Intermediate	05/05/09	CAMO-09-8167	49.8	1.0
	MCOI-6	Intermediate	08/19/09	CAMO-09-9535	41.9	1.2
	R-14 port depth 1200.6 ft	Regional	11/13/08	CAMO-09-792	3.5	1.3
	R-14 port depth 1200.6 ft	Regional	05/07/09	CAMO-09-8206	4.1	1.4
	R-1	Regional	03/07/07	UF070200G01R01	n/a	1.2
	R-1	Regional	02/22/08	CAMO-08-10453	5.5	1.2
	R-1	Regional	05/20/08	CAMO-08-12742	7.9	1.2
	R-1	Regional	11/16/09	CAMO-10-3899	5.52	1.5
	R-1	Regional	02/11/10	CAMO-10-9733	5.2	1.5
	R-1	Regional	11/12/10	CAMO-11-1260	5.22	1.4
	R-33 port depth 995.5 ft	Regional	11/11/08	CAMO-09-794	4.5	1.3
	R-33 port depth 995.5 ft	Regional	05/05/09	CAMO-09-8203	5.5	1.4
	R-33 port depth 995.5 ft	Regional	05/06/09	CAMO-09-8199	4.5	1.3
	R-33 port depth 1112.4 ft	Regional	11/11/08	CAMO-09-795	5.6	1.3
	R-15	Regional	02/28/07	UF070200G15R01	n/a	1.0
	R-15	Regional	02/25/08	CAMO-08-10436	7.8	1.0
	R-15	Regional	05/20/08	CAMO-08-12752	5.3	1.0

Table H-5.0-1 (continued)

Canyon	Location	Aquifer Type	Collection Date	Sample ID	UIUC Cr(VI)	$\delta^{53}\text{Cr}$ (‰)
	R-15	Regional	08/15/08	CAMO-08-14540	8.5	1.0
	R-15	Regional	11/10/11	CAMO-12-1483	14.96	1.0
	R-42	Regional	10/09/08	CAMO-08-16441	893	1.1
	R-42	Regional	11/20/08	CAMO-09-826	916.1	1.1
	R-42	Regional	02/20/09	CAMO-09-2871	937	1.1
	R-42	Regional	05/11/09	CAMO-09-8210	1023.1	1.1
	R-42	Regional	08/14/09	CAMO-09-9570	825	1.0
	R-42	Regional	11/05/09	CAMO-10-3900	1001	1.2
	R-42	Regional	02/10/10	CAMO-10-9739	977	1.2
	R-42	Regional	11/10/10	CAMO-11-1274	1022.45	1.0
	R-28	Regional	03/06/07	UF070200G28R01	392.48	1.0
	R-28	Regional	11/14/07	CAMO-08-8712	373.45	1.0
	R-28	Regional	02/15/08	CAMO-08-10441	416.9	1.1
	R-28	Regional	05/14/08	CAMO-08-12767	428.6	1.0
	R-28	Regional	08/15/08	CAMO-08-14542	— ^b	1.1
	R-28	Regional	11/10/08	CAMO-09-809	436	1.1
	R-28	Regional	05/01/09	CAMO-09-8178	420.4	1.1
	R-28	Regional	11/10/10	CAMO-11-1272	410.91	1.0
	R-13	Regional	02/28/07	UF070200G13R01	n/a	1.0
	R-13	Regional	02/14/08	CAMO-08-10444	3.9	1.1
	R-13	Regional	05/14/08	CAMO-08-12772	3.6	1.1
	R-13	Regional	08/14/08	CAMO-08-14534	4.3	0.8
	R-13	Regional	11/10/08	CAMO-09-810	4.1	1.1
	R-13	Regional	04/30/09	CAMO-09-8179	3.9	1.2
	R-34	Regional	03/13/07	UF070200G34R01	n/a	1.2
	R-34	Regional	02/19/08	CAMO-08-10450	n/a	1.2
	R-34	Regional	05/28/08	CAMO-08-12781	3.7	1.0
	R-34	Regional	08/15/08	CAMO-08-14545	4.2	1.2
	R-44 port depth 895 ft	Regional	08/17/09	CAMO-09-9919	8.24	1.2
	R-44 port depth 895 ft	Regional	11/13/09	CAMO-10-4774	13.1	1.2
	R-44 port depth 895 ft	Regional	02/10/10	CAMO-10-9738	8.3	2.3
	R-44 port depth 895 ft	Regional	11/18/10	CAMO-11-1275	11.97	1.0
	R-44 port depth 895 ft	Regional	11/17/11	CAMO-12-1498	13.46	1.0
	R-44 port depth 985.3 ft	Regional	08/17/09	CAMO-09-9925	8.74	1.1
	R-44 port depth 985.3 ft	Regional	11/13/09	CAMO-10-4772	10.6	1.2
	R-44 port depth 985.3 ft	Regional	02/10/10	CAMO-10-9736	4.4	1.3
	R-44 port depth 985.3 ft	Regional	11/18/10	CAMO-11-1277	4.94	1.3

Table H-5.0-1 (continued)

Canyon	Location	Aquifer Type	Collection Date	Sample ID	UIUC Cr(VI)	$\delta^{53}\text{Cr}$ (‰)
	R-44 port depth 985.3 ft	Regional	11/17/11	CAMO-12-1501	4.87	1.2
	R-45 port depth 880 ft	Regional	08/19/09	CAMO-09-10252	12	1.3
	R-45 port depth 880 ft	Regional	11/16/09	CAMO-10-4769	13.4	1.3
	R-45 port depth 880 ft	Regional	01/27/10	CAMO-10-9734	13.6	1.3
	R-45 port depth 880 ft	Regional	11/19/10	CAMO-11-1280	16.58	1.2
	R-45 port depth 880 ft	Regional	11/16/11	CAMO-12-1492	18.82	1.2
	R-45 port depth 974.9 ft	Regional	08/19/09	CAMO-09-10255	5.97	1.7
	R-45 port depth 974.9 ft	Regional	11/16/09	CAMO-10-4771	7.47	1.6
	R-45 port depth 974.9 ft	Regional	01/27/10	CAMO-10-9735	8.2	1.5
	R-45 port depth 974.9 ft	Regional	11/19/10	CAMO-11-1281	9.45	1.4
	R-45 port depth 974.9 ft	Regional	11/16/11	CAMO-12-1496	10.74	1.3
	R-50 port depth 1077 ft	Regional	05/27/10	CAMO-10-17421	57	1.1
	R-50 port depth 1077 ft	Regional	11/16/10	CAMO-11-1313	66.2	1.2
	R-50 port depth 1077 ft	Regional	11/18/11	CAMO-12-1504	89.65	1.0
	R-50 port depth 1185 ft	Regional	05/27/10	CAMO-10-18980	4.4	1.9
	R-50 port depth 1185 ft	Regional	11/16/10	CAMO-11-1315	4.21	1.0
	R-50 port depth 1185 ft	Regional	11/28/11	CAMO-12-1808	3.7	1.2
Sandia	SCI-1	Intermediate	08/22/07	UF070800SCI101	n/a	0.4
	SCI-1	Intermediate	11/16/07	CASA-08-7412	n/a	0.4
	SCI-1	Intermediate	02/22/08	CASA-08-10569	16	0.5
	SCI-1	Intermediate	05/21/08	CASA-08-12860	13.6	0.3
	SCI-1	Intermediate	08/19/08	CASA-08-14367	14.6	0.4
	SCI-1	Intermediate	11/13/08	CASA-09-872	14.2	0.3
	SCI-1	Intermediate	05/06/09	CASA-09-8267	13	0.4
	SCI-2	Intermediate	10/21/08	CASA-09-502	587	1.2
	SCI-2	Intermediate	11/18/08	CASA-09-960	665.3	1.2
	SCI-2	Intermediate	02/13/09	CASA-09-2991	632.7	1.2
	SCI-2	Intermediate	05/06/09	CASA-09-8315	622	1.1
	SCI-2	Intermediate	08/04/09	CASA-09-10368	511	1.1
	SCI-2	Intermediate	11/17/09	CASA-10-3894	596	1.1
	SCI-2	Intermediate	02/08/10	CASA-10-12690	560	1.2
	SCI-2	Intermediate	11/16/10	CASA-11-1362	558.73	1.1
	R-11	Regional	02/13/07	UF070200G11R01	n/a	1.2
	R-11	Regional	11/07/07	CASA-08-7433	n/a	1.1
	R-11	Regional	02/06/08	CASA-08-10546	20.5	1.4
	R-11	Regional	05/12/08	CASA-08-12870	22.4	1.1
	R-11	Regional	08/11/08	CASA-08-14383	20.8	1.2
	R-11	Regional	11/05/08	CASA-09-883	18.5	1.3

Table H-5.0-1 (continued)

Canyon	Location	Aquifer Type	Collection Date	Sample ID	UIUC Cr(VI)	$\delta^{53}\text{Cr}$ (‰)
	R-11	Regional	04/29/09	CASA-09-8275	18.4	1.2
	R-11	Regional	11/16/11	CASA-12-1380	16.55	1.2
	R-35a	Regional	08/30/07	UF07080GR35a01	n/a	3.9
	R-35a	Regional	02/21/08	CASA-08-10557	2.8	2.1
	R-35a	Regional	05/13/08	CASA-08-12874	1.6	3.2
	R-35a	Regional	08/12/08	CASA-08-14389	3	2.0
	R-35a	Regional	11/06/08	CASA-09-884	3.2	2.2
	R-35a	Regional	02/04/09	CASA-09-3014	3.5	2.0
	R-35a	Regional	04/28/09	CASA-09-8304	3.3	2.4
	R-35a	Regional	08/03/09	CASA-09-10390	3.35	2.3
	R-35a	Regional	11/04/09	CASA-10-3895	3.28	2.3
	R-35a	Regional	02/11/10	CASA-10-9846	3.3	2.1
	R-35a	Regional	11/11/10	CASA-11-1372	3.24	1.9
	R-35a	Regional	11/17/11	CASA-12-1384	3.68	1.9
	R-35b	Regional	08/29/07	UF07080GR35b01	n/a	1.2
	R-35b	Regional	11/10/07	GWR35b-08-8639	n/a	1.4
	R-35b	Regional	02/07/08	CASA-08-10558	n/a	1.5
	R-35b	Regional	05/13/08	CASA-08-12878	3.6	1.8
	R-35b	Regional	08/12/08	CASA-08-14385	4.6	1.3
	R-35b	Regional	11/06/08	CASA-09-886	4.7	1.4
	R-35b	Regional	02/02/09	CASA-09-3017	4.4	1.5
	R-35b	Regional	04/27/09	CASA-09-8307	4.5	1.5
	R-35b	Regional	11/11/10	CASA-11-1375	5.17	1.2
	R-35b	Regional	11/09/11	CASA-12-1386	4.79	1.2
	R-36	Regional	05/12/08	CASA-08-12885	4.1	0.9
	R-36	Regional	08/12/08	CASA-08-14397	4.5	1.1
	R-36	Regional	11/06/08	CASA-09-892	4.8	1.2
	R-36	Regional	02/05/09	CASA-09-3024	4.6	1.3
	R-36	Regional	04/28/09	CASA-09-8312	4.8	1.2
	R-10 port depth 874 ft	Regional	02/21/07	UF07020GR10101	1.593	1.3
	R-10 port depth 874 ft	Regional	05/27/08	CASA-08-12861	2.1	1.4
	R-10 port depth 874 ft	Regional	08/13/08	CASA-08-14372	2.6	1.5
	R-10 port depth 874 ft	Regional	11/03/08	CASA-09-877	2.7	1.4
	R-10 port depth 1042 ft	Regional	02/21/07	UF07020GR10201	n/a	1.4
	R-10 port depth 1042 ft	Regional	05/27/08	CASA-08-12866	2.2	1.4
	R-10 port depth 1042 ft	Regional	08/13/08	CASA-08-14375	2.5	1.6
	R-10 port depth 1042 ft	Regional	11/12/08	CASA-09-878	3.2	1.4
	R-10 port depth 1042 ft	Regional	05/12/09	CASA-09-8271	2.6	1.5

Table H-5.0-1 (continued)

Canyon	Location	Aquifer Type	Collection Date	Sample ID	UIUC Cr(VI)	$\delta^{53}\text{Cr}$ (‰)
	R-10a	Regional	02/20/07	UF07020GR10A01	n/a	1.3
	R-10a	Regional	02/19/08	CASA-08-10564	4.9	1.3
	R-10a	Regional	05/27/08	CASA-08-12869	4.4	1.3
	R-10a	Regional	08/13/08	CASA-08-14378	4.8	1.2
	R-43 port depth 903.9 ft	Regional	06/19/09	CAMO-09-10502	2.08	1.4
	R-43 port depth 903.9 ft	Regional	06/19/09	CAMO-09-10504	1.89	1.4
	R-43 port depth 903.9 ft	Regional	08/18/09	CASA-09-10396	2.25	1.2
	R-43 port depth 903.9 ft	Regional	11/19/09	CASA-10-4776	2.31	1.4
	R-43 port depth 903.9 ft	Regional	02/02/10	CASA-10-9842	3.4	1.1
	R-43 port depth 903.9 ft	Regional	11/16/10	CASA-11-1378	12.53	1.0
	R-43 port depth 903.9 ft	Regional	11/15/11	CASA-12-1393	32.78	0.9
	R-43 port depth 969.1 ft	Regional	06/19/09	CAMO-09-10512	1.59	1.4
	R-43 port depth 969.1 ft	Regional	06/18/09	CAMO-09-10509	1.54	1.4
	R-43 port depth 969.1 ft	Regional	08/18/09	CASA-09-10401	1.58	1.6
	R-43 port depth 969.1 ft	Regional	02/02/10	CASA-10-9845	1.9	2.1
	R-43 port depth 969.1 ft	Regional	11/16/10	CASA-11-1381	2.01	2.0
	R-43 port depth 969.1 ft	Regional	11/15/11	CASA-12-1395	2.94	1.8

^a n/a = Chromium(VI) was not measured on initial samples.

^b — = Error in calibration.

Appendix I

Investigations of Light Stable Isotopes

I-1.0 INTRODUCTION

Nitrate is a constituent of potential concern in the Chromium Investigation monitoring group of Sandia and Mortandad Canyons at Los Alamos National Laboratory (LANL or the Laboratory). Groundwater samples were collected from 2005 to 2012 and analyzed for stable isotopes of dissolved nitrate ($^{15}\text{N}/^{14}\text{N}$ and $^{18}\text{O}/^{16}\text{O}$), sulfate ($^{34}\text{S}/^{32}\text{S}$), and bulk water ($^{18}\text{O}/^{16}\text{O}$ and $^2\text{H}/^1\text{H}$). The purpose of this investigation is to evaluate the mixing of different nitrate sources along surface water and groundwater flow paths. An assessment of nitrate and sulfate stable isotopes in groundwater in this region can provide insight into flow paths and sources of other groundwater contaminants.

I-2.0 NITRATE ISOTOPE BACKGROUND

Nitrate (NO_3^-) is highly water-soluble and behaves as a nonadsorbing conservative anion under the circumneutral pH and oxidizing conditions prevalent in common aquifer substrates. The addition of one or more sources of anthropogenic nitrate into groundwater systems that contain natural nitrate (i.e., background nitrate) will increase nitrate concentrations and change the nitrogen and oxygen isotope ratios in nitrate (Mariotti et al. 1988, 227714).

Nitrogen and oxygen isotopes in nitrate are typically reported in delta (δ) notation as follows:

$$\delta^{15}\text{N} = \{[(^{15}\text{N}/^{14}\text{N}_{\text{sample}})/(^{15}\text{N}/^{14}\text{N}_{\text{standard}})-1]*1000\} \quad \text{Equation I-1}$$

$$\delta^{18}\text{O} = \{[(^{18}\text{O}/^{16}\text{O}_{\text{sample}})/(^{18}\text{O}/^{16}\text{O}_{\text{standard}})-1]*1000\} \quad \text{Equation I-2}$$

in units of per mil (‰) or parts per thousand. All stable isotope ratios are reported in the standard δ -notation as the per mil (‰) deviation relative to Vienna Standard Mean Ocean Water (VSMOW) for $\delta^{18}\text{O}$ and atmospheric N_2 for $\delta^{15}\text{N}$. It is important to note the distinction between $\delta^{18}\text{O}$ of nitrate and the $\delta^{18}\text{O}$ of water. Oxygen isotope exchange between nitrate and water does not occur at neutral pHs on the time scales of nitrate contaminant studies (Böhlke et al. 2003, 227710).

The $\delta^{15}\text{N}$ and $\delta^{18}\text{O}$ values in nitrate are imparted based on the mechanism of production of source nitrates and during subsequent processes or chemical reactions that cause a change (fractionation) to the stable isotope ratio. In natural groundwater systems, the observed nitrate isotope ratios, therefore, reflect mixing of nitrate from different sources with distinct isotopic compositions or from isotopic fractionations to the $\delta^{15}\text{N}$ and $\delta^{18}\text{O}$ value during chemical reactions or biological uptake in the environment. The ranges of $\delta^{15}\text{N}$ and $\delta^{18}\text{O}$ values in common environmental sources are well documented (Xue et al. 2009, 227717). A major caveat when considering nitrate stable isotope ratios in groundwater systems is the potential for active microbial denitrification. As the light isotopes of N and O in nitrate are preferentially consumed by bacterial reduction, the residual nitrate increases in $\delta^{15}\text{N}$ and $\delta^{18}\text{O}$. The change in $\delta^{18}\text{O}$ vs. $\delta^{15}\text{N}$ during denitrification (the denitrification vector, $\epsilon^{18}\text{O}:\epsilon^{15}\text{N}$) typically lies in a ratio of approximately 1:2 (Sigman et al. 1997, 227715). However, the slope of the denitrification vector is dependent on nitrogen and oxygen isotope enrichment factors (ϵ), which vary with nitrate concentration, available microbial populations, groundwater residence times, and groundwater chemistry. A good example of this process is seen in the typical high $\delta^{15}\text{N}$ and $\delta^{18}\text{O}$ values detected for sewage effluent resulting from denitrification in waste treatment plants and after release in reducing conditions in the environment (e.g., Deutsch et al. 2009, 227713). Active microbial denitrification occurs in groundwater systems only when the necessary chemical and biological components are present and environmental conditions are appropriate. For example, heterotrophic bacteria reduce nitrate during the coupled oxidation of electron donors such as organic

matter, dissolved organic carbon, sulfide, iron(II), chromium(III), or manganese(II). Other indications of microbial denitrification in groundwater chemistry include N_2 concentrations that are higher than atmospheric abundance, occurrences of metastable nitrite (NO_2^-), elevated sulfate concentrations from oxidation of dissolved sulfide, and/or occurrences of oxidized aqueous and solid species of manganese or iron (Mariotti et al. 1988, 227714).

Overall, geochemical data suggest active microbial denitrification is not a prevalent process in most Pajarito Plateau groundwater systems. Most groundwater samples have dissolved oxygen concentrations greater than 3.5 mg/L, which correlates to greater than 45% dissolved oxygen saturation. Concentrations of dissolved SO_4 range from 2.9 mg/L to 108 mg/L in all samples, suggesting the groundwater is oxidizing with respect to sulfur. Since sulfate is reduced at a lower redox potential than nitrate, it is likely that if sulfate reduction is not occurring, then nitrate reduction is also not occurring. Although the oxidation-reduction potential (Eh) is moderately to highly oxidizing (between 158 mV and 605 mV), some samples have sufficient reducing potential for nitrite stability, demonstrating it is thermodynamically possible to reduce nitrate in this groundwater setting. Total organic carbon (TOC) may also act as an electron acceptor; however, TOC concentrations range from 0.44 mgC/L to 5.41 mgC/L within all aquifer systems, which is too low to be a significant electron acceptor. The absence of nitrite in any samples collected from these wells suggests minimal nitrate reduction to nitrite. Overall, data on redox-sensitive species suggest nitrate stable isotope ratios are largely unaffected by denitrification in the subsurface at the site.

I-3.0 SAMPLE COLLECTION AND PRESERVATION

Water samples were collected from perennial springs and alluvial, intermediate, and regional groundwater monitoring wells using dedicated peristaltic pumps. Well locations are shown in Figure I-3.0-1. Water samples for stable isotope analyses were collected in 40-mL amber borosilicate vials without headspace at 4°C until analysis at the Laboratory's Earth and Environmental Sciences Division's (EES) analytical facility. Samples for nitrate isotopes were filtered through a 0.45- μ m nylon filter in the field; samples for water isotopes were unfiltered. Samples for nitrate concentration were collected as part of the anion suite in 125-mL high-density polyethylene bottles and analyzed at General Engineering Laboratory (GEL) or the EES analytical facility. Results from both filtered and unfiltered anion samples are used and showed no systematic bias. Samples were analyzed within 1 mo of collection. From 2008 to 2012, the New Mexico Environment Department (NMED) U.S. Department of Energy (DOE) Oversight Bureau (OB) collected 203 samples from the Pajarito Plateau for stable isotope ratios of aqueous sulfate. A subset of these data, relevant to the Sandia and Mortandad Canyons area, is used in this appendix.

I-4.0 ANALYTICAL METHODOLOGY

Groundwater samples were analyzed for aqueous nitrate nitrogen and oxygen isotope ratios using a modified version of the microbial denitrification technique described by (Sigman et al. 2001, 227716; Casciotti et al. 2002, 227711). In this method, N_2O gas is evolved from dissolved nitrate, sampled and collected with a GV Instruments trace gas analyzer and analyzed with a GV Instruments Isoprime Mass Spectrometer (GV Instruments, Manchester, UK). Samples were calibrated using International Atomic Energy Agency (IAEA) and U.S. Geological Survey (USGS) nitrate standards IAEA-NO-3 and USGS-32 ($\delta^{15}N = +4.7$ and $+180\text{‰}$ versus atmospheric N_2 , respectively) for $\delta^{15}N$ and using IAEA-NO-3 and USGS-34 ($\delta^{18}O = +25.6\text{‰}$ and -27.9‰ versus VSMOW, respectively) for $\delta^{18}O$. Analytical precision was routinely $<0.25\text{‰}$ for $\delta^{15}N$ and $<0.50\text{‰}$ for $\delta^{18}O$.

Anion concentrations were measured following U.S. Environmental Protection Agency (EPA) Methods EPA:300.0, EPA:353.1, or EPA:353.2. EPA Method 300.0 uses ion chromatography (Dionex IC25, LC25, Dionex 4-mm-diameter analytical column AS14A, and a matching Dionex guard column AG14A). Nitrate concentration data are reported in terms of nitrate as total nitrogen ($\text{NO}_3\text{-N}$).

Stable isotope ratios for hydrogen and oxygen in water were measured using a GV Instruments Isoprime continuous flow isotope ratio mass spectrometer (GV Instruments, Manchester, UK). The $\delta^{18}\text{O}$ and δD values were calibrated using in-house standards calibrated to IAEA standards (VSMOW, SLAP, and GISP) and are reported relative to VSMOW. $\delta^{18}\text{O}$ was measured through analysis of CO_2 equilibrated with 400 μL of water on a GV Instruments Multiflow peripheral instrument. δD was measured using chromium reduction from water using a GV Instruments Eurovector Elemental Analyzer. Analytical linearity was monitored and corrected for by analyzing standards after every five samples for both methods. Analytical precision on an in-house standard was $< \pm 0.16\text{‰}$ for $\delta^{18}\text{O}$ and $< \pm 0.99\text{‰}$ on replicate analyses for δD .

The NMED data for stable isotope ratios of sulfur in sulfate ($\delta^{34}\text{S}$) were analyzed by Zymax or Isotech. Samples were precipitated as barium sulfate and analyzed by elemental analyzer–isotopic ratio mass spectrometer. Oxygen isotope ratios of sulfate were analyzed but are not included because of discrepancies in results between the two laboratories.

I-5.0 RESULTS AND DISCUSSION

The analytical results are publicly available in Intellus. Nitrate concentrations and $\delta^{15}\text{N}$ results are also shown on the map in Figure I-3.0-1 and the plots in Figures I-5.0-1 and I-5.0-2. Nitrate $\delta^{15}\text{N}$ and $\delta^{18}\text{O}$ results are shown in Figures I-5.0-3 and I-5.0-4. Water isotopes (δD and $\delta^{18}\text{O}$) and sulfate $\delta^{34}\text{S}$ values from wells and springs in the area of interest (Figure I-5.0-5) are also reported.

I-5.1 Water Isotopes (δD and $\delta^{18}\text{O}$)

Stable isotope ratios of δD and $\delta^{18}\text{O}$ of water are also used to provide insight into water sources and mixing (Figure I-5.0-5). On the Pajarito Plateau, the regional aquifer is recharged in large part from high-elevation snowmelt infiltrating along the Pajarito fault zone and in canyon bottoms and is characterized by $\delta^{18}\text{O}$ between -10.5‰ and -11.3‰ , and δD between -73‰ and -80‰ . More positive $\delta^{18}\text{O}$ and δD are found in waters sourced from lower-elevation recharge with a greater summer monsoon component; this signal is more typically observed in alluvial and intermediate groundwater in canyons headed on the Pajarito Plateau itself rather than in the mountain front, including Sandia, Mortandad, and DP Canyons.

Some major points can be seen in the water isotopes. Intermediate wells SCI-1 and SCI-2 are more positive compared with the regional wells, suggesting a large component of low-elevation recharge. Regional wells R-28 and R-42 are the most positive of the regional wells in $\delta^{18}\text{O}$ and δD , suggesting a significant flow path from the low-altitude recharged alluvial systems and the vadose zone to this area, which is consistent with the overall geochemical conceptual model as delineated in section 7.2 of the investigation report. MCOI-6 has $\delta^{18}\text{O}$ and δD values similar to R-28 and R-42, which is consistent with other geochemical indicators (Appendix D). $\delta^{18}\text{O}$ and δD in Los Alamos Canyon intermediate wells vary considerably among one another, indicating recharge to some of the perched-intermediate zones (e.g., LAOI-3.2a, TA-53i) is local, whereas other intermediate wells in Los Alamos Canyon are recharged from water derived from the mountain front.

I-5.2 Nitrate Sources

Nitrate in the Sandia and Mortandad Canyons perched alluvial and intermediate groundwaters likely originates from at least three different nitrate sources, in addition to background nitrate.

Treated sewage effluent from wastewater treatment facilities has been discharged into upper Sandia Canyon at Technical Area (TA-03) since the early 1950s and is currently released at National Pollutant Discharge Elimination System (NPDES) Outfall 001. These effluents are the likely source of greater than 90% of the nitrate in surface and alluvial waters in Sandia Canyon. Two sewage effluent sources from the Laboratory were measured in 2009 as part of other studies, and those results are presented here for comparison purposes. The NPDES Outfall 001 had a $\delta^{15}\text{N}$ value of +33.5‰ and a $\delta^{18}\text{O}$ value of -7.2‰; this outfall discharges a combination of wastewaters from the TA-46 Sanitary Wastewater System Consolidation (SWSC) plant, the TA-03 steam plant, and the TA-03 power plant to upper Sandia Canyon. The 13-S Outfall had nitrate with $\delta^{15}\text{N}$ = +24.9‰ and a $\delta^{18}\text{O}$ value of -2.2‰; this “outfall” is for the effluent stream from the TA-46 SWSC plant, which is not discharged directly to the environment but rather is currently routed up to Outfall 001 and mixed with other effluent, as described above. Sewage effluent $\delta^{15}\text{N}$ and $\delta^{18}\text{O}$ values have been shown to vary considerably (Xue et al. 2009, 227717) because of different treatment processes and conditions. Although $\delta^{15}\text{N}$ values for sewage wastewater effluents are typically between +4 and +19‰ (avg. = 10‰ to 11‰) (Xue et al. 2009, 227717), some studies have found wastewater effluent with $\delta^{15}\text{N}$ of nitrate up to +25‰ to +40‰ (e.g., Deutsch et al. 2009, 227713). As discussed above, partial denitrification in the waste treatment facility or the wetland would increase residual nitrate $\delta^{15}\text{N}$ and $\delta^{18}\text{O}$ values. A wetland 0.5 mi downstream of the NPDES Outfall 001 provides some reductive capacity, and most recharge to the perched-intermediate zone is thought to occur in the infiltration window in the vicinity of alluvial well SCA-2 and intermediate well SCI-1. Both SCA-2 and SCI-1 have nitrate $\delta^{15}\text{N}$ values (SCI-1: $\delta^{15}\text{N}$ = 23.2‰ to 28.4‰, avg. = 25.3‰; SCA-2: $\delta^{15}\text{N}$ = 27.2‰ to 29.9‰, avg. = 28.1‰), strongly suggesting a sewage source.

The Mortandad Canyon watershed has received industrial effluents containing nitrate derived from treated sewage effluent and neutralized nitric acid since the early 1950s. Since 1963, releases from the Radioactive Liquid Waste Treatment Facility (RLWTF) at TA-50 (NPDES Outfall 051) into Effluent Canyon, a tributary of Mortandad Canyon, have consisted of neutralized nitric acid. Two isotopically distinct forms of neutralized nitric acid have been discharged from the NPDES Outfall 051. The typical form discharged from the facility contained the stable nitrogen isotopes in approximately normal proportions for unmodified nitric acid. Effluent from the NPDES Outfall 051 has not been analyzed directly throughout its history for nitrate stable isotope ratios; however, it is inferred from the acid treatment processes used at the facility that neutralized nitric acid comprises the bulk of its nitrate effluent. Releases from the NPDES Outfall 051 in 2009 were measured for an independent study that found $\delta^{15}\text{N}$ from +14.3 to +15.5‰ and $\delta^{18}\text{O}$ from -2.0 to +0.7‰, but nitrate stable isotope ratios of past effluent are unknown. Average $\delta^{15}\text{N}$ and $\delta^{18}\text{O}$ values of $2.54 \pm 2.8\text{‰}$ and $25.0 \pm 0.9\text{‰}$ were measured from four modern nitric acid samples at the Laboratory and are consistent with previously reported values (Böhlke et al. 2003, 227710). The results from Outfall 051 and from the nitric acid samples are presented here for comparison purposes. The $\delta^{15}\text{N}$ value of nitrate formed from nitric acid is unlikely to change significantly during treatment and neutralization; however, the $\delta^{18}\text{O}$ value for oxygen in nitrate has been shown to exchange with oxygen in water in high molarity nitric acid solutions (>1 M) in time scales from hours to months (Böhlke et al. 2003, 227710). As the nitric acid neutralized at the RLWTF was used at high molarity and recycled numerous times as part of plutonium processing, the +25‰ $\delta^{18}\text{O}$ signal is not expected to be observed in most neutralized nitric acid effluent. In light of the discrepancy between measured effluent values from 2009 and those predicted for neutralized nitric acid, it is unclear what the exact $\delta^{15}\text{N}$ and $\delta^{18}\text{O}$ values of nitrate from the NPDES outfall were during most previous releases. Effluent

nitrate concentrations in Outfall 051 have been reduced below 10 mg/L since 1999, and the outfall has not discharged since November 2010 (section 2.1.2).

A second form of nitrate that is isotopically depleted with respect to ^{15}N was discharged from the NPDES Outfall 051 from 1986 to 1989. Waste from an isotope production study, this ^{15}N -depleted nitric acid constituted 60% of all nitric acid neutralized and released into the aqueous waste stream at TA-50 RLWTF between 1986 and 1989 (Broxton et al. 2002, 076006). Information regarding the process, enrichment yield, and actual stable isotope ratios of the depleted nitric acid is not available. The exact isotope values of effluent released during this time are not known, but negative $\delta^{15}\text{N}$ values as low as -48‰ have been found for nitrate in alluvial well MCO-7 in Mortandad Canyon. The occurrence of negative $\delta^{15}\text{N}$ values in the most upgradient intermediate well (MCOI-4) in Mortandad Canyon suggests some infiltration at, or upgradient of, this location (Figure I-3.0-1).

Additional sewage effluent nitrate sources to the Mortandad Canyon drainage discharged from historical septic systems, including sewage lagoons, at TA-35 into Mortandad and Ten Site Canyons, a tributary to Mortandad Canyon, from 1951 to 1986 (Birdsell et al. 2006, 094399). The isotopic composition of nitrate from past sewage effluent is not known but is probably greater than the average $\delta^{15}\text{N}$ sewage effluent value of 10‰ , considering the likelihood of denitrification in treatment ponds.

Los Alamos Canyon provides an additional potential source of nitrate and other contaminants to the area (Figure I-3.0-1). Southward transport through the perched-intermediate zone in the Puye Formation is posited as a potential groundwater flow path to provide nitrate from Los Alamos Canyon to the Sandia Canyon perched-intermediate zone and potentially the underlying regional aquifer. Chemical processing from radioactive liquid waste treatment at TA-21 released nitrate into DP Canyon, a tributary of Los Alamos Canyon, through Outfall 21-011(k) from 1952 to 1986 (LANL 1995, 052350). As with the RLWTF, details of waste-treatment processes at TA-21 are not available, and it is not known if identical treatment processes were used at both sites. In DP Canyon, nitrate concentrations from 2.1 mg/L to 4.4 mg/L $\text{NO}_3\text{-N}$ were detected in intermediate wells R-6i, LAOI-3.2, and LAOI-3.2a. These have $\delta^{15}\text{N}$ values of 10.9‰ , 10.7‰ , and 9.7‰ , respectively. The nitrate $\delta^{18}\text{O}$ values for these wells (12.3‰ , 7.6‰ , and 5.2‰ , respectively) are much more positive than in wells that more clearly sample sewage-derived nitrate, such as SCI-1 and SCI-2 (Figure I-5.0-3). The downcanyon intermediate-well LAOI-7 also has a high $\delta^{15}\text{N}$ value (9.3‰) but a much lower nitrate concentration ($0.3\text{ mg/L NO}_3\text{-N}$). Other Los Alamos Canyon wells have lower nitrate concentrations $<1.2\text{ mg/L NO}_3\text{-N}$ and lower $\delta^{15}\text{N}$ values with a smaller range (2.1‰ to 6.2‰). Past releases of nitrate in Los Alamos Canyon were likely variable in both volume and concentration of nitrate and its stable isotope ratio.

A component of background nitrate is present throughout the Pajarito Plateau. An independent study was conducted at the Laboratory and nearby areas to identify current groundwater sources (e.g., springs and wells) that are representative of background groundwater conditions for a wide range of major, minor, trace elements, metals, and radionuclides (LANL 2007, 095817). Forty-three samples from 14 groundwater springs and 7 monitoring well locations were selected to define the concentration and stable isotope ratios of background nitrate in the Pajarito Plateau (LANL 2007, 095817). A previous study (Chrystal et al. 2009, 227718) used this data set to define background nitrate isotopic compositions from across the Pajarito Plateau as the following: average $\delta^{15}\text{N}$ values of $4.7 \pm 0.9\text{‰}$ (min = 1.9‰ , max = 6.7‰); $\delta^{18}\text{O}$ values of $-2.4 \pm 2.1\text{‰}$ (min = -6.5‰ , max = 2.5‰); and $\text{NO}_3\text{-N}$ concentrations $0.51 \pm 0.22\text{ mg/L}$ (min = 0.12 , max = 1.26). Nitrate in monitoring wells with both low concentrations ($<0.73\text{ mg/L NO}_3\text{-N}$), and $\delta^{15}\text{N}$ and $\delta^{18}\text{O}$ values within the ranges above are most readily interpreted as background.

I-5.3 Alluvial Groundwater

Perched alluvial groundwater is not the focus of this study; however, some data are provided. SCA-2 (Figure I-3.0-1) were analyzed, and, as discussed above, provides an insight into the end-member for a Sandia Canyon source. SCA-2 has 0.3 ppm $\text{NO}_3\text{-N}$ with a $\delta^{15}\text{N}$ value of +29.9‰, consistent with a nitrate source from NPDES Outfall 001.

In Los Alamos Canyon, the alluvial DP Spring has $\delta^{15}\text{N}$ of 3.8‰ and $\delta^{18}\text{O}$ value of +10.6‰ (Figure I-5.0-4). Its high $\delta^{18}\text{O}$ value, combined with a low $\delta^{15}\text{N}$, is consistent with a nuclear-processing signal. A nearby alluvial well in Los Alamos Canyon, LAO-3a, has 1.2 mg/L $\text{NO}_3\text{-N}$ and a more typical nitrate isotope ratio ($\delta^{15}\text{N} = 4.4\text{‰}$, $\delta^{18}\text{O} = 0.4\text{‰}$) (Figure I-5.0-4). The Los Alamos Canyon alluvial wells sample water that recharges the Los Alamos Canyon intermediate zone. DP Spring and LAO-3a are likely not recording the full range of nitrate isotopic compositions in Los Alamos Canyon because intermediate wells R-6i, LAOI-3.2, and LAOI-3.2a have higher $\delta^{15}\text{N}$ values, as discussed above. The nitrate concentrations and isotopic compositions may also no longer reflect the composition of Outfall 21-011(k) effluent since that outfall stopped releasing in 1986. The Los Alamos Canyon perched-intermediate zone is a possible source of nitrate and other constituents to the Sandia Canyon perched-intermediate zone.

The eight Mortandad alluvial wells (MCA-2, MCO-5, MCO-6, MCO-7, MCO-7.5, MT-1, MT-3, and MT-4) have nitrate concentrations that range between 0.8 mg/L and 3.5 mg/L $\text{NO}_3\text{-N}$. In general, nitrate concentrations in these alluvial wells generally have decreased since 2005 (Figure I-5.3-1); this trend is consistent with declining concentrations of nitrate effluent released from NPDES Outfall 051 since 1994 and especially since 1999 (LANL 2006, 094161). The ^{15}N -depleted nitrate, released in the late 1980s, provides a means to assess travel times in the vadose zone because the stable isotope ratios in nitrate from the alluvial wells show considerable variation in $\delta^{15}\text{N}$ through time (Figures I-5.3-2 to I-5.3-6). The most upgradient alluvial wells, MCO-5 and MCO-6, show significant increases in nitrate $\delta^{15}\text{N}$ values from less than -20‰ in 2005 to -5‰ in 2009 (Figure I-5.3-2 and I-5.3-3). In Mortandad Canyon, alluvial well MCO-7, located near intermediate well MCOI-4, had the lowest $\delta^{15}\text{N}$ value (-48‰) in September 2005, but $\delta^{15}\text{N}$ in this well has subsequently increased to -16‰ by August 2009 (Figure I-5.3-4). Alluvial wells MT-3 and MCO-7.5 are located farther downcanyon from MCOI-6 and show a different trend in nitrate $\delta^{15}\text{N}$ values (Figures I-5.3-5 and I-5.3-6). In these wells, $\delta^{15}\text{N}$ decreases sharply from approximately -10‰ to -15‰ in 2005 to below -30‰ in 2006; although $\delta^{15}\text{N}$ at MT-3 had increased to -25‰ by 2008, $\delta^{15}\text{N}$ at MCO-7.5 has remained below -30‰. Alluvial wells MCA-2, MT-1, and MT-4 were analyzed for nitrate stable isotope ratios in 2005, and all have $\delta^{15}\text{N}$ values less than -18‰, reflecting the ^{15}N -depleted nitric acid source; however, no subsequent samples were collected from these wells, so nitrate stable isotope histories at these wells are not known. Overall, temporal variations in nitrate $\delta^{15}\text{N}$ values in the Mortandad Canyon alluvial wells suggest the ^{15}N -depleted neutralized nitric acid contaminant plume has migrated past the upgradient alluvial wells (near MCOI-4) and more recently has reached the downcanyon alluvial wells near MCOI-6. This hypothesis is consistent with previous research concluding that alluvial groundwater locally recharges perched-intermediate zones in the Mortandad Canyon watershed (LANL 2006, 094161).

I-5.4 Intermediate-Depth and Regional Groundwater

In Mortandad Canyon, wells MCOI-4, MCOI-5, and MCOI-6 (Figure I-3.0-1) provide insight into the conceptual model for the perched-intermediate zones. Intermediate wells MCOI-4 and MCOI-6 have $\text{NO}_3\text{-N}$ concentrations of 10.6 mg/L and 8.1 mg/L, respectively, which are significantly higher than $\text{NO}_3\text{-N}$ concentrations in intermediate-well MCOI-5 (3.9 mg/L) and Mortandad Canyon alluvial wells (see also Appendix D). Well MCOI-4 is in the Puye Formation and upgradient of the deeper MCOI-6 in the Cerros del Rio basalt. MCOI-4 currently contains the highest nitrate concentrations in intermediate and regional

wells in the Chromium Investigation monitoring group (10.6 mg/L $\text{NO}_3\text{-N}$), although it shows a general trend of decreasing concentration since a maximum of 17.7 mg/L in June 2007 (Figure I-5.4-1). Similarly, MCOI-6 has decreased in nitrate concentration since a maximum in November 2007 (20.4 mg/L $\text{NO}_3\text{-N}$) to its most recent value of 8.1 mg/L (Figure I-5.4-2). Both MCOI-4 and MCOI-6 are notable in that $\delta^{15}\text{N}$ values are negative (MCOI-4: -5.6‰ ; MCOI-6: -33.2‰), uniquely indicating a significant portion of the nitrate is derived from the ^{15}N -depleted treated nitric acid from NPDES Outfall 051 in the late 1980s. Time-series trends for MCOI-4 (Figure I-5.4-1) show $\delta^{15}\text{N}$ has increased from -13.3‰ (June 2005) to -2.4‰ (August 2009), with a decrease to its most recent value of -5.6‰ (July 2010), which overall suggests the ^{15}N -depleted portion of the nitrate plume is passing beyond this well. MCOI-6 also shows notable recent changes to $\delta^{15}\text{N}$ (Figure I-5.4-2). Nitrate $\delta^{15}\text{N}$ values decreased from -26.4‰ (June 2005) to -38.0‰ (August 2008), followed by an increase in $\delta^{15}\text{N}$ to -33.2‰ (July 2010). For both MCOI-4 and MCOI-6, the recent increases in $\delta^{15}\text{N}$ correlate with a decline in nitrate concentrations, resulting from lower effluent volumes and nitrate concentration released from NPDES Outfall 051 since the 1990s. The observed temporal trends in $\delta^{15}\text{N}$ values in intermediate wells MCOI-6 and MCOI-4 are similar to the trends observed in the alluvial wells immediately above them, suggesting a vertical hydrogeologic connection exists between the alluvial and intermediate perched zones with a travel time from less than 20 yr to approximately 30 yr.

Although intermediate-well MCOI-5 is less than 75 m south of MCOI-6 and at approximately the same depth, it appears to preserve a significantly different contaminant transport history. MCOI-5 contains 3.9 mg/L $\text{NO}_3\text{-N}$ and $\delta^{15}\text{N}$ has decreased from 9.2‰ (June 2005) to 3.6‰ (July 2010) (Figure I-5.4-3). The saturated zones between MCOI-5 and MCOI-6 may not be connected, and other contaminants (e.g., perchlorate, tritium, sulfate, chromium, and chloride) found in MCOI-5 are distinct from those in MCOI-4 and MCOI-6 (LANL 2006, 094161, Appendix D). MCOI-5 also has much lower water isotopes ($\delta^{18}\text{O} = -11.2\text{‰}$; $\delta\text{D} = -78.6$) than MCOI-4 and MCOI-6 (Figure I-5.0-5). Because MCOI-5 is located on the south side of Mortandad Canyon, near the tributary of Ten Site Canyon, it appears that historical contamination sources within Ten Site Canyon are distinct from those released in Mortandad Canyon. In particular, these data do not provide clear evidence the ^{15}N -depleted neutralized nitric acid-contaminant plume has reached MCOI-5 during this sampling period; however, the recent decrease in $\delta^{15}\text{N}$ suggests a greater component of the ^{15}N -depleted nitrate plume is beginning to reach this well. Historical sewage from Ten Site Canyon and standard neutralized nitric acid effluent are the most plausible dominant sources of nitrate in MCOI-5.

The isotopic characteristics of intermediate wells in Los Alamos Canyon span a significant range in $\delta^{15}\text{N}$ (from 2.1‰ to 10.9‰) and $\delta^{18}\text{O}$ (-6.9‰ to $+12.3\text{‰}$) (Figure I-5.0-5). Intermediate-well TA-53i samples the Puye Formation between Los Alamos Canyon and Sandia Canyon and may reflect a possible pathway between the two canyons. This well has 1.1 mg/L $\text{NO}_3\text{-N}$, a $\delta^{15}\text{N}$ value of 4.2‰ , and $\delta^{18}\text{O}$ value of -0.8‰ . $\delta^{15}\text{N}$ in this well has decreased from 5.8‰ (July 2009) to 4.2‰ (March 2011) (Figure I-5.4-5), reflecting a change in the $\delta^{15}\text{N}$ value of source nitrate from Los Alamos Canyon.

The Sandia intermediate wells provide information on nitrate sources to the regional aquifer. SCI-1 is located in the Puye Formation within the infiltration zone for Sandia Canyon groundwater and at the northwest periphery of the Chromium Investigation monitoring group. The nitrate stable isotope ratios at this well reflect both a sewage signal and the effect of transport through the wetland and subsurface after the outfall but before reaching the infiltration zone. Distinct nitrogen and oxygen stable isotope ratios ($\delta^{15}\text{N} = 28.4\text{‰}$, $\delta^{18}\text{O} = 5.8\text{‰}$, $\text{NO}_3\text{-N} = 2.4$ mg/L) were measured and are consistent with denitrified sewage effluent and are similar to those in the alluvial well SCA-2 ($\delta^{15}\text{N} = 29.9\text{‰}$, $\delta^{18}\text{O}$ was not measured). Intermediate well SCI-2 is deeper and downgradient of SCI-1 and has a lower $\delta^{15}\text{N}$ value ($\delta^{15}\text{N} = 13.0\text{‰}$, $\delta^{18}\text{O} = 1.3\text{‰}$). This finding is consistent with mixing between waters from the Sandia sewage source observed in intermediate well SCI-1 with either nitrate in waters as currently seen in regional wells R-11

and R-43 screen 1 or possibly with the waters from Los Alamos Canyon to the north with isotopic characteristics similar to intermediate wells LAOI-7 and TA-53i. The time series for SCI-2 (Figure I-5.4-4) shows that $\delta^{15}\text{N}$ has increased from +11.1‰ in October 2008 to +13.0‰ in November 2011, and suggests either an increasing contribution of the denitrified sewage nitrate component in recent years, a decreased contribution from Los Alamos Canyon, or temporal variations in $\delta^{15}\text{N}$ in nitrate of one of the other sources.

I-5.5 Regional Groundwater

Nitrate stable isotopes provide evidence for recharge and mixing into the regional aquifer from the perched-intermediate zones.

Regional wells R-28 and R-42 are central to the chromium plume and also contain among the highest nitrate concentrations in the regional aquifer (R-28 = 3.4 mg/L; R-42 = 5.8 mg/L $\text{NO}_3\text{-N}$) (Figure I-5.0-2). These waters have nitrate stable isotope ratios similar to those in intermediate well SCI-2 (R-28: $\delta^{15}\text{N}=11.2\text{‰}$, $\delta^{18}\text{O}=-0.6\text{‰}$; R-42: $\delta^{15}\text{N}=10.7\text{‰}$, $\delta^{18}\text{O}=-0.2\text{‰}$) (Figure I-5.0-4). This provides evidence for a transport pathway from perched-intermediate groundwater to the regional aquifer near R-42 and R-28, and suggests a common nitrate mixing history with SCI-2. Further isotopic evidence for a connected transport pathway to the regional aquifer is observed in the water isotopes of $\delta^{18}\text{O}$ and δD in these wells, which are among the most positive values of the regional wells, reflecting a greater contribution of local-sourced alluvial waters (Figure I-5.0-5).

The negative $\delta^{15}\text{N}$ nitrate signature observed in the perched-intermediate wells MCOI-4 and MCOI-6 has not been seen in any regional wells in Mortandad and Sandia Canyons, indicating contaminant travel times to the regional aquifer beneath Mortandad Canyon are greater than 20 yr.

Two of the regional wells in the study area with the highest nitrate concentrations are regional well R-43 screen 1 (Figure I-5.0-2), located close to the infiltration zone at intermediate well SCI-2 (Figure I-3.0-1), and the downcanyon regional well R-11. R-43 screen 1 has had relatively constant nitrate isotope compositions ($\delta^{15}\text{N} = 4.2\text{‰}$, $\delta^{18}\text{O} = -1.9\text{‰}$) and nitrate concentrations (5.6 mg/L $\text{NO}_3\text{-N}$) since November 2008 (Figure I-5.5-1). Like R-43, R-11 also has a high nitrate concentration (5.3 mg/L $\text{NO}_3\text{-N}$) and similar nitrate stable isotope compositions ($\delta^{15}\text{N} = 3.9\text{‰}$, $\delta^{18}\text{O} = -2.7\text{‰}$). These wells have much lower $\delta^{15}\text{N}$ compared with R-28 and R-42, pointing to a different source. These nitrate stable isotope values point to a source of ^{15}N -enriched sewage effluent, perhaps from older treatment methods, or could be interpreted as waters similar to those at intermediate well TA-53i moving from Los Alamos Canyon southward below Sandia Canyon. R-45 screen 1 is located in Mortandad Canyon south of R-11. It also has nitrate concentrations (2.4 mg/L $\text{NO}_3\text{-N}$) above typical background, and $\delta^{15}\text{N}$ (4.9‰) and $\delta^{18}\text{O}$ (-2.7‰) results that are similar to R-11 and R-43 (Figures I-5.0-2 and I-5.0-4).

Two other regional wells in the Chromium Investigation monitoring group have nitrate isotope characteristics that stand out. R-50 screen 1, on the south side of the chromium plume, has 1.5 mg/L $\text{NO}_3\text{-N}$ and $\delta^{15}\text{N} = 7.2\text{‰}$; $\delta^{15}\text{N}$ has increased from lower values (5.5‰) in July 2010 (Figure I-5.5-2). This $\delta^{15}\text{N}$ value is noticeably higher than other regional wells in the monitoring group other than R-28 and R-42 and likely indicates some mixing of nitrate from near R-28 and R-42 occurs at this well. R-61 screen 1 was installed in 2011 and is also located on the south side of the chromium plume. Its higher nitrate concentration (1.7 mg/L $\text{NO}_3\text{-N}$) and higher $\delta^{15}\text{N}$ (6.0‰) may also indicate a similar nitrate transport history to the southern margin of the chromium plume. A contribution of nitrate from Mortandad Canyon intermediate waters, as suggested by other geochemical tracers (e.g., perchlorate in R-61) to these wells, is not precluded by the $\delta^{15}\text{N}$ results; however, the Mortandad-derived nitrate would have predated the ^{15}N -depleted releases in the late 1980s. In this sense, the nitrate isotope data are consistent with a model

in which regional aquifer waters in the southern part of the chromium plume contain a greater proportion of contaminants from a Mortandad Canyon source than from regional aquifer waters to the north.

R-36, farther down Sandia Canyon, also has slightly high $\delta^{15}\text{N}$ (6.6‰) (Figure I-5.0-4). This well has a more complicated setting and may be receiving a component of nitrate from a different source such as sewage from Pueblo Canyon (other positive $\delta^{15}\text{N}$ values likely derived from sewage are also observed in R-12 and R-9, in lower Sandia and Los Alamos Canyons, respectively, not plotted).

I-5.6 Sulfate Stable Isotopes

Samples for sulfate stable isotopes were collected by NMED–DOE OB from 2008 to 2012. These data augment other geochemical and stable isotope results and provide further support to conceptual models for vadose zone and groundwater pathways to the regional aquifer in the Chromium Investigation monitoring group. Results for average $\delta^{34}\text{S}$ values and sulfate concentrations are shown in Figure I-5.6-1.

For purposes of this study, sulfate stable isotope results are best interpreted with respect to patterns and groupings among wells. Although a limited data set on sulfate sources was collected, the $\delta^{34}\text{S}$ values of the source terms vary considerably, and the ranges of the source terms overlap and do not fully constrain the observed $\delta^{34}\text{S}$ values in the monitoring wells. In a manner similar to nitrate stable isotope behavior during reduction, $\delta^{34}\text{S}$ will increase during biogenic sulfate reduction, which is likely to occur in reducing conditions or at low pH. Because nitrate reduction is not prevalent in the oxidizing aquifer (section I-2.0), sulfate reduction cannot be significant because of redox conditions, and $\delta^{34}\text{S}$ values will be unchanged once sulfate enters the groundwater system. Background sulfate in uncontaminated regional wells and springs ranges from +4.0‰ to +8.9‰ (avg. = +7.1‰). Most sources of sulfate are generally lighter. Treated sewage effluent (five samples from four sewage treatment plants) ranged from +1.4‰ to +7.7‰ (avg. = +5.4‰). Two samples of sewage effluent from the NPDES Outfall 001 at TA-03 differed considerably (+6.0‰ versus +1.4‰), suggesting isotopic variations may occur during processing. Cooling tower effluent from two outfalls (NPDES Outfall 03A027 at TA-03 and NPDES Outfall 03A048 at TA-53) also show light $\delta^{34}\text{S}$ signals (avg. = +0.9‰) ranging from –3.2‰ to +6.6‰. Two samples of sulfuric acid had $\delta^{34}\text{S}$ values of +2.0‰ and –6.3‰.

Most of the monitoring wells fall within the range of background $\delta^{34}\text{S}$ of +4.0‰ to +8.9‰, and have SO_4 concentrations less than 10 mg/L; however, it is possible some portion of the sulfate in these wells could be derived from anthropogenic sources,

Certain monitoring wells are of particular note regarding sulfate stable isotope signals. Intermediate wells SCI-1 and SCI-2 in Sandia Canyon have SO_4 concentrations over 100 ppm and average $\delta^{34}\text{S}$ values of –0.3‰ and +3.7‰, respectively. Regional wells R-28 and R-42 have high SO_4 concentrations (46 ppm and 64 ppm, respectively) and $\delta^{34}\text{S}$ values (+3.6‰ and +5.1‰, respectively) close to those of SCI-2, suggesting a common source and a direct flow path to the regional aquifer in this area. Other regional wells with elevated SO_4 concentrations and relatively low $\delta^{34}\text{S}$ values likely originating from an SCI-2 drip point to the regional aquifer include R-50 screen 1 (13.6 ppm, $\delta^{34}\text{S}$ = +4.5‰) and R-62 (23.3 ppm, $\delta^{34}\text{S}$ = +4.4‰) near the southern and western periphery of the chromium plume. Intermediate well TA-53i also has relatively low $\delta^{34}\text{S}$ values (4.2‰) and elevated SO_4 concentrations (17.7 ppm), which may suggest the perched-intermediate zones at TA-53i and SCI-2 are linked. Ultimately, the sulfate source for the Sandia Canyon drip point is not clearly identified based on the sulfate isotope ratio; however, cooling tower effluent seems a probable source for sulfate at intermediate well SCI-1, with sulfate at SCI-2, R-28, and R-42 resulting from mixing between the SCI-1 source and a higher $\delta^{34}\text{S}$ sulfate source. Mortandad Canyon intermediate well MCOI-6 has an average SO_4 concentration of 49.8 ppm and $\delta^{34}\text{S}$ = 2.8‰; this $\delta^{34}\text{S}$ value is consistent those at R-28 and R-42 but also with sulfate values at Mortandad alluvial wells

MCO-5, MCO-6, and MCO-7 ($\delta^{34}\text{S}$ from 2.4‰ to 4.4‰). The isotopic composition of sulfate sources in Mortandad Canyon was likely variable, however, because intermediate well MCOI-4 also has elevated SO_4 concentrations (26 ppm) but higher $\delta^{34}\text{S}$ values (+8.4‰).

I-6.0 SUMMARY

Nitrate stable isotopes provide evidence for infiltration pathways from the alluvial to intermediate to regional aquifers in the region to supplement other geochemical indicators (e.g., Appendix D). A cross-section showing proposed pathways is shown in Figure I-6.0-1. Strong evidence is provided for a connected transport pathway from the intermediate-depth perched zone in the Cerros del Rio basalt near SCI-2 to the centroid of the chromium plume at R-28 and R-42. Nitrate at these wells likely has a considerable contribution that originated from Sandia Canyon, passing through the upper vadose zone (SCI-1) and mixing with a second nitrate source, possibly from Los Alamos Canyon. R-50 and R-61, at the southern edge of the chromium plume, may also be starting to see nitrate similar to that detected in R-28 and R-42. The negative $\delta^{15}\text{N}$ nitrate present in MCOI-4 and MCOI-6 is clear evidence for an origin from the NPDES Outfall 051; however, this signal is not clearly observed in any of the regional wells in the Chromium Investigation monitoring group. Because of changes in sewage treatment, nitric acid use in plutonium and actinide processing (which can lead to a complex array of signals) and changes in treatment technology through time, it is not possible to explicitly relate groundwater nitrate isotope signatures to modern effluent sources. Nonetheless, it is possible to analyze patterns in the nitrate isotope data to examine flow and transport pathways and to compare these with conceptual models derived from other contaminants and from hydrologic modeling considerations. Overall, the nitrate isotope data discussed here are consistent with the conceptual model presented in section 7.2 and Appendix D of this report.

I-7.0 REFERENCES

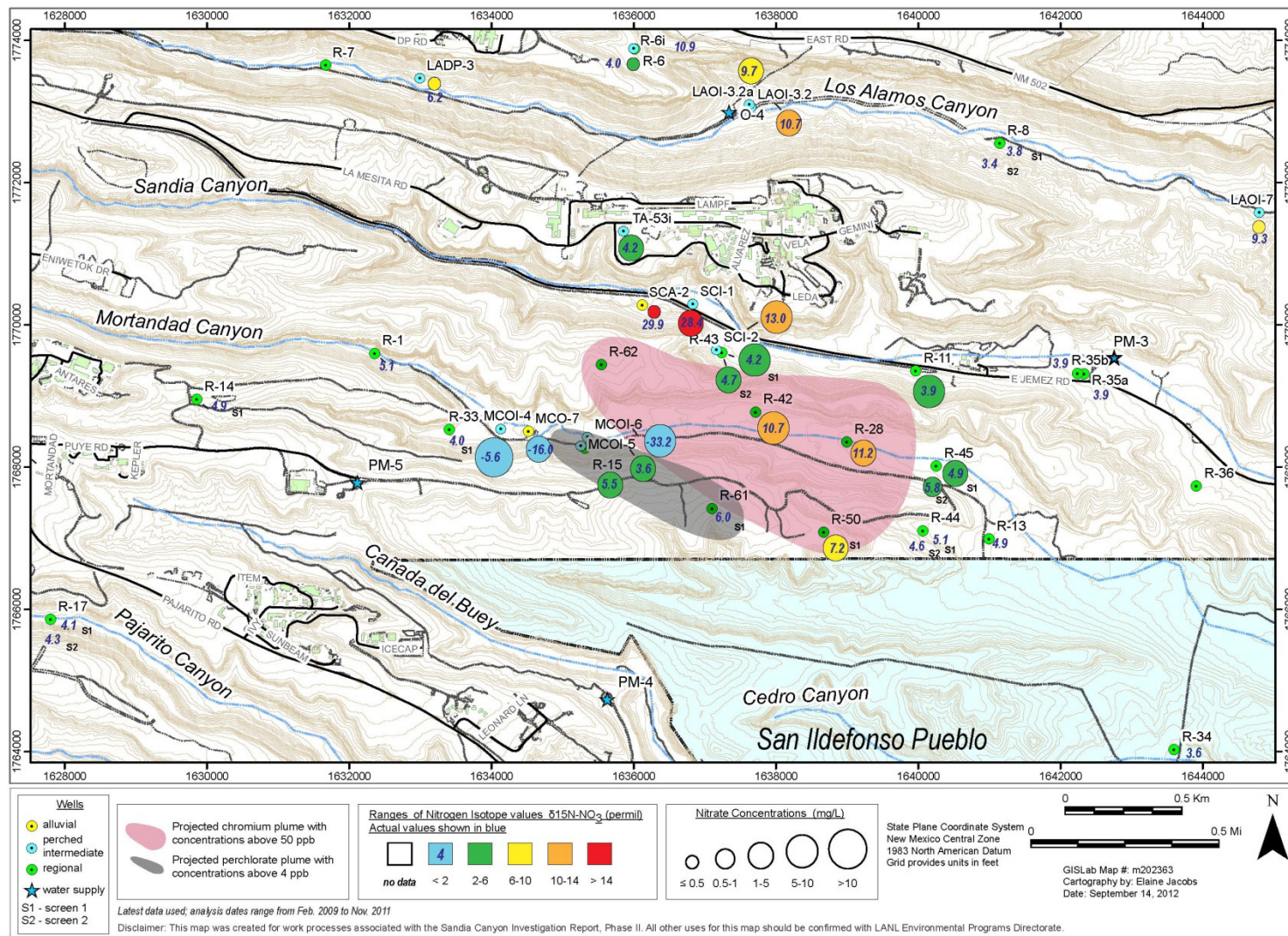
The following list includes all documents cited in this appendix. Parenthetical information following each reference provides the author(s), publication date, and ER ID. This information is also included in text citations. ER IDs are assigned by the Environmental Programs Directorate's Records Processing Facility (RPF) and are used to locate the document at the RPF and, where applicable, in the master reference set.

Copies of the master reference set are maintained at the NMED Hazardous Waste Bureau and the Directorate. The set was developed to ensure that the administrative authority has all material needed to review this document, and it is updated with every document submitted to the administrative authority. Documents previously submitted to the administrative authority are not included.

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Figure I-3.0-1 Well locations and nitrate $\delta^{15}\text{N}$ results

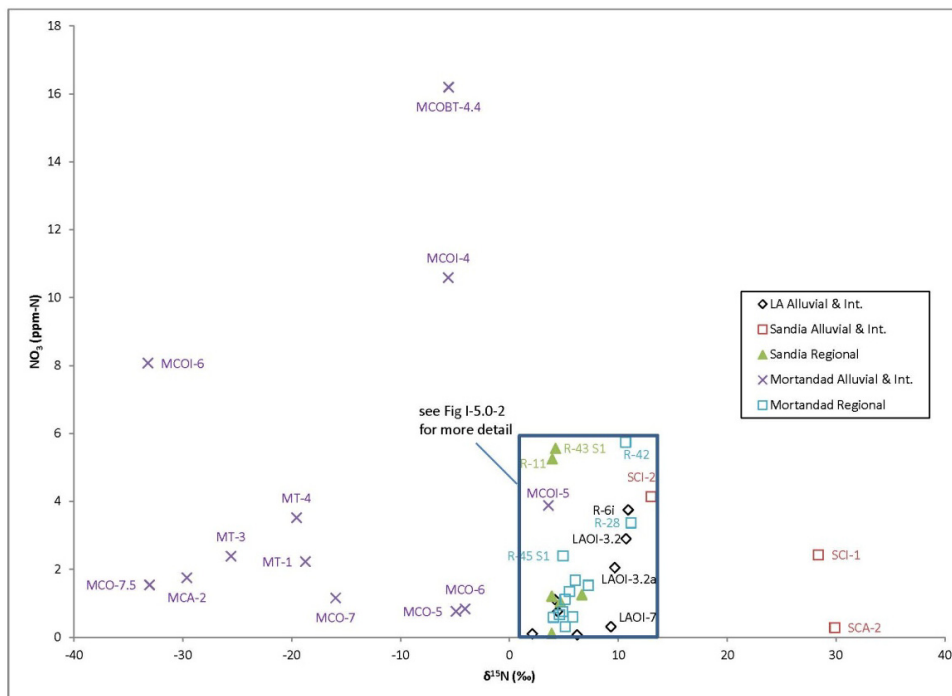


Figure I-5.0-1 Nitrate concentration and $\delta^{15}\text{N}$ results from monitoring wells in Sandia, Mortandad, and Los Alamos Canyons.

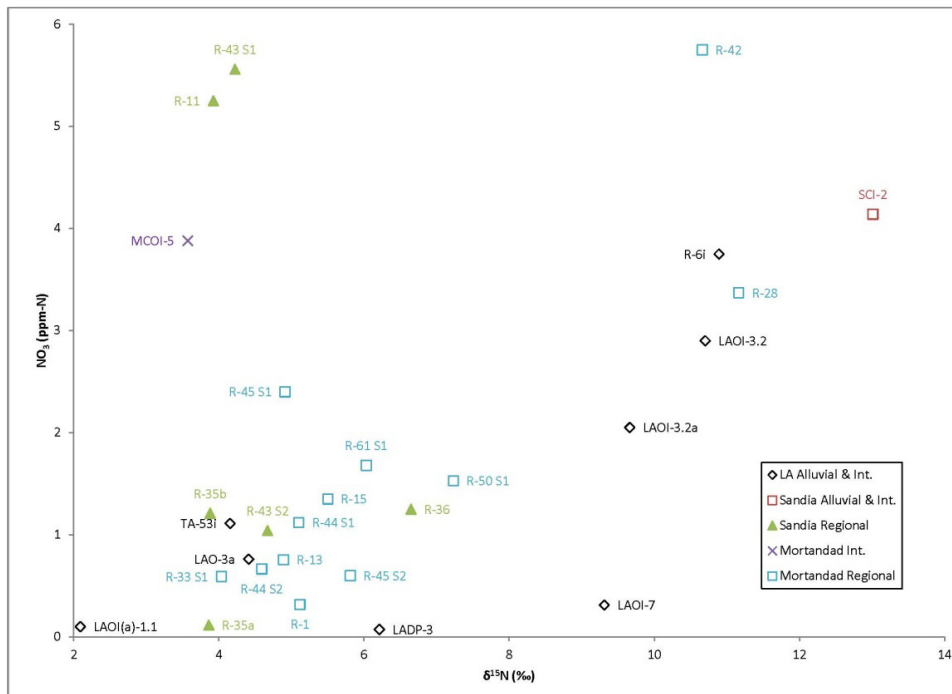


Figure I-5.0-2 Nitrate concentration and $\delta^{15}\text{N}$ results from monitoring wells in Sandia, Mortandad, and Los Alamos Canyons, with detail to show the regional wells

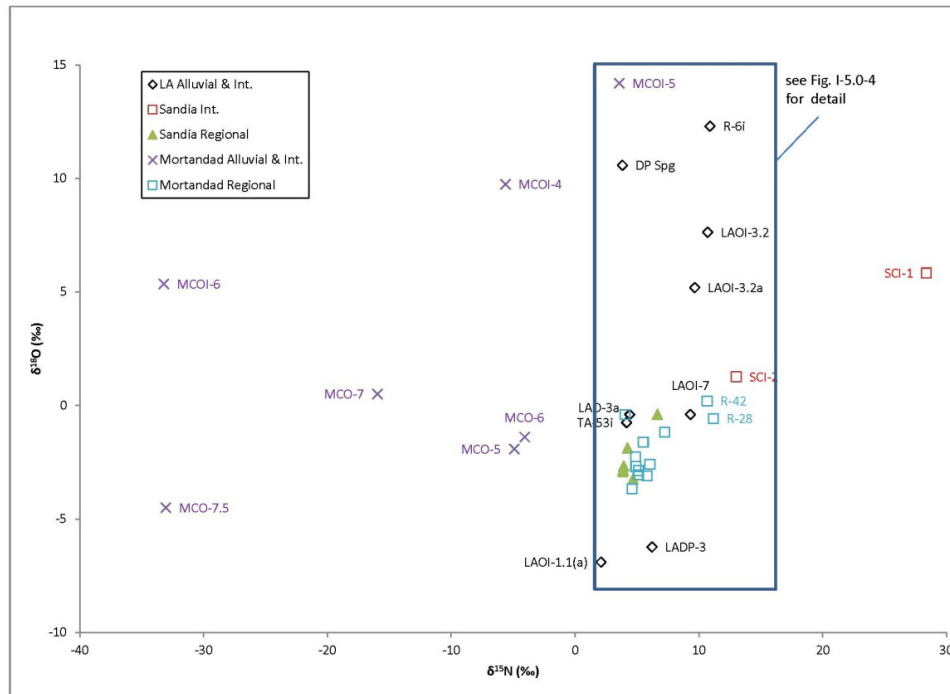


Figure I-5.0-3 Nitrate $\delta^{15}\text{N}$ and $\delta^{18}\text{O}$ results from monitoring wells in Sandia, Mortandad, and Los Alamos Canyons

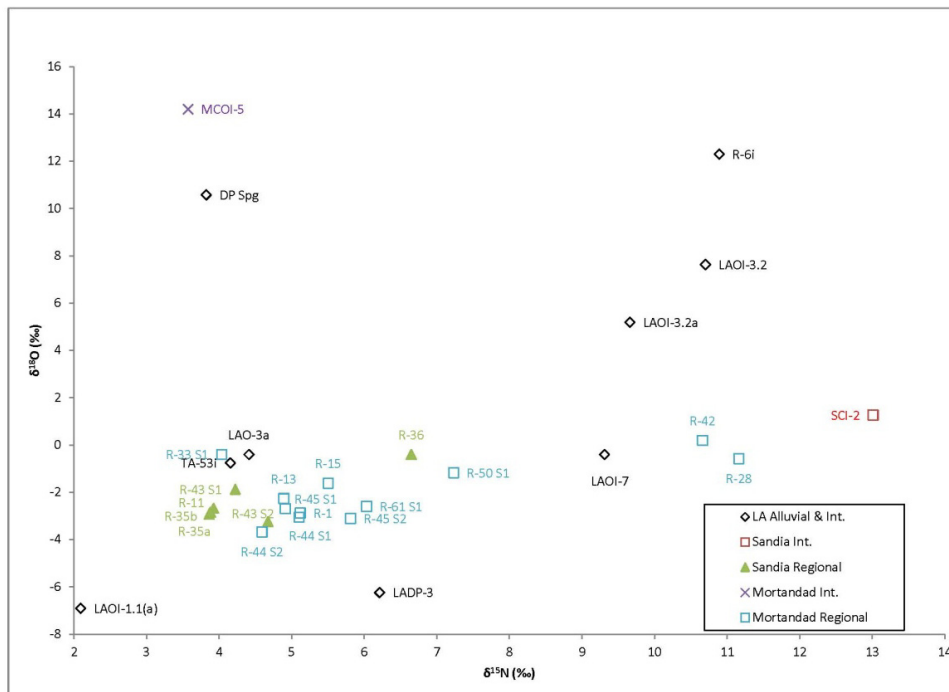


Figure I-5.0-4 Nitrate $\delta^{15}\text{N}$ and $\delta^{18}\text{O}$ results from monitoring wells in Sandia, Mortandad, and Los Alamos Canyons, with more detail

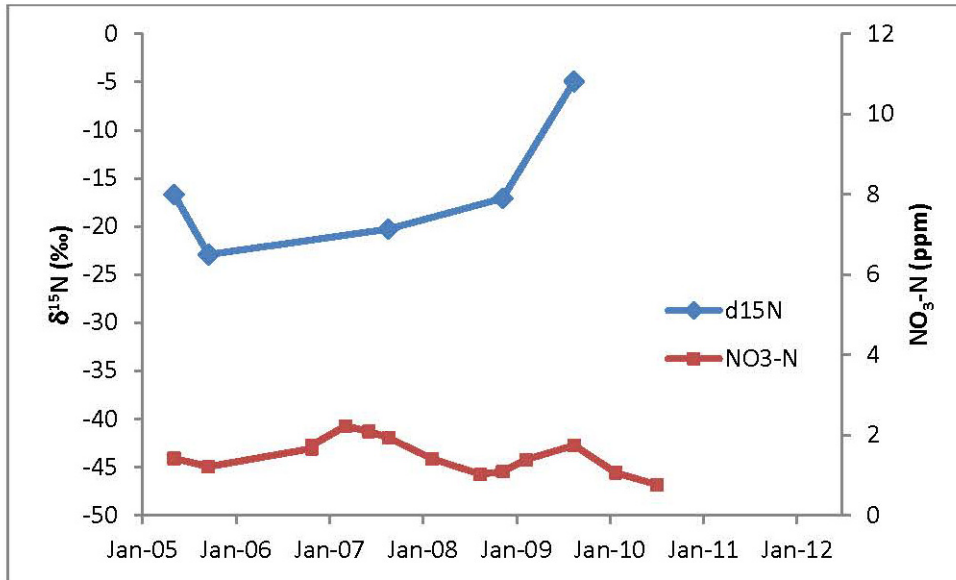


Figure I-5.3-2 Time-series trends in nitrate concentration and nitrate $\delta^{15}\text{N}$ in MCO-5

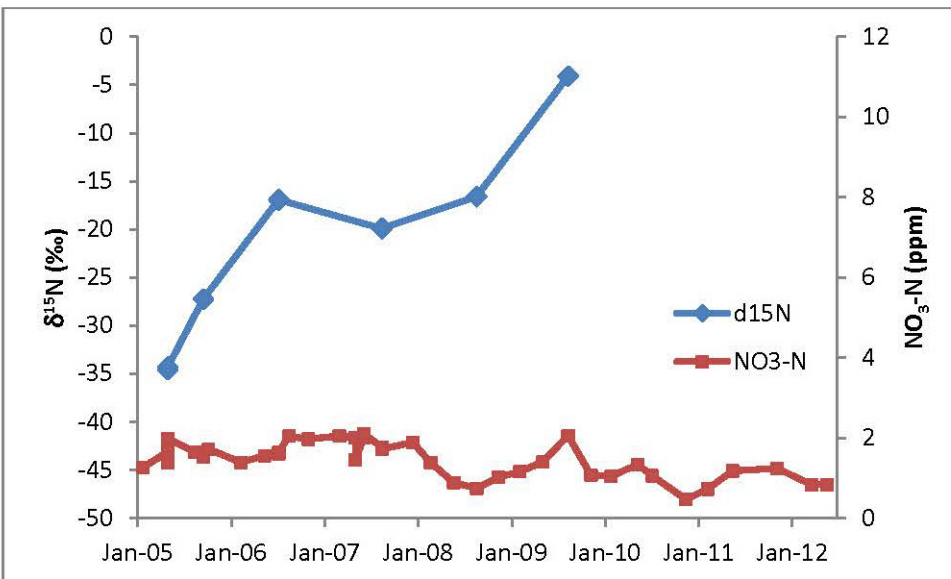


Figure I-5.3-3 Time-series trends in nitrate concentration and nitrate $\delta^{15}\text{N}$ in MCO-6

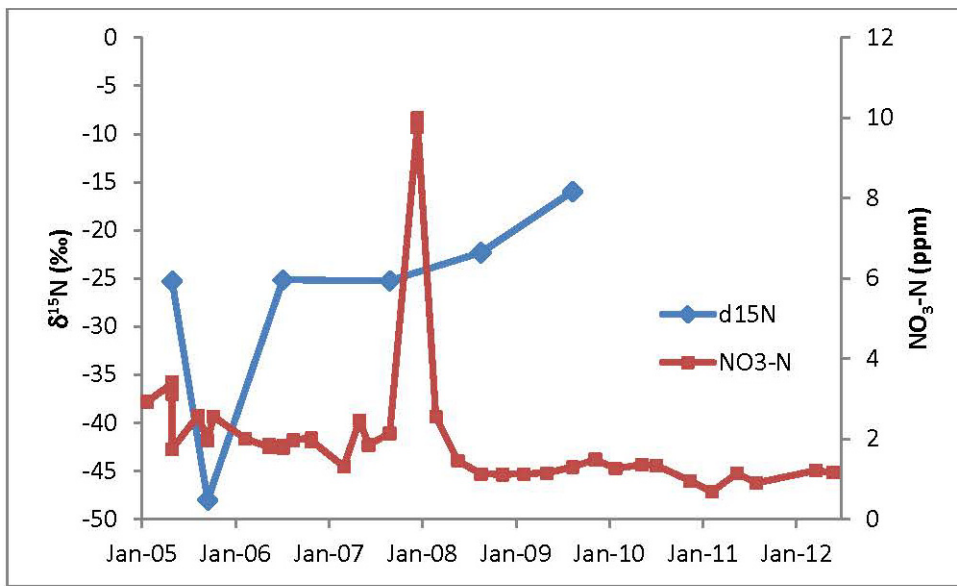


Figure I-5.3-4 Time-series trends in nitrate concentration and nitrate $\delta^{15}\text{N}$ in MCO-7

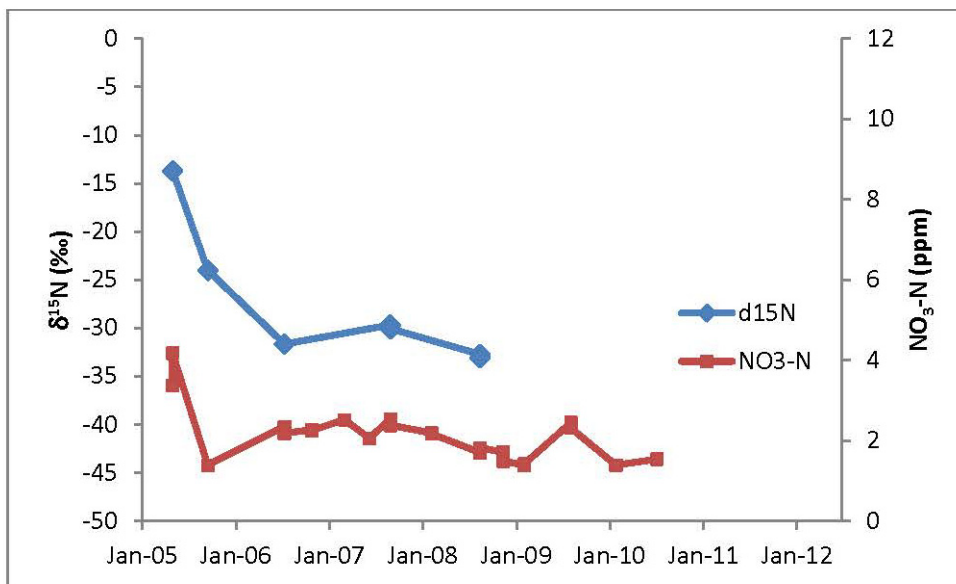


Figure I-5.3-5 Time-series trends in nitrate concentration and nitrate $\delta^{15}\text{N}$ in MCO-7.5

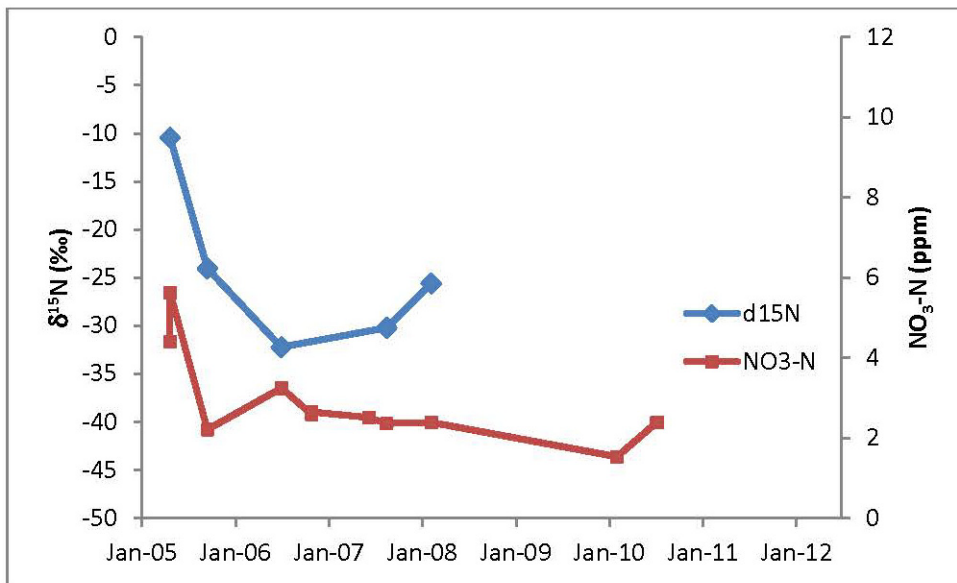


Figure I-5.3-6 Time-series trends in nitrate concentration and nitrate $\delta^{15}\text{N}$ in MT-3

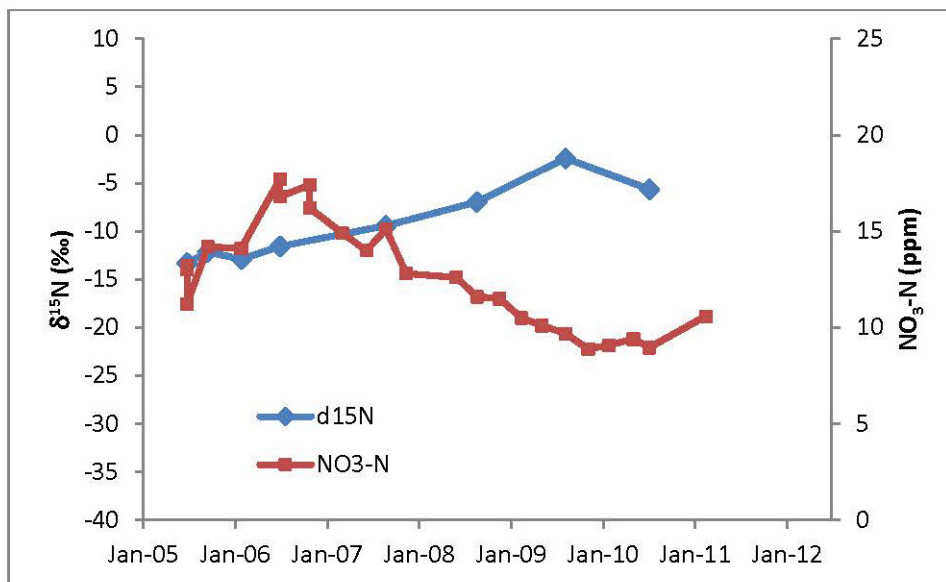


Figure I-5.4-1 Time-series trends in nitrate concentration and nitrate $\delta^{15}\text{N}$ in MCOI-4

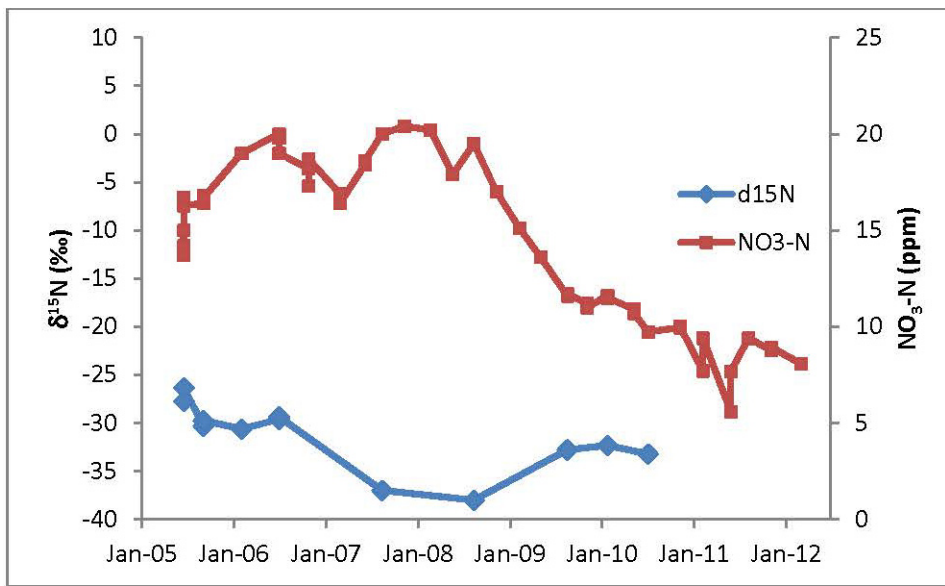


Figure I-5.4-2 Time-series trends in nitrate concentration and nitrate $\delta^{15}\text{N}$ in MCOI-6

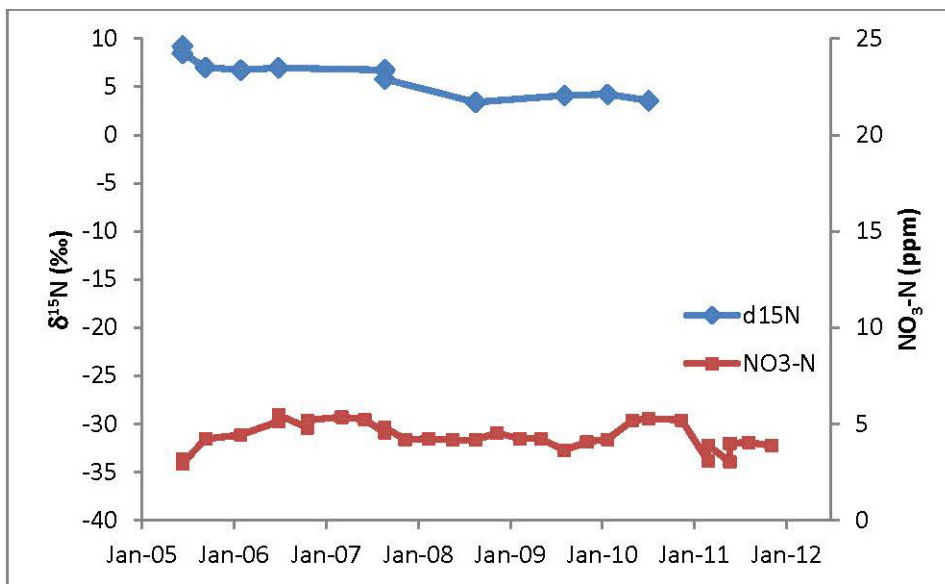


Figure I-5.4-3 Time-series trends in nitrate concentration and nitrate $\delta^{15}\text{N}$ in MCOI-5

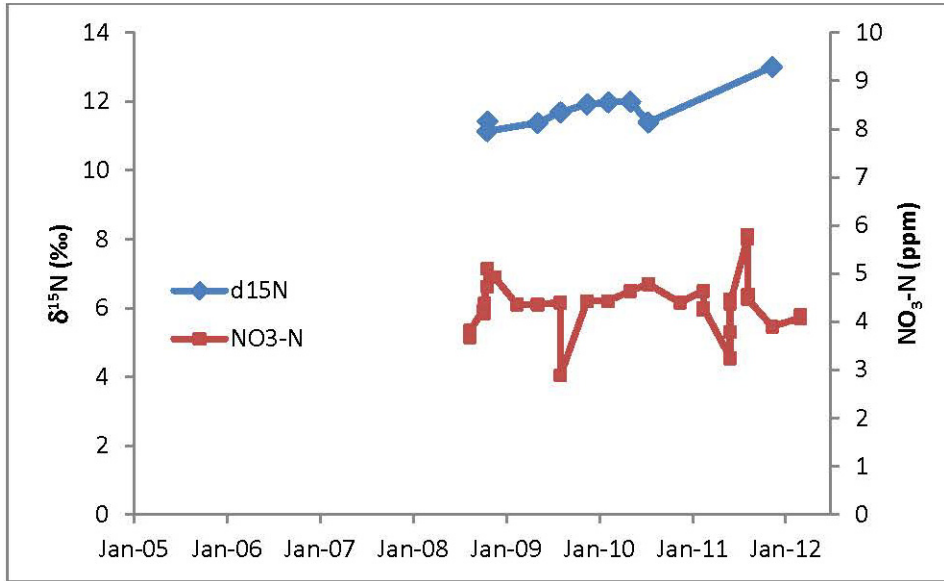


Figure I-5.4-4 Time-series trends in nitrate concentration and nitrate $\delta^{15}\text{N}$ in SCI-2

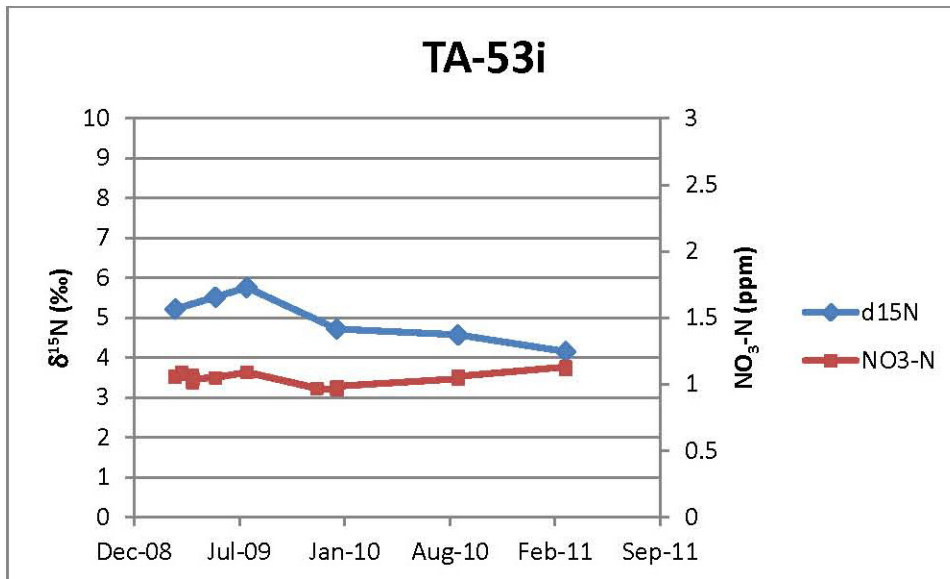


Figure I-5.4-5 Time-series trends in nitrate concentration and nitrate $\delta^{15}\text{N}$ in TA-53i.

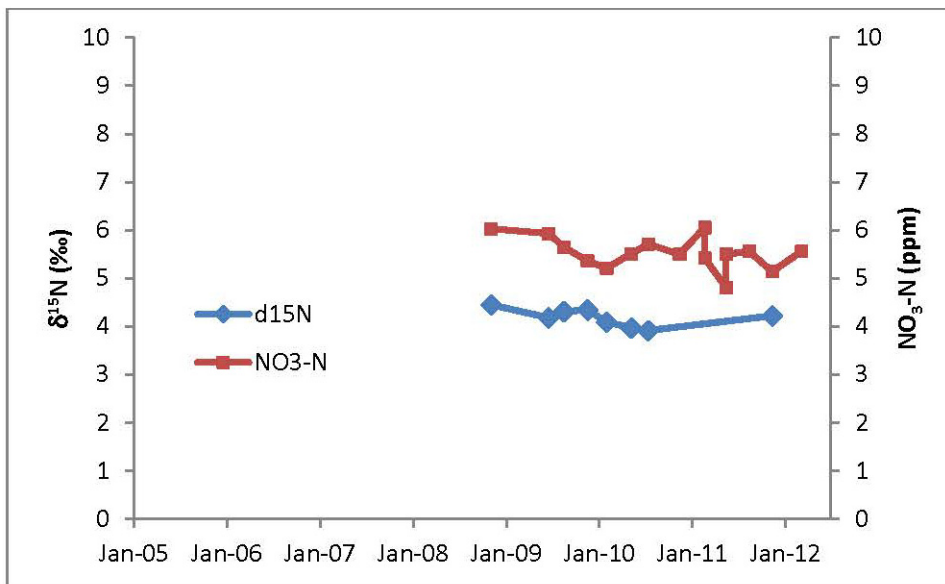


Figure I-5.5-1 Time-series trends in nitrate concentration and nitrate $\delta^{15}\text{N}$ in R-43 screen 1

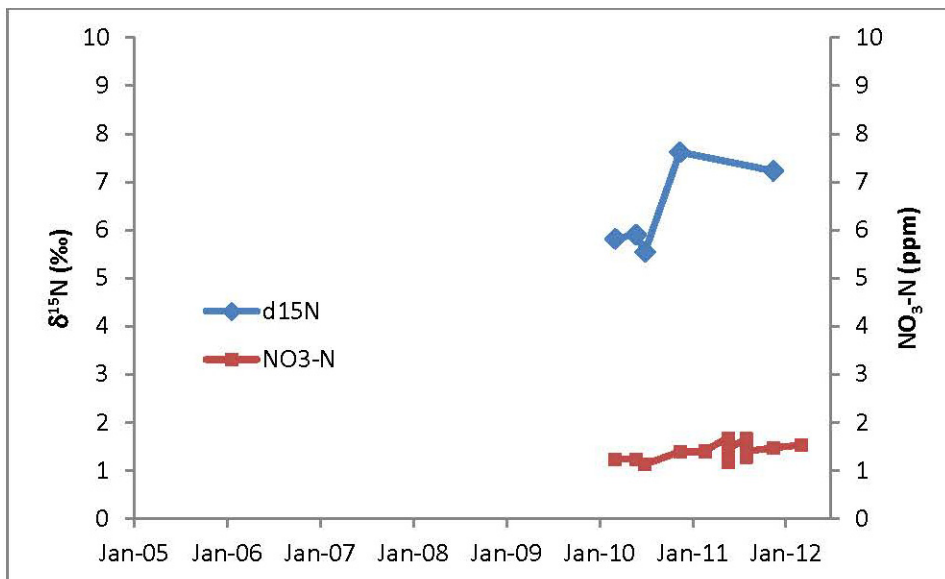


Figure I-5.5-2 Time-series trends in nitrate concentration and nitrate $\delta^{15}\text{N}$ in R-50 screen 1

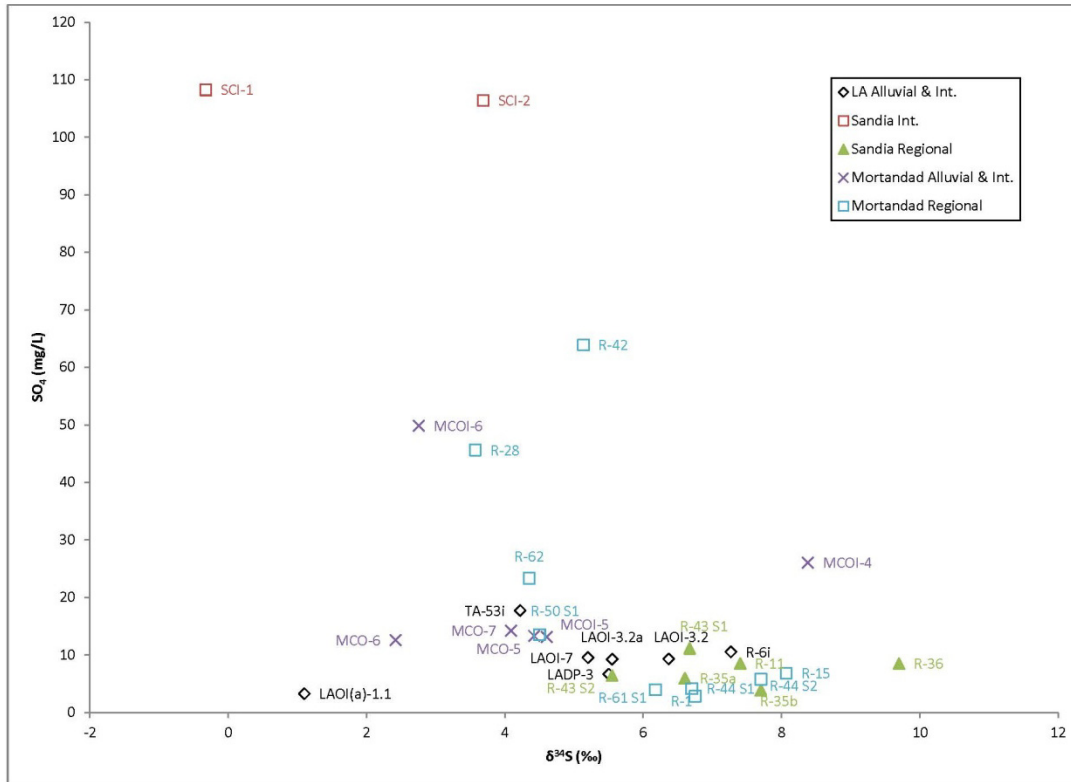


Figure I-5.6-1 Sulfate concentration and $\delta^{34}\text{S}$ results from monitoring wells in Sandia, Mortandad, and Los Alamos Canyons

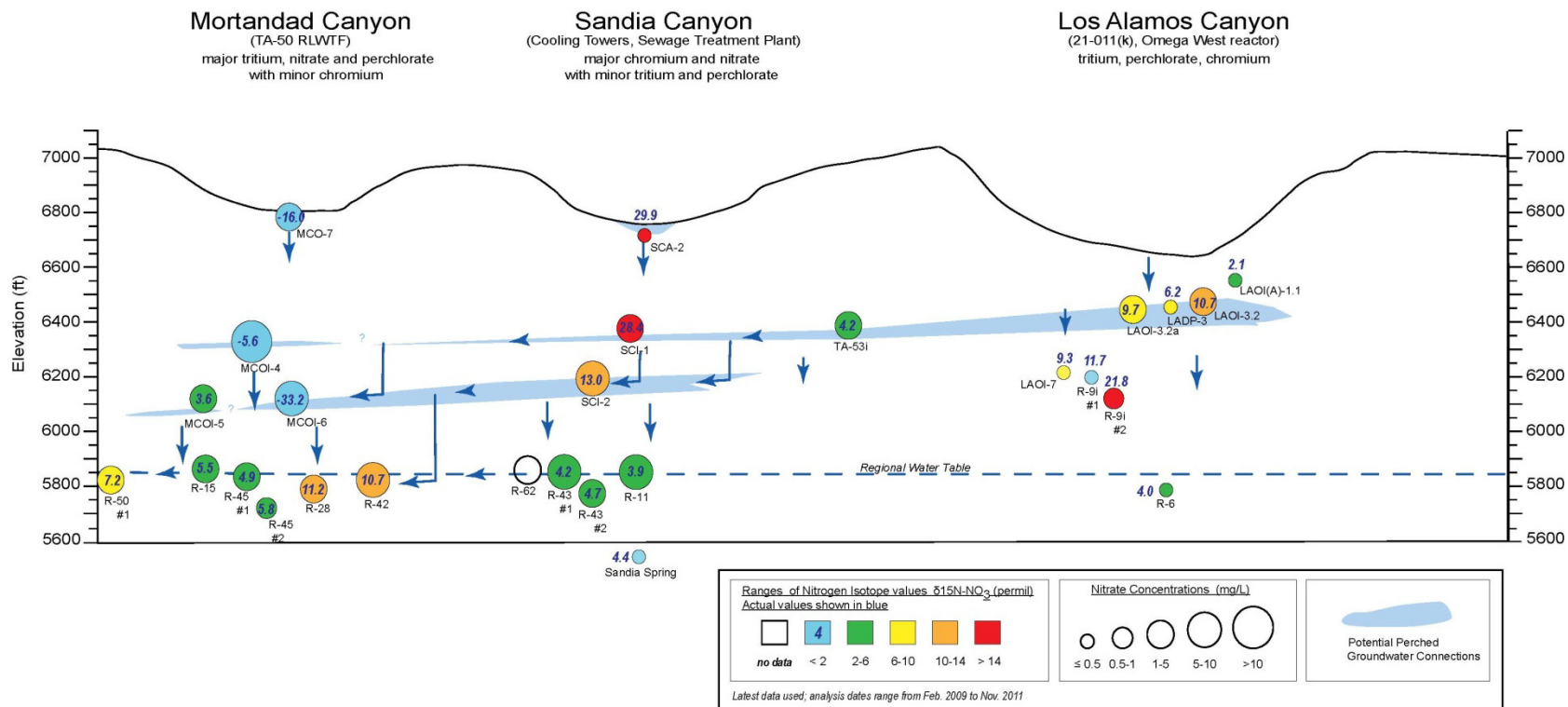


Figure I-6.0-1 Cross-section showing groundwater flowpaths, nitrate concentrations, and nitrate $\delta^{15}\text{N}$ results

Appendix J

*Analytical Simulation of Chromium Contaminant Transport
in the Regional Aquifer and Estimation of the Potential Zones
of Contaminant Arrival at the Top of the Regional Aquifer*

J-1.0 INTRODUCTION

Numerical flow and transport models of the unsaturated zone and the regional aquifer in the Sandia Canyon area are discussed in Appendix J of the chromium fate and transport update report (LANL 2008, 102996). In this report, an alternative approach for simulation is applied that uses an analytical solution of contaminant transport in the regional aquifer; similar modeling analyses were also presented in the Sandia Canyon Investigation Report (hereafter, the Phase I SCIR) (LANL 2008, 102996). The analytical model was developed to inform and enhance the understanding of the fate and transport of chromium in the environment. The goals of this study are to (1) calibrate the analytical model against available chromium concentration data observed in the regional aquifer, (2) estimate potential zones of contaminant arrival at the regional water table based on the available site data, and (3) estimate spatial and temporal (past and current) distributions of chromium mass in the regional aquifer and their associated uncertainties. The simulations do not represent groundwater transport in the unsaturated zone; that was addressed in Appendix J of the chromium fate and transport modeling report (LANL 2008, 102996).

The effects of geochemical interactions of chromium with rocks along the flow paths in the regional aquifer are not explicitly represented in the model analyses. Chromium reduction and retardation are represented mathematically in the model through processes that simulate these geochemical interactions. It is important to note chromium reduction from chemical reactions converting Cr^{6+} into Cr^{3+} decreases the contaminant mass but does not slow down the contaminant transport. The reduced Cr^{3+} becomes functionally immobile and is not considered a portion of the contaminant plume because reverse oxidization reactions of Cr^{3+} to Cr^{6+} are considered to be negligible because of slow kinetics of the involved reactions. Chromium retardation from adsorption or chemical reactions between Cr^{6+} in the solid and water phase that do not reduce the Cr^{6+} slows down Cr^{6+} transport but does not decrease the contaminant mass.

This appendix describes the current state of the development of this model and discusses the modeling results. The updated model builds upon a similar analytical model applied in Appendix L of the Phase I SCIR (LANL 2009, 107453). The differences between the previous version are that the model includes new Cr^{6+} calibration targets from wells R-50, R-61, and R-62, along with updated Cr^{6+} concentrations from existing wells, multiple source zones are incorporated, and the potential for reduction and reaction in the aquifer are included.

J-2.0 ANALYTICAL SOLUTIONS OF CONTAMINANT TRANSPORT

The analytical solution for concentration $c(x,y,z,t)$ of a contaminant released at a point source in the regional aquifer with coordinates $(0, 0, z_0)$ has the following form (cf., Wexler 1992, 106994; Wang et al. 2004, 090535):

$$c(x, y, z, t) = \frac{1}{8\theta(v\pi)^{3/2}\sqrt{\alpha_L\alpha_{TH}\alpha_{TV}}} \int_0^t \frac{I(t-\tau)}{(\tau)^{3/2}} \exp\left(-\lambda - \frac{(x-v\tau)^2}{4\alpha_L v\tau} - \frac{y^2}{4\alpha_{TH} v\tau}\right) \\ \times \left\{ \exp\left[-\frac{(z-z_0)^2}{4\alpha_{TV} v\tau}\right] + \exp\left[-\frac{(z+z_0)^2}{4\alpha_{TV} v\tau}\right] \right\} d\tau$$

Equation J-1

where α_L , α_{TH} , and α_{TV} are the longitudinal, transverse horizontal, and transverse vertical dispersivities [L], respectively; λ is the half-life decay constant [T^{-1}]; θ is effective transport porosity [-], and $I(t)$ is the contaminant mass flux (mass per unit time) [MT^{-1}]. The contaminant flux in this case can be transient and vary in any functional or piecewise fashion. The groundwater flow occurs along the x solution axis with Darcy velocity v . The half-life decay constant λ is applied to represent zero-order chemical reactions reducing Cr^{6+} into Cr^{3+} with a reaction rate constant R . The retardation factor R_f [-] is applied to simulate geochemical reaction that slow down the contaminant migration but do not reduce Cr^{6+} ; the pore (linear) velocity becomes $(R_f v) / \theta$. The retardation factor can be computed based on the distribution coefficient K_d [L^3/M] assuming a linear sorption model approximates retardation from adsorption or nonreducing reactions. The solution represents flow in a uniform aquifer bounded at the top ($z = 0$) and with infinite thickness. If $z_0 = 0$, the source location will be at the top of the aquifer (at the regional water table). Since the size of the location where contaminants have reached the regional aquifer is expected to have some dimensions (larger than a point with zero size), an analytical solution is applied to simulate the transport for the concentration of chromium $c(x,y,z,t)$ released at a finite dimension source within the region aquifer (Figure J-2.0-1) (cf., Wexler 1992, 106994; Wang et al. 2004, 090535):

$$c(x,y,z,t) = \frac{1}{8\pi x_S y_S z_S} \int_0^t I(t-\tau) \exp(-\lambda\tau) \left[\operatorname{erfc}\left(\frac{x - \frac{1}{2}x_S - v\tau}{2\sqrt{\alpha_L v\tau}}\right) - \operatorname{erfc}\left(\frac{x + \frac{1}{2}x_S - v\tau}{2\sqrt{\alpha_L v\tau}}\right) \right] \\ \times \left[\operatorname{erfc}\left(\frac{y - \frac{1}{2}y_S - v\tau}{2\sqrt{\alpha_{TH} v\tau}}\right) - \operatorname{erfc}\left(\frac{y + \frac{1}{2}y_S - v\tau}{2\sqrt{\alpha_{TH} v\tau}}\right) \right] \\ \times \left[\operatorname{erfc}\left(\frac{z - (z_0 + z_S)}{2\sqrt{\alpha_{TV} v\tau}}\right) - \operatorname{erfc}\left(\frac{z - z_0}{2\sqrt{\alpha_{TV} v\tau}}\right) + \operatorname{erfc}\left(\frac{z + (z_0 + z_S)}{2\sqrt{\alpha_{TV} v\tau}}\right) \right. \\ \left. - \operatorname{erfc}\left(\frac{z + z_0}{2\sqrt{\alpha_{TV} v\tau}}\right) \right] d\tau$$

Equation J-2

The only difference between solutions in Equations J-1 and J-2 is the size of the region within which the contaminants are released into the regional aquifer. In Equation J-2, the region has a parallelepiped (box) shape with sizes x_S , y_S , and z_S along each axes, respectively (Figure J-2.0-1), revealing the depth of the source below the water table. Equations J-1 and J-2 suggest that if contaminant mass flux is steady, after some time the contaminant concentrations will reach steady values as well. As a result, the plume will reach steady shape, which will be manifested by steady contour lines of contaminant concentrations. Equations J-1 and J-2 do not include the background concentrations of chromium. However, background Cr^{6+} concentrations are taken into account in the modeling work discussed below.

Equation J-2 represents the solutions for a single contaminant source. To account for multiple contaminant sources, the solution is superimposed multiple times. In these cases, each source is characterized with different dimensions x_S , y_S , and z_S along each axes and different contaminant fluxes $I(t)$.

The analytical solution of contaminant transport based on Equation J-2 for single and multiple contaminant sources is obtained using the code MADS (Model Analyses for Decision Support, available at <http://mads.lanl.gov>). It is important to note that various U.S. Geological Survey (USGS) codes for simulation of contaminant transport (such as ART3D, BIOSCREEN) currently use a solution proposed by Domenico (1987, 106996). However, this solution has been shown to be inaccurate, especially in situations where contaminant transport is dominated by plume dispersion, as demonstrated by other researchers (Srinivasan et al. 2007, 106993; West et al. 2007, 106995). The solution presented in Equation J-2 is used (cf., Wexler 1992, 106994; Wang et al. 2004, 090535) because it simulates

three-dimensional (3-D) contaminant transport even in the dispersion-dominated case. Recently, the analytical solutions applied in these USGS codes have been corrected.

The major limitations in applying the analytical solution rather than a numerical model for simulation of 3-D contaminant transport are that the analytical solution contains some assumptions: (1) the aquifer has uniform hydrogeological properties, (2) groundwater flow is steady state and uniform, (3) pumping effects from water-supply wells cannot be accounted for, and (4) the solution in Equation J-2 does not consider a potential vertical component of the groundwater flow. However, other analytical solutions account for this effect (cf., Wang et al. 2004, 090535). The major benefits in applying the analytical solution rather than a numerical model are (1) execution time is very fast (less than a second); (2) the analytical solution accurately represents aquifer dispersion (numerical models generally overestimate the dispersion as demonstrated in the chromium fate and transport update report (LANL 2008, 102996); (3) aquifer anisotropy can be efficiently captured; and (4) transients in the input contaminant flux and the observed concentrations at the monitoring wells can be easily incorporated in the model. It is important to note the execution time is critical for the performance of the analyses presented below. The estimation of the potential zones of contaminant arrivals requires on the order of 10^7 to 10^8 analytical model executions. A single execution of a numerical model with similar scale and complexity requires ~10 min.

In the applied method for simulating contaminant transport in the regional aquifer, the anisotropy of the aquifer can be represented using different analytical approaches. The aquifer anisotropy in the horizontal plane is captured by taking into account the uncertainty in the direction of advective transport (caused by groundwater flow). As discussed in Appendix G and shown in Figure G-1.2-1, the hydraulic gradient suggests that the flow direction near R-42 and R-28 is east-southeast (with possible diversions to the south or north). However, there is uncertainty in this flow-direction estimate because of (1) the relatively small magnitude of the hydraulic gradient in this area as well as (2) the 3D and aquifer heterogeneity effects that impact the pressure measurements at individual well screens (screens have different depths and lengths; none of the screens in the study area straddles the regional water table). The flow directions may also be influenced by groundwater mounding of the regional water table from infiltration recharge. In addition, the aquifer permeability may exhibit horizontal anisotropy from the large-scale aquifer structures in the Puye Formation and Santa Fe Group such as tilted beds with contrasting hydraulic properties and channelized stream gravels. The anisotropy may divert the flow in a direction that is not aligned with the hydraulic gradient but instead is more aligned with the dominant principle direction in the permeability tensor (Freeze and Cherry 1979, 088742). Furthermore, aquifer heterogeneity from local zones with high and low permeability may divert a predominant portion of the groundwater flow in 3-D space to aquifer areas having minimal flow resistances (highest permeability). The best approach to account for all these complexities is through development of 3-D numerical models that account for screen depths, aquifer heterogeneity and 3-D groundwater flow effects (including aquifer recharge and municipal water supply pumping). Such an approach is implemented in Appendix K of this report. However, the flexibility to simulate a large uncertainty space with the analytical model is used to constrain the more time-consuming 3-D simulations.

The analyses of the R-28 pumping test conducted in 2012 and all of the previous short-term pumping tests conducted in the study area (Appendix L) demonstrate the aquifer beneath Sandia and Mortandad Canyons is heterogeneous. The R-28 pumping test data did not demonstrate pronounced aquifer anisotropy. However, the interpretation of the pumping test data is uncertain because of the small magnitude of the drawdowns in the observation wells around R-28 (Appendix L).

In the analytical model, the aquifer anisotropy in the vertical direction is captured through selection of the dispersivity coefficients. The longitudinal dispersivity in Equation J-2 controls dispersion along the advective contaminant flow path, while the transverse horizontal and vertical dispersivities control the dispersion transverse to the advective flow path. The ratio between horizontal and vertical transverse

dispersivities is representative of vertical anisotropy. Layering of aquifer material may cause lower vertical transverse dispersivity. By varying the ratio of the dispersivities, the impact of aquifer anisotropy on the contaminant transport is effectively captured.

J-3.0 MODEL PARAMETERS

The parameters applied in model simulations are listed in Table J-3.0-1. The initial estimates and calibration ranges are estimated based on the available site-specific data and literature data.

The x and y coordinates of the potential contaminant-arrival location vary in a rectangular area that encompasses a region around R-42 and R-28 (Figure J-3.0-1); the x and y coordinate bounds are listed in Table J-3.0-1. The parallelepiped box similar to the one presented in Figure J-2.0-1 is applied in the model to simulate the potential zone in the regional aquifer where the contaminants arrive at the top of the regional aquifer ($z = 0$). The zone has unknown lateral location and lateral size but has a fixed vertical location ($z = 0$ m) and size ($dz = 1$ m) (Table J-3.0-1). The assumed 1-m-thick contaminant-arrival region represents the zone of the initial mixing of vadose-zone contaminants with the regional aquifer groundwater. Seasonal fluctuations of the regional water table may also influence the vertical dimension of this region. The lateral location (coordinates) and lateral dimensions of the contaminant-arrival region are adjusted during model calibration to match the calibration data.

Contaminant mass flux is assumed steady and equal to fixed value (in kg/yr) within a specified time window from a starting time t_0 (in years) to an ending time t_1 (also in years). The plausible mass flux values are defined to be within a wide range to account for the existing uncertainty (Table J-3.0-1). The time of arrival of contaminants at the top of the aquifer, t_0 , is estimated to vary between 1960 (i.e., chromium was released in Sandia Canyon from 1956 to 1972) and 2012 (R-28 was drilled in 2004) to accommodate the existing uncertainty. The time at which contaminants cease to arrive in the regional aquifer, t_1 , is fixed (2160) and does not influence the simulations performed below. Contaminant half-life decay representing chromium reduction is ignored in most of the simulations by setting the half-life decay coefficient to a large value (10^{+6} [1/yr]; Table J-3.0-1). This assumption is based on analysis of chromium isotope data presented in Appendix H, which suggests little to no reduction of Cr^{6+} to Cr^{3+} currently occurs in the regional aquifer. However, for some of the simulations discussed below, the half-life is allowed to be adjusted by the model during the calibration process to account for chromium reduction (Table J-3.0-1).

Setting initial estimates and uncertainty ranges of the pore velocity (Table J-3.0-1) requires a detailed analysis of the available data. Based on the single-hole pumping tests, the aquifer permeability in monitoring wells near the chromium plume ranges between 1 and 135 ft/d (0.3 and 41 m/d), with a best estimate of about 40 ft/d (12 m/d). A similar estimate is obtained based on hydrogeologic analysis of the 2012 pumping test of R-28 (Appendix L). Table J-3.0-2 lists and Figure J-2.0-2 presents spatial permeability data; the figure suggests no obvious spatial trend in the permeability distribution. In addition, the permeability estimates do not appear to be correlated with the hydrostratigraphic units (Table J-3.0-2).

No site-specific estimates of the effective transport porosity are available; based on literature data, porosity of sandstones and gravels is expected to vary between 0.1 and 0.2 with a best estimate of 0.15 (Freeze and Cherry 1979, 088742). The best estimate of the effective water-filled porosity of the aquifer pore space is 0.3; this parameter characterizes the available water volume for contaminant mixing. In contrast, the effective transport porosity characterizes the connected pore space controlling the advective contaminant flow through the aquifer. The hydraulic gradient in the vicinity of the chromium plume is on the order of 0.001, with an uncertainty range from 0.0005 to 0.002 (Appendix G). Based on all these data, the best estimate for the advective transport velocity (also called pore velocity) of a nonreactive contaminant is on the order of 40-50 m/yr with an uncertainty range between 1 and 600 m/yr (Table J-3.0-1). Chromium

(Cr⁶⁺) is not expected to be a nonreactive contaminant. Chromium retardation and reduction are geochemical reactions that may impact the contaminant concentrations and migration velocity. Therefore, the uncertainty range (1 and 600 m/yr) in the effective Cr⁶⁺ migration velocity also account for uncertainties in the geochemical reactions influencing contaminant mobility.

The direction of the advective flow downgradient from the contaminant-arrival zone is represented by the angle between the easterly gradient axis and the flow vector. The angle can vary from 0 (flow due east) to -90 (due south), allowing for a wide range of uncertainty in the advective flow direction (Table J-3.0-1). No site-specific estimates of the dispersivity coefficients are available; initial estimates and uncertainty ranges are based on literature data that take into account the scale at which contaminant transport occurs (Freeze and Cherry 1979, 088742; Neuman 1990, 090184; Gelhar et al. 1992, 102465). The longitudinal dispersivity is typically 1/10th of the traveled distance by the contaminant; typically, the transverse horizontal and vertical dispersivities are assumed to be 1/10 and 1/100 of the longitudinal dispersivity, respectively. All these parameters are assumed to be uncertain; the model is allowed to adjust these parameters to calibrate against observed chromium concentrations. There are alternative ways to characterize to potential interdependencies between dispersivities and their relationship with the travelled distance. In the Phase I SCIR (LANL 2008, 102996), the dispersivities are assumed to be independent. In this case, the longitudinal, transverse lateral, and transverse vertical dispersivities were allowed to vary independently of each other. As a result, the model analyses presented in the Phase I SCIR allowed for simulations where transverse dispersivities are larger than the longitudinal dispersivity. This was acceptable because aquifer heterogeneity and multiple arrival locations can produce plumes that are more dispersed transversely than longitudinally. Here, the analyses are performed assuming coupled dispersivities; this does not allow transverse dispersivities to become larger than the longitudinal dispersivity. This is because the new analyses allow for multiple contaminant-arrival zones which can represent more realistically the apparent plume dispersion in the regional aquifer.

The model analyses are performed allowing for multiple contaminant-arrival zones. Each zone is defined with a separate set of coordinates, sizes, and contaminant flux; the same aquifer properties are applied to simulate contaminant migration from each contaminant-arrival zone.

J-4.0 CALIBRATION DATA FOR CHROMIUM CONCENTRATIONS AT THE MONITORING WELLS NEAR SANDIA CANYON

To perform the fate and transport modeling of chromium contamination in the subsurface, it is important to have a model that produces predictions consistent with the observed field data. This objective can be achieved through a formal process of model calibration (inversion) against existing data measurements. The data considered in the calibration process are called calibration targets. The chromium (Cr⁺⁶) concentrations in the regional aquifer observed at the regional monitoring wells near Sandia Canyon are key calibration targets. The goal of the modeling is to predict chromium concentrations in the regional aquifer resulting from releases in Sandia Canyon (circa 1956 to 1972) that are consistent with the existing observations.

However, the chromium concentrations used to calibrate the model are uncertain. Uncertainties in the calibration data are caused by various factors discussed the chromium fate and transport update report (LANL 2008, 102996, Appendix G). The important sources of uncertainty are (1) background values of chromium concentrations in the regional aquifer and (2) fluctuations in the observed chromium concentrations at the monitoring wells near Sandia Canyon (Figure D-3.0-3 in Appendix D). The background concentration of chromium in the regional aquifer is estimated to be between 5 and 6 ppb (LANL 2008, 102996). The current model analyses assume the background concentration of Cr⁶⁺ is 5 ppb.

Appendix G of the chromium fate and transport update report (LANL 2008, 102996) presents a formal process for estimating calibration targets and their respective uncertainty ranges. A similar approach is applied in this appendix; the calibration set presented in previous reports (LANL 2008, 102996; LANL 2009, 107453) is expanded to include the new data collected at R-50 (screens 1 and 2), R-61, and R-62 (screens 1 and 2). The calibration data are presented in Table J-4.0-1.

The calibration data are applied to calibrate the analytical model of contaminant transport in the regional aquifer. The calibration is performed using Levenberg-Marquardt (Moré 1978, 106991) and Squads (Vesselinov and Harp 2011, 227709) optimization techniques. The objective function applied during optimization is computed as a sum of the squared differences between observed and simulated concentrations at all the well screens listed in Table J-4.0-1.

The calibration and analysis of the analytical model of chromium contaminant transport is also performed using the code MADS (available at <http://mads.lanl.gov>). MADS is C/C++ code designed to be an open-source framework for model-based decision support employing system and physics simulation models. MADS performs various types of model analyses, including sensitivity analysis, parameter estimation, uncertainty quantification, model calibration, selection, and averaging.

J-5.0 ESTIMATION OF POTENTIAL ZONES OF CONTAMINANT ARRIVAL AT THE REGIONAL WATER TABLE

J-5.1 Methodology

The methodology to identify contaminant-arrival zones is general, and it can consider wide ranges of uncertainties related to conceptual models (e.g., alternative water table maps), model parameters, single and multiple contaminant-arrival zones (simultaneously affecting regional aquifer concentrations), and transients in the contaminant mass flux arriving at the top of the regional aquifer. However, the analysis below assumes that contaminant flux is uniform in time; currently the potential transients are accounted for by defining a time interval within which the uniform flux is applied. (As discussed above, the time interval is defined by beginning and end times in years.) The assumption is that the contaminant mass flux arriving at the regional aquifer is steady; this assumption is generally consistent with the current observations of chromium concentrations at most of the regional monitoring wells, which are also relatively steady (Appendix D). Steady-state concentrations are not expected to continue indefinitely because the original chromium source released to Sandia Canyon had a finite release period (from 1956 to 1972). However, the assumption of a steady contaminant flux can be applied as an approximation to evaluate the current distribution of the chromium mass in the regional aquifer. It should be noted in the case of multiple contaminant-arrival zones, each zone can have a different initial arrival time and different steady flux. In this way, multiple contaminant-arrival zones can effectively represent transients in the contaminant flux and arrival time to the regional aquifer.

Because ambient groundwater flow velocities are relatively high, the recent concentrations at the contaminant-arrival zone, rather than past transient concentrations, predominantly cause the observed current concentrations at the monitoring wells. As a result, it is difficult to evaluate what past chromium concentrations were upon arrival at the top of the regional aquifer because the data regarding past chromium concentrations in the regional aquifer are insufficient. Nevertheless, the analytical model of chromium transport in the regional aquifer is applied to evaluate the maximum contaminant mass that may have arrived at the regional aquifer between 1956 and 2004 and still yield concentrations consistent with the current observations.

The approaches for estimating the potential zones of contaminant-arrival at the regional water table presented here are similar to those in the chromium fate and transport update report (LANL 2008, 102996) and Phase I SCIR (LANL 2009, 107453). The presented approach allows for (1) efficient evaluation of the uncertainty in model predictions (because of fast execution times); (2) efficient estimation of 3-D contaminant migration (the numerical model applied in 2008 was constrained to two dimensions to reduce execution times); (3) efficient estimation of plume dispersion (the 2008 analyses was performed for a set of discrete dispersivity values—here the dispersivity values are directly estimated in the calibration process); (4) efficient estimation of the dimensions of the area associated with contaminant-arrival zones; (5) estimation of uncertainty in advective transport direction; (6) estimation of transients in contaminant transport (the 2008 analyses relied on the assumption that the contaminant plume is at a steady shape; the current analyses does not make this assumption); and (7) estimation of the impact of chromium reduction and retardation on contaminant transport using simple geochemical models. The major difference between the approach presented here and previous analyses is that all the model parameters were adjusted during model calibration.

The previous analyses implemented an approach where the contaminant source locations were fixed along predefined lateral grids (100 × 100 m and 50 × 50 m). This provided limitations on the implemented analyses but also helped the optimization process because the number of problem degrees of freedom was reduced by two. The analyses presented here implements novel robust model analyses techniques that do not require such constraints. As a result, the analyses presented here are more general.

The potential zones of contaminant arrival at the regional water table are estimated through a calibration process that accounts for existing uncertainties. The model calibrations are executed multiple times for a series of different initial guesses for the contaminant-arrival location(s). The initial guesses are random values within the lateral bounds presented in Figure J-3.0-1. After that the calibration algorithm is allowed to adjust the location of the contaminant-arrival locations jointly with other model parameters. If the contaminant-arrival locations and model parameters (Table J-3.0-1) are successfully adjusted, and the model predictions are within the calibration ranges (Table J-4.0-1), a plausible simulation result based on a plausible set of model parameters is identified. This approach allows for efficient exploration of the parameter uncertainties.

J-5.2 Results

The identified plausible contaminant-arrival locations at the top of regional aquifer for the case of a single contaminant-arrival zone are shown in Figure J-5.2-1 as solid purple dots located at the center of the arrival location. However, the dots in Figure J-5.2-1 do not show the areal extent of each of the source zones they represent in the plausible simulations. In this case, 492 possible model solutions satisfy the calibration targets, but all of them are practically equivalent. These results are generally consistent with the results presented in Figures J-5.1-15 and J-5.1-16 in Appendix J of the chromium fate and transport update report (LANL 2008, 102996) and Figure L-5.2-1 in Appendix L of the Phase I SCIR (LANL 2009, 107453). A comparison of the figures presented in these reports demonstrates the new data collected at R-42, R-43, R-44, R-45, R-50, R-61, and R-62 effectively constrain the spatial extent of the contaminant mass in the regional aquifer. In both reports, the contaminants are predicted to arrive at the top of the regional aquifer in an area near R-42. It is important to note that simulation results in the chromium fate and transport update report (LANL 2008, 102996) were obtained without using the concentration data collected at R-42, R-43, R-44, and R-45, and the results in the Phase I SCIR (LANL 2009, 107453) were obtained without R-50, R-61, and R-62 data. This demonstrates consistency in the modeling analyses and a general trend of diminishing reduction of uncertainty in the model predictions with the drilling of new wells and collection of new data. However, all the previous analyses considered a single contaminant-arrival zone. The results presented in Figure J-5.2-1 are for multiple simulations using a single

contaminant-arrival zone; in this case, the contaminant-arrival zone represents a laterally-elongated rectangle located south of R-42. A total of 492 solutions for the single-source analyses honor the available concentration, and all of them are practically equivalent. One of the plumes obtained for the case of a single contaminant-arrival zone is presented in Figure J-5.2-2. The large size of the single-source zone, approximately the darkest blue rectangular area shown in the figure, suggests that multiple contaminant-arrival zones may also yield plausible solutions that will calibrate to the observed concentrations.

Figure J-5.2-3 presents a series of plausible contaminant-arrival locations (purple dots) in the regional aquifer consistent with the available hydrogeological and geochemical data for the case of multiple (2, 3, and 4) contaminant-arrival zones. More than 5000 acceptable model solutions are generated, and many of them are very similar. Figure J-5.2-3 shows the lateral distribution of the contaminant-arrival zones is focused in the area near R-42. However, because multiple contaminant-arrival zones are allowed, the problem definition and resulting solutions are less constrained. It is important to note that some of the solutions place contaminant-arrival zones near the lateral bounds imposed on the plausible arrival locations.

Figure J-5.2-4 shows the same data presented in Figure J-5.2-3, however, in the form of density maps. In Figure J-5.2-4, each plot shows where within explored model domain the contaminant-arrival zones are clustered with higher probability. In the case of a single contaminant-arrival zone (Figure J-5.2-4a), all the solutions are located west-southwest of R-42, which matches the results presented in Figure J-5.2-1. In the case of two potential contaminant-arrival zones (Figure J-5.2-4b), most of the solutions are clustered in two areas: (1) around R-42, and (2) near R-62. A series of solutions are also clustered near the upper-right corner of the explored model domain; however, as discussed below, these contaminant-arrival zones have very low contaminant concentrations. They have been proposed during the automated process of model calibration to match slightly elevated concentrations of R-11. However, as discussed in Appendix K, the elevated concentrations of R-11 may have been caused by aquifer heterogeneity, which is not represented in these analytical model analyses.

In the case of three and four potential contaminant-arrival zones (Figures J-5.2-4c–d), most of the solutions are clustered in three areas: (1) around R-42, (2) near R-62, and (3) near R-28. Similar to the results presented in Figure J-5.2-4b, a series of solutions are also clustered near the upper-right corner of the explored model domain. In addition, the results in Figures J-5.2-4c–d represent small clusters of solutions near the southern boundary of the explored model domain. These solutions have been proposed during the automated process of model calibration to match slightly elevated concentrations of R-15 and R-61.

Figure J-5.2-5 shows an average estimate of the plausible chromium concentrations along the regional water table near the contaminant arrival locations. The estimate is computed by averaging the concentrations of all the plausible model-predicted contaminant plumes assuming 1, 2, 3, and 4 arrival locations (Figures J-5.2-5a–d). Each figure presents the model predictions of the contaminant concentrations in the regional aquifer. All the figures use different concentration scales. The single contaminant-arrival zone solution (Figure J-5.2-5a) is almost equivalent to the result presented in Figure J-5.2-2. The solutions for more than one contaminant-arrival zones (Figures J-5.2-5b–d) demonstrate consistent results; the highest contaminant concentrations are expected near R-42 and R28 with potential elevated concentrations upgradient from R-42/R-28 in the area near R-62. All the other potential contaminant arrival locations presented in Figure J-5.2-3 and analyzed in Figures J-5.2-4b–d are producing consistently lower concentrations in the regional aquifer than the results presented in Figures J-5.2-5b–d.

Table J-5.2-1 lists the averaged estimates associated with the successfully calibrated analytical models. The values are compared with the results presented in the Phase I SCIR (LANL 2009, 107453). The newly obtained results and the previous results are consistent. Most importantly, the new analysis predicts a larger present-day mass of chromium in the aquifer (1100 kg total has been introduced in the regional aquifer since the contaminant was released; this also represents the total mass currently distributed within the aquifer). The uncertainty range of this estimate is between 200 and 3000 kg. For the case of a single contaminant-arrival zone, the mass is very well constrained between 960 and 1020 kg.

J-5.3 Discussion and Conclusions

Plume characterization is a challenging and nonunique problem because multiple models and contamination scenarios can be consistent with the available site data and knowledge. Exploration of the conceptual, parameter and observation uncertainties is challenging and requires substantial computational time and robust computational algorithms. The code MADS (<http://mads.lanl.gov>) provides a computationally efficient and robust framework for these types of analyses.

Model analyses explored solutions with up to four contaminant-arrival zones at the top of the regional aquifer. Each contaminant-arrival zone is characterized with unknown location, size, mass flux, and initial release time. The models included up to 25 unknown model parameters constrained by prior information and calibration data. Model analyses utilized state-of-the-art computational techniques that meet the problem-specific requirements. Because of the complexity of the problem, manual trial-and-error model analyses were also beneficial for efficient exploration of the plausible parameter space and model conceptualizations.

Model analyses were particularly focused to explore uncertainty in model parameters and conceptualizations. Various alternative scenarios were explored: (1) contaminant-arrival zones beneath the wetland in upper Sandia Canyon, (2) contaminant-arrival zones upgradient of R-62, (3) stagnant plumes with very low velocity of contaminant migration, and (4) contaminant-arrival zones causing increasing concentration trends at R-50 and R-43.

Based on the interpretation of the regional water-level data (Appendix G) and the model analyses presented here, the best estimate of the groundwater flow direction is about 20 degrees south of east (-20°); this observation is consistent with the current conceptualization of both chromium and ClO_4 plumes. Alternatively, some of the models converged with groundwater flow direction of about 65 degrees south of east (-65°) downgradient from R-28, producing more pronounced diversion to the south (towards R-50); however, this scenario requires pronounced aquifer heterogeneity and/or anisotropy. More southern groundwater flow directions may also be caused by aquifer water-supply pumping and/or infiltration recharge.

As discussed above, the groundwater transport velocity in the regional aquifer near R-28 may be on the order of 40 to 50 m/yr or even higher. If the contaminant-arrival location is near R-42, it may take less than 8 yr for contaminants to reach R-28 (the distance between the two wells is ~ 400 m). Because relatively short travel times to R-28 are expected, it is not surprising that chromium concentrations at R-28 have been relatively stable since 2004 when the chromium was initially detected at R-28. This finding also suggests the contaminant plume has already reached a steady condition in the region between the potential contaminant-arrival location and well R-28. In addition, because of the relatively short distance between R-28 and potentially downgradient wells (500 m to R-44 and 400 m to R-45), it may also be expected that the contaminant plume has already reached or is approaching a steady-shape condition at R-44 and R-45. Future data collection at R-13, R-44, R-45, and R-50 will be critical for better understanding the shape of the plume downgradient of R-42 and R-28. The model analyses of the

observed relatively low concentrations at R-45, R-44, and R-13 (expected to be downgradient from R-42 and R-28) suggest the following:

- small mass fluxes at contaminant-arrival zones located relatively close to all of the wells with the high concentrations such as R-62, R-50, R-42 and R-28; this is not a very plausible scenario because it implies that the wells are all coincidentally drilled downgradient from the potential contaminant-arrival zones;
- contaminant flow diversion to the north or to the south of R-45, R-44, and R-13 due to aquifer heterogeneity or infiltration recharge mounding;
- relatively slow contaminant flow; in this case, the major portion of the contaminant plume has not yet arrived at R-45, R-44, and R-13. Because the distance from R-28 to R-45/R-44 is ~400 m, the effective pore velocity should be relatively small (much less than 40 m/yr; ~4 m/yr);
- contaminant plume dispersion resulting from aquifer heterogeneity; and
- chromium retardation and/or reduction in the regional aquifer (chromium retardation slow down the contaminant transport process; chromium reduction will reduce contaminant concentrations).

Performed model analyses demonstrate that if the current contaminant-arrival rates (contaminant mass flux) at the top of the regional aquifer stay steady, the R-42/R-28 concentrations are expected to remain steady as well. However, in this case, the concentrations downgradient from R-42/R-28 may increase; in addition to R-50, future concentrations above 50 ppb may be detected in R-44 and R-45 as well. The concentrations downgradient from R-42/R-28 may not increase if the contaminant migration in the regional aquifer is characterized by:

- pronounced plume heterogeneity caused by multiple contaminant-arrival rates and/or heterogeneous aquifer properties (permeability/porosity/geochemical properties) causing substantial plume dispersion and channeling;
- chromium reduction in the regional aquifer (if a zero-order reaction rate is assumed, the reaction rate may be characterized with a half-life rate on the order of 1 to 10 yr⁻¹; this estimate is uncertain).

It is important to note that if there is substantial chromium reduction in the aquifer materials, a larger contaminant mass than shown in Table J-5.2-1 may have reached the regional aquifer. However, the reduced mass (Cr⁺³) would become immobile and not be evident in the measured groundwater concentrations. Therefore, it is important to have some bounds on the potential chromium reduction capacity of the regional aquifer materials to better quantify the potential for future plume growth downgradient of R-42/R-28.

The model analyses identified more than 5000 alternative models that are consistent with the available data. Many of these models are implausible. The set of multiple plausible models consistent with the available data can be grouped into the following three categories (scenarios) related to their performance:

1. A subset of model scenarios is characterized by (1) single or multiple contaminant-arrival zones near the wells with the highest concentrations (R-42, R-28, R-62, and R-50) and (2) no chromium retardation/reduction in the regional aquifer. In these cases, the model accurately reproduces the observed concentrations; the model predicted aquifer concentrations relatively quickly reach their steady values. Under this model scenario, most of the currently observed concentrations will remain steady in the future and will not exceed 50 ppb; the concentration at R-13 may increase to ~25 ppb. However, these models require that a relatively small amount of chromium mass reach the regional aquifer (~300 kg total or less).

2. A subset of alternative models is characterized by (1) single or multiple contaminant-arrival zones (1–4) upgradient from the wells with the highest concentrations (R-42, R-28, R-62, and R-50) and (2) chromium reduction in the regional aquifer ($t_{1/2}=1\text{--}5\text{ yr}^{-1}$ or higher). In these cases, the model accurately reproduces the detected concentrations. According to the model, the concentrations will remain steady in the future; however, a larger chromium mass may have reached the regional (~4000 kg or more), but much of that mass will be stable and immobile as Cr^{+3} .
3. Another subset of cases is characterized by (1) single or multiple contaminant-arrival zones (1–4) upgradient from the wells with the highest concentrations (R-42, R-28, R-62, and R-50) and (2) no chromium reduction in the regional aquifer. In these cases, the model accurately reproduces the observed concentrations. However, the concentrations are predicted to increase above 50 ppb in the downgradient wells in the near future (R-44/R-45/R-13).

These three scenarios are potentially equally probable based on the simulation results. It is important to note the observed concentration at R-62 (200 ppb; Table J-4.0-1) may suggest an additional contaminant-arrival zone near R-62; in addition to the contaminant-arrival zone(s) associated with the contaminants observed at R-42/R-28. However, all the calibration data also can be matched with a model that has a single, elongated contaminant-arrival zone. The best model prediction for the case of a single contaminant-arrival zone is presented in Figure J-5.2-2, and it accurately matches the R-62 data.

The observed concentration trend in R-43 (Figure D-3.0-3) can be explained by an additional contaminant-arrival zone upgradient of R-43 with contaminant arrival in approximately 2006 and chromium mass flux of ~1 kg/yr. The observed concentration trend at R-50 can be explained by an additional contaminant-arrival zone upgradient of R-50 with contaminant arrival in approximately 2009 and chromium mass flux of ~1 kg/yr. In both cases, the contaminant mass flux depends on the pore (linear) flow velocity; here the model analyses are performed assuming 20 m/yr.

According to the model analyses, it is not feasible for contaminant-arrival zones beneath the Sandia Canyon wetland to cause currently observed concentrations in the area near R-62, R-42, and R-28 (~4.5 km upgradient from R-62). If a contaminant plume is originating in the regional aquifer beneath the wetland and the aquifer is relatively uniform (no pronounced channeling of the contaminant flow between R-1 and R-7), it cannot be expected that more than 10 ppb of the currently detected chromium in R-62 originates from beneath the wetland. Higher contaminant mass may have contributed to the currently observed concentrations at R-62, R-42, and R-28, if the potential contaminant-arrival zone at the regional aquifer is located closer to R-62.

The pore (linear) groundwater flow velocity in the regional aquifer beneath the Sandia Canyon wetland is potentially higher than the velocity in the area of R-42 and R-28 because of the much higher hydraulic gradients in the regional aquifer (see Appendix G for more details). The best velocity estimate is on the order of 100 m/yr with an uncertainty range of 36 to 365 m/yr because of the uncertain lateral hydraulic gradient ~0.01 – 0.1; permeability ~1 m/d; effective porosity 0.1. Assuming a velocity of 100 m/yr in the model analyses, a single contaminant-arrival zone to the regional aquifer near the wetland may be carrying a mass flux to the regional aquifer at a rate of ~20 kg/yr and produce concentrations close to background at all the downgradient wells (R-14, R-46, R-60, R-64, R-7, R-6, R-43, R-62, R-15, R-33, and R-1). If the groundwater flow velocity in the regional aquifer is 36 and 365 m/yr, the contaminant flux will be ~8 and 80 kg/yr, respectively. In all three cases, the concentration in the regional near the contaminant-arrival zone is predicted to be less than 50 ppb (~20 ppb). In this model analysis, the goal is to explore plumes that are highly dispersed and will produce close to background concentrations in the regional aquifer. In this way, the analyses provide an answer to the question “What is the highest mass flux to the regional aquifer near the wetland that can remain undetected by the current monitoring well network?”

The model analyses are applied to address the question “Is it possible to have a ‘stagnant’ plume characterized with very low contaminant transport velocity?” However, this scenario practically requires multiple contaminant-arrival zones collocated with most of the monitoring wells detecting elevated chromium concentrations. This scenario also requires substantial chromium retardation because the current hydrogeologic information suggests that the pore (linear) groundwater velocity is relatively large in the central portions of the plume.

It should be noted that having additional vadose-zone flow paths and contaminant-arrival zones (some of the vadose-zone flowpaths may have not reached the regional aquifer) upgradient of R-62 increases the potential for chromium reduction in the subsurface because the chromium mass can interact with a larger rock volume. This may be important for the contaminant mass-balance analyses.

J-6.0 REFERENCES

The following list includes all documents cited in this appendix. Parenthetical information following each reference provides the author(s), publication date, and ER ID. This information is also included in text citations. ER IDs are assigned by the Environmental Programs Directorate’s Records Processing Facility (RPF) and are used to locate the document at the RPF and, where applicable, in the master reference set.

Copies of the master reference set are maintained at the New Mexico Environment Department Hazardous Waste Bureau and the Directorate. The set was developed to ensure that the administrative authority has all material needed to review this document, and it is updated with every document submitted to the administrative authority. Documents previously submitted to the administrative authority are not included.

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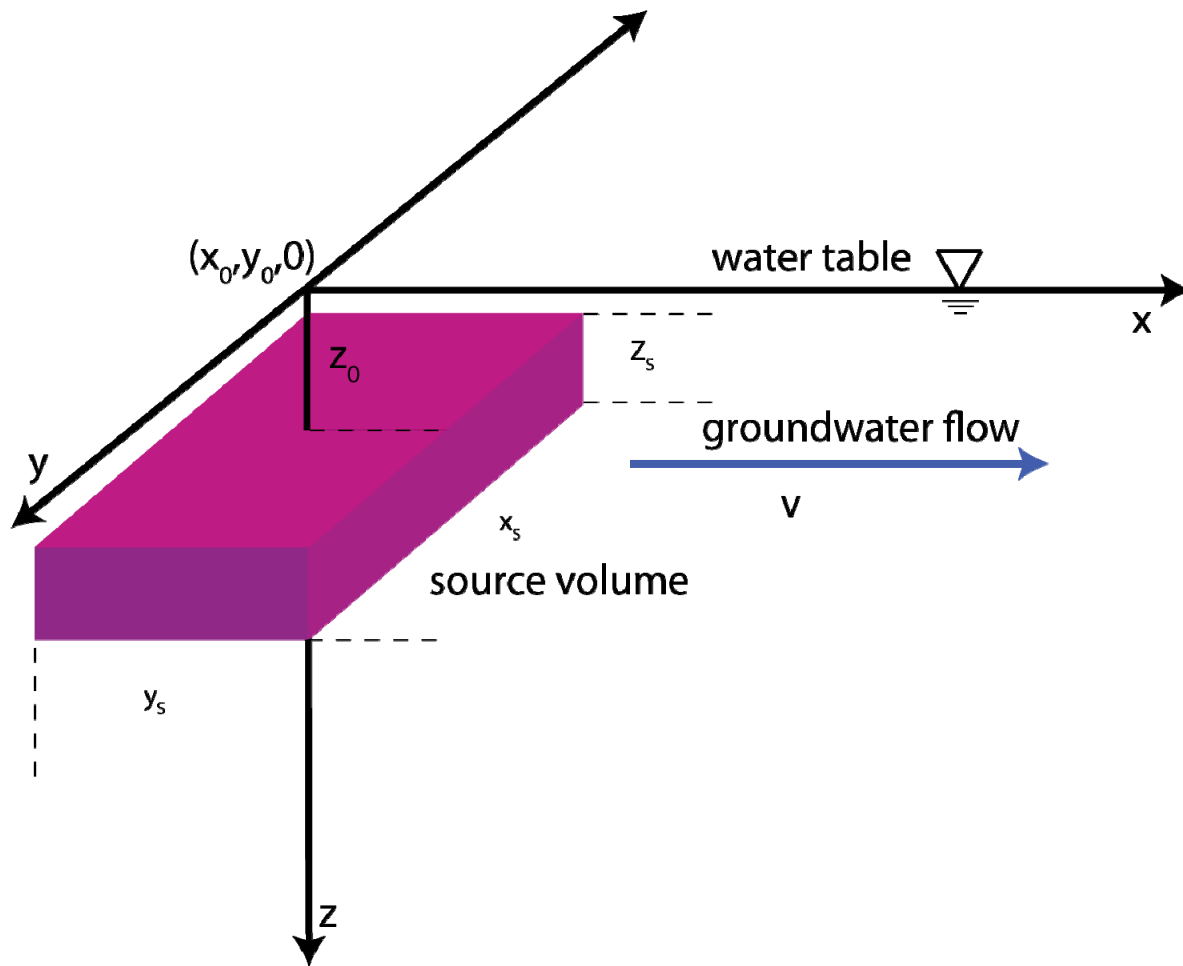
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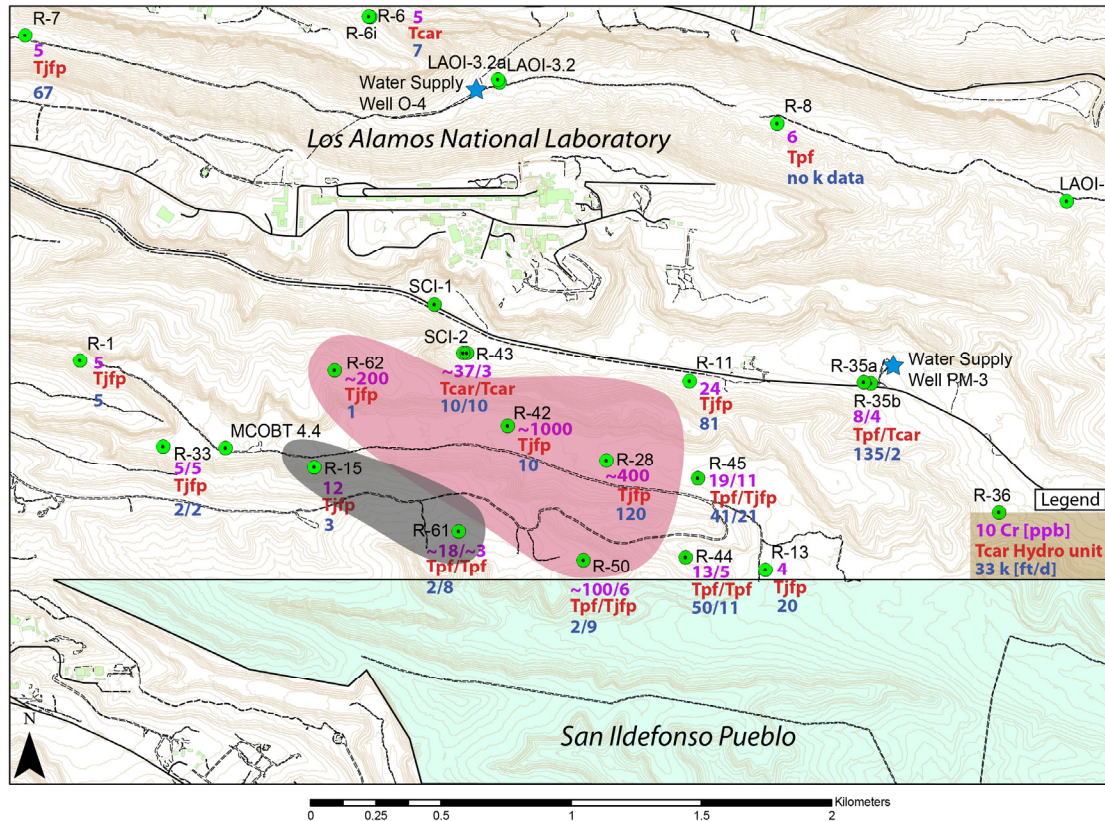
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Note: The upper boundary is a no-flow boundary or a water table boundary.

Figure J-2.0-1 Schematic diagram of a 3-D source body within the regional aquifer



Notes: Representative 2012 chromium concentrations [ppb], screened hydrostratigraphic unit and permeability estimates ([ft/d] based on single-hole pumping tests during well development) are listed for each well screen (upper/lower in the case of multiple-screen wells).

Figure J-2.0-2 Monitoring wells near the chromium (pink-shaded area) and perchlorate (gray-shaded area) plumes (perchlorate concentrations measured in the regional wells are not shown in the figure; the perchlorate concentrations are discussed in Appendix D).

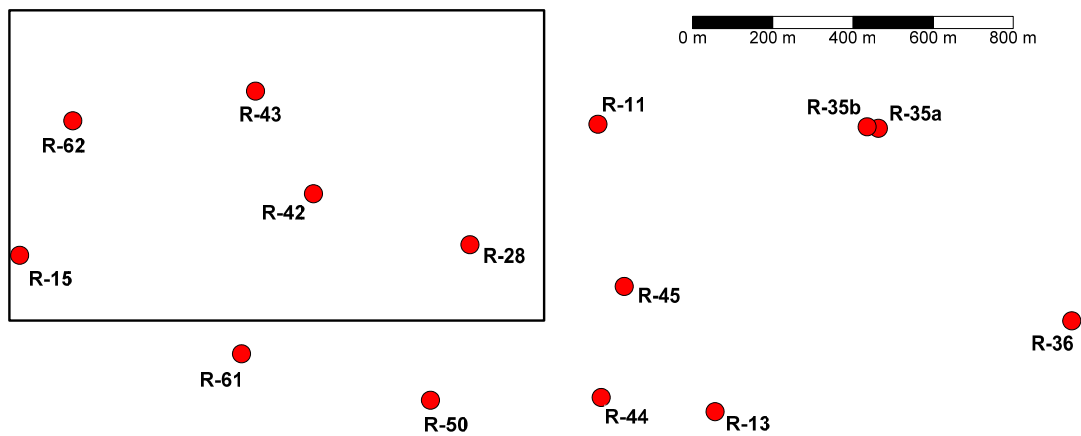


Figure J-3.0-1 Two-dimensional representation of the lateral bounds constraining the potential contaminant-arrival zones at the top of the regional aquifer

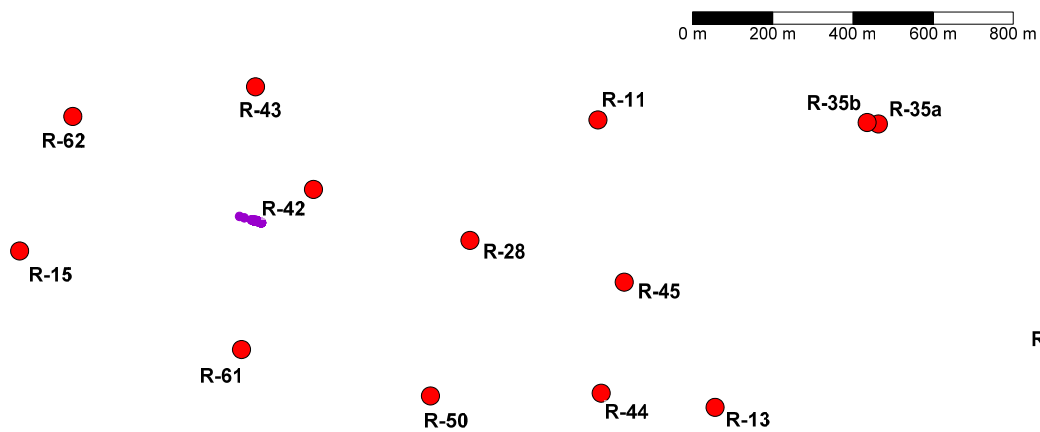
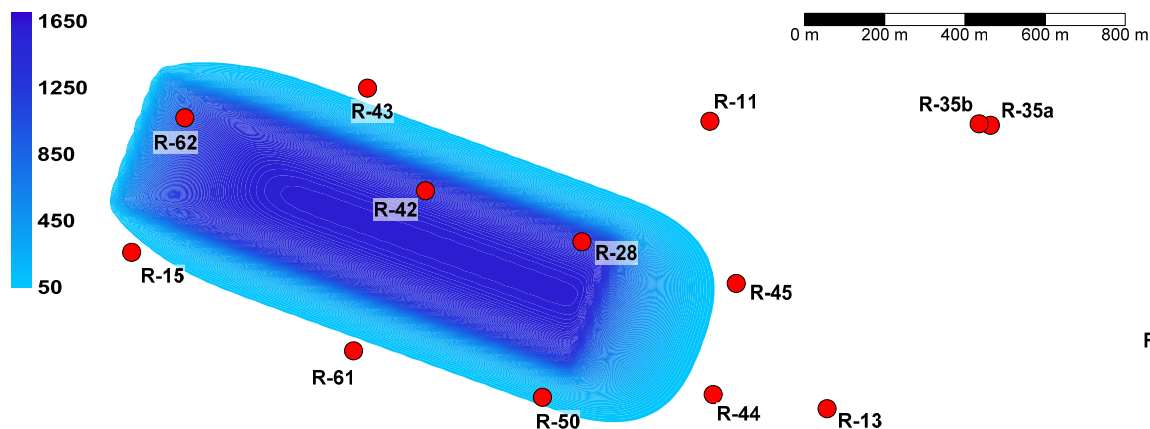
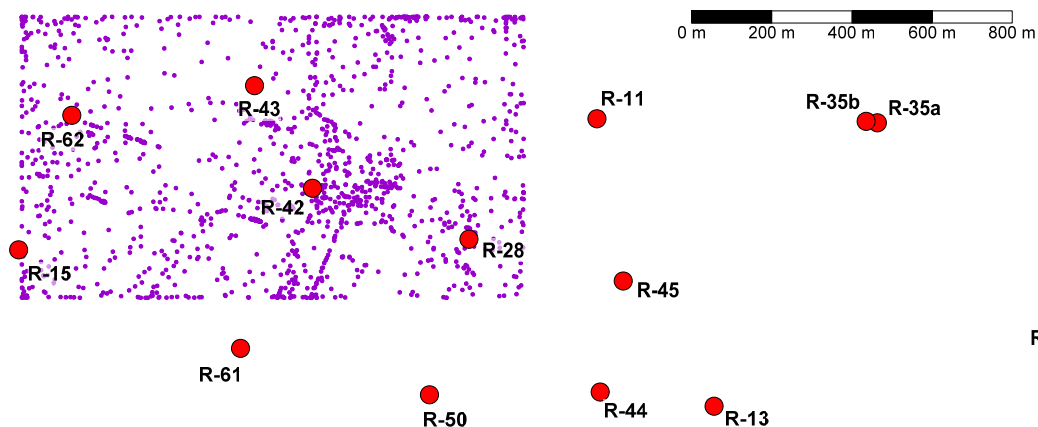


Figure J-5.2-1 Series of plausible contaminant-arrival locations (purple dots) in the regional aquifer consistent with the available hydrogeological and geochemical data for the case of a single contaminant-arrival zone



Note: Plume is plotted showing chromium concentrations higher than 50 ppb.

Figure J-5.2-2 Best estimate for model predicted contaminant concentrations along the top of the regional aquifer, assuming a single contaminant-arrival zone



Notes: The best estimate is computed by averaging the concentrations of all the of plausible model-predicted contaminant plumes (a subset of these plumes is presented in Figure J-5.2-2).

Figure J-5.2-3 Series of plausible contaminant-arrival locations (purple dots) in the regional aquifer consistent with the available hydrogeological and geochemical data for the case of multiple contaminant-arrival zones. More than 5000 solutions are possible, and many of these are very similar.

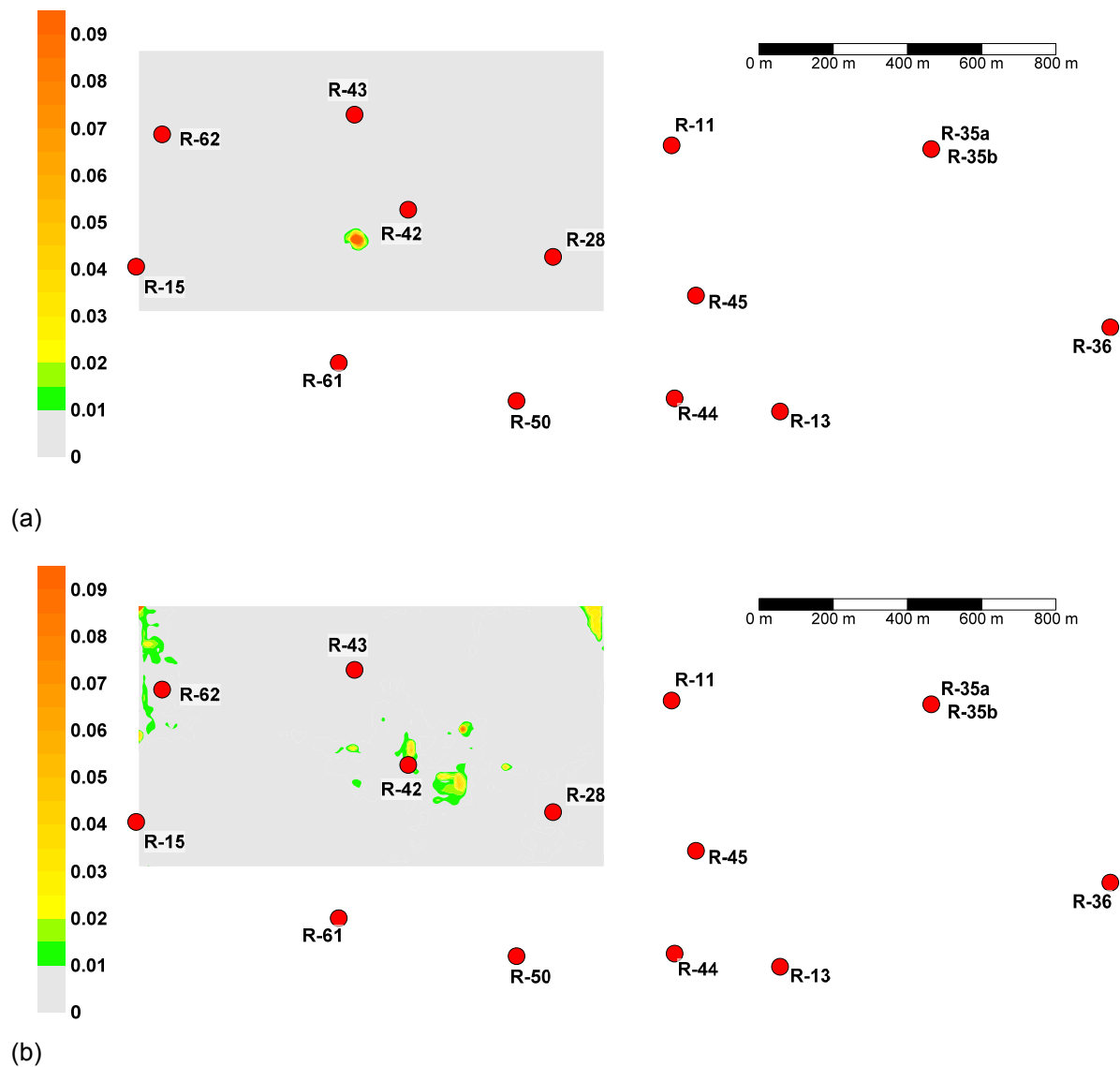


Figure J-5.2-4 Density maps of the plausible contaminant-arrival locations in the regional aquifer consistent with the available hydrogeological and geochemical data for the case of multiple contaminant-arrival zones: (a) single-source zone, (b) two-source zones, (c) three-source zones, and (d) four-source zones.

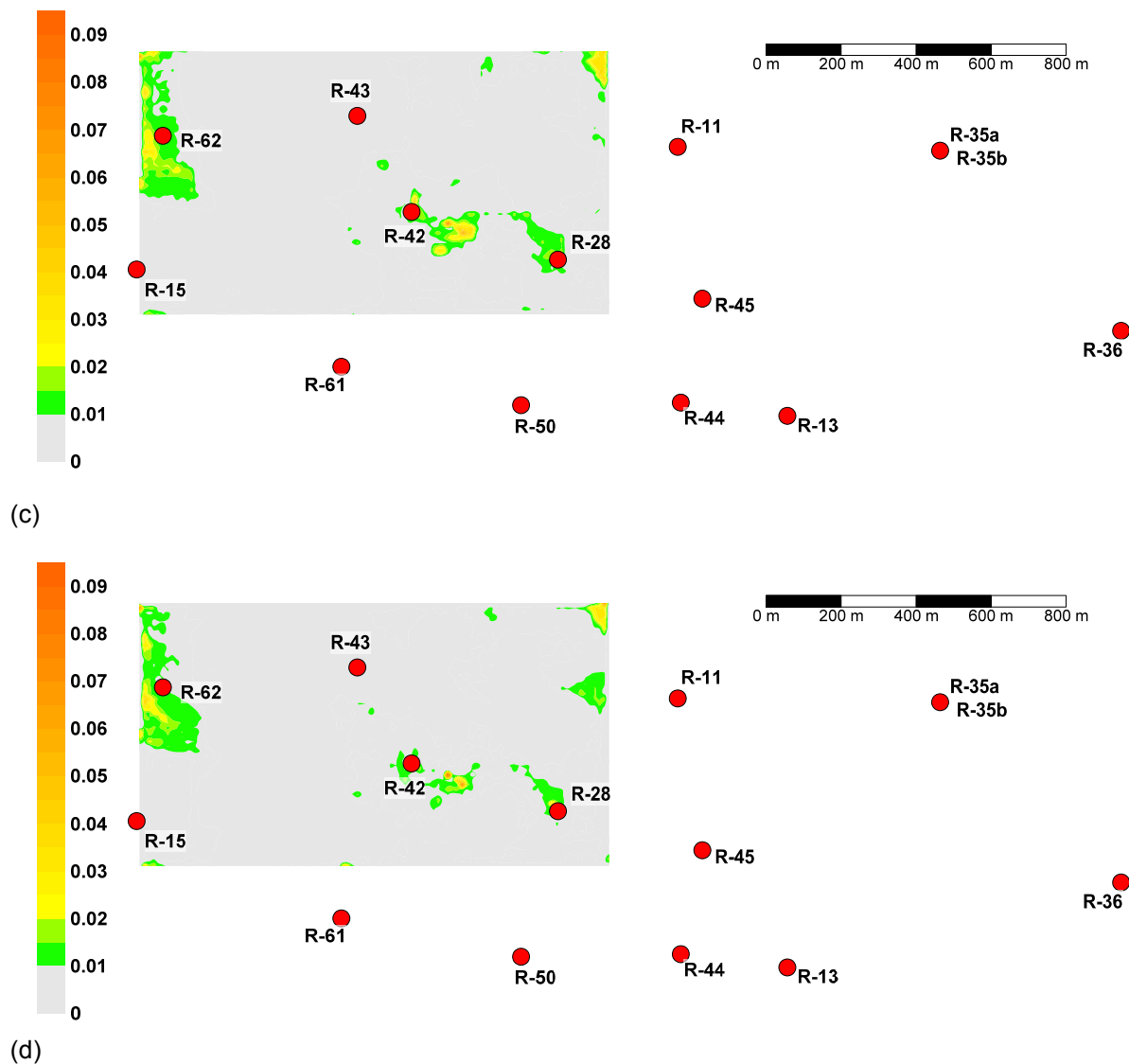


Figure J-5.2-4 (continued)

Density maps of the plausible contaminant-arrival locations in the regional aquifer consistent with the available hydrogeological and geochemical data for the case of multiple contaminant-arrival zones: (a) single-source zone, (b) two-source zones, (c) three-source zones, and (d) four-source zones.

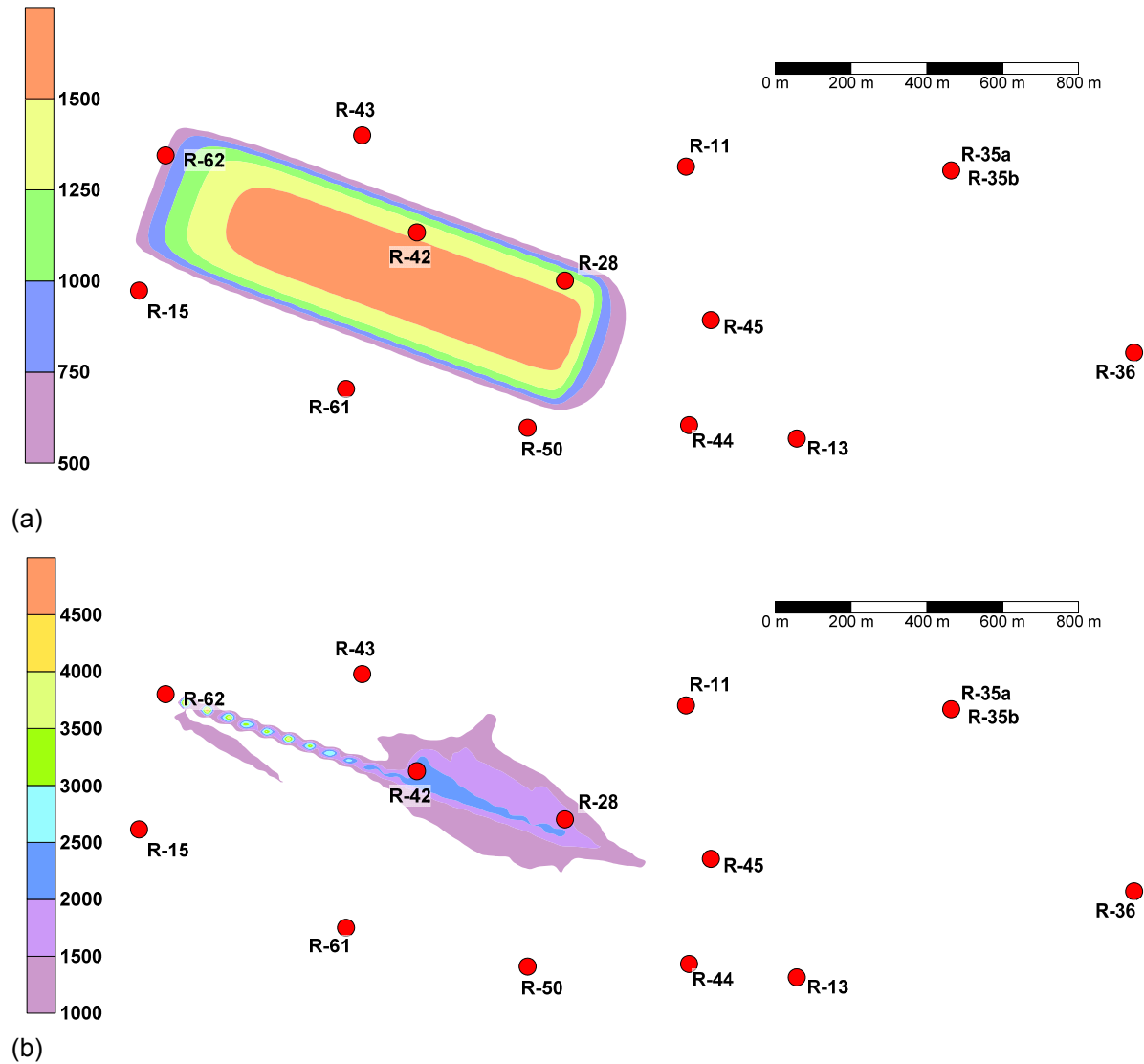
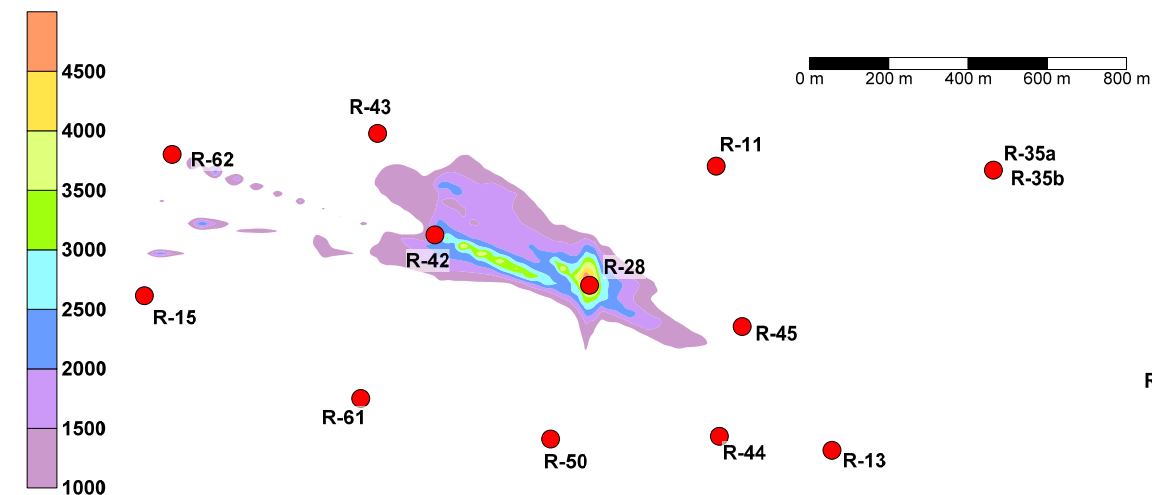
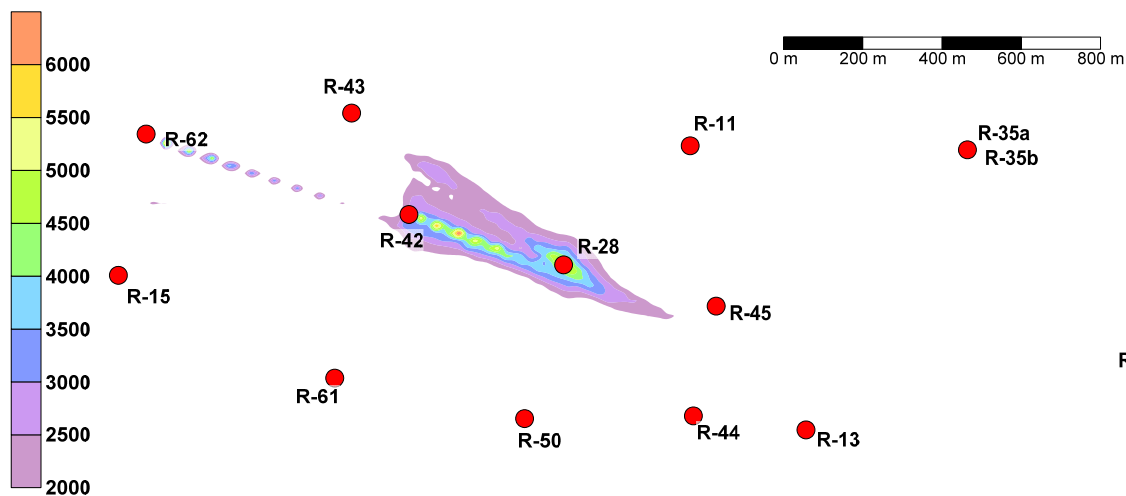


Figure J-5.2-5 Averaged chromium concentrations along the regional water table in the areas near the contaminant-arrival zones based on all acceptable model solutions: (a) single-source zone, (b) two-source zones, (c) three-source zones, (d) four-source zones. Note the scale differences in the plots.



(c)



(d)

Figure J-5.2-5 (continued)

Averaged chromium concentrations along the regional water table in the areas near the contaminant-arrival zones based on all acceptable model solutions: (a) single-source zone, (b) two-source zones, (c) three-source zones, (d) four-source zones. Note the scale differences in the plots.

Table J-3.0-1
Model Parameters for Analytical Simulation of Contaminant Transport

Model Parameter	Unit	Initial Estimate	Calibration Rang	
			Minimum	Maximum
Background concentration	ppb	5	Fixed	
Source x coordinate	m	—*	498,450	499,700
Source y coordinate	m	—	538,850	539,550
Source z coordinate	m	0 (at top of the aquifer)	Fixed	
Source x dimension	m	200	1	1500
Source y dimension	m	200	1	1500
Source z dimension	m	1 (1m below the top of the aquifer)	Fixed	
Contaminant flux to the regional aquifer	kg/yr	10	0.01	100
Contaminant-arrival time	yr	1980	1960	2012
Contaminant cessation time	yr	2160	Fixed	
Half-life decay (accounting for potential Cr^{6+} reduction to Cr^{3+})	1/yr	10^{+6}	10^{-1}	10^{+6}
Flow angle	Degree	-24	-90	0
Effective water-filled porosity	Unitless	0.3	Fixed	
Effective pore (linear) velocity of contaminant migration (accounting for potential Cr^{6+} retardation)	m/yr	40	1	600
Longitudinal dispersivity	m	10	10	200
Horizontal transverse dispersivity	m	5	1	100
Vertical transverse dispersivity	m	0.1	0.01	5

* — = No initial estimate available.

Table J-3.0-2
Permeability Estimates Based
on Single-Hole Pumping Test during Well
Development at the Monitoring Wells Near Sandia Canyon

Unit					
Tjfp		Tpf		Tcar	
Well (screen)	K (ft/d)	Well (screen)	K (ft/d)	Well (screen)	K (ft/d)
R-7	67	R-45 #1	41	R-35a	2
R-1	5	R-44 #1	50	R-6	7
R-33 #1	2	R-44 #2	11	R-36	33
R-33 #2	2	R-13	20		
R-42	10	R-35b	135		
R-28	85	R-61 #1	3		
R-45 #2	21	R-61 #2	1.5		
R-11	81	R-50 #1	9		
R-15	3				
R-50 #2	6				
R-62	1				
Count	11	Count	8	Count	3
Mean	26	Mean	34	Mean	14
Variance	1160	Variance	1980	Variance	277

Notes: Stratigraphic units are Tpf = Pliocene Puye Formation, Tjfp = Miocene pumiceous sediments, and Tcar = Miocene Chamita Formation.
Blank cells represent different number of data for each unit.

Table J-4.0-1
Calibration Data for Chromium Concentrations
Observed at the Monitoring Wells Near Sandia Canyon

#	Well # screen ID	Coordinates		Screen Depths		Averaged Concentrations [ppb]			
		x [m]	y [m]	z0 [m]	z1 [m]	Time	Observed	Acceptable Range	
								Min	Max
1	R-1	497541	539375	8.23	16.46	2004	5	5	10
						2005	5	5	10
						2006	5	5	10
						2007	5	5	10
						2008	5	5	10
						2009	5	5	10
						2010	5	5	10
						2011	5	5	10
						2012	5	5	10
2	R-11	499883	539296	5.57	12.55	2004	20	5	40
						2005	20	5	40
						2006	20	5	40
						2007	20	5	40
						2008	20	5	40
						2009	20	5	40
						2010	20	5	40
						2011	20	5	40
						2012	20	5	40
3	R-13	500174	538580	36.73	55.14	2004	5	5	10
						2005	5	5	10
						2006	5	5	10
						2007	5	5	10
						2008	5	5	10
						2009	5	5	10
						2010	5	5	10
						2011	5	5	10
						2012	5	5	10
						2004	5	5	10

Table J-4.0-1 (continued)

#	Well # screen ID	Coordinates		Screen Depths		Averaged Concentrations [ppb]			
		x [m]	y [m]	z0 [m]	z1 [m]	Time	Observed	Acceptable Range	
								Min	Max
4	R-15	498442	538969	0.00	15.04	2004	8	0	16
						2005	8.5	0.5	16.5
						2006	9	1	17
						2007	9.5	1.5	17.5
						2008	10	2	18
						2009	10.5	2.5	18.5
						2010	11	3	19
						2011	11.5	3.5	19.5
						2012	12	4	20
5	R-28	499564	538996	13.15	20.41	2004	400	300	500
						2005	400	300	500
						2006	400	300	500
						2007	400	300	500
						2008	400	300	500
						2009	400	300	500
						2010	400	300	500
						2011	400	300	500
						2012	400	300	500
6	R-33#1	497855	539040	4.57	11.28	2004	5	5	10
						2005	5	5	10
						2006	5	5	10
						2007	5	5	10
						2008	5	5	10
						2009	5	5	10
						2010	5	5	10
						2011	5	5	10
						2012	5	5	10
7	R-33#2	497855	539040	39.62	42.67	2004	5	5	10
						2005	5	5	10
						2006	5	5	10
						2007	5	5	10
						2008	5	5	10
						2009	5	5	10
						2010	5	5	10
						2011	5	5	10
						2012	5	5	10

Table J-4.0-1 (continued)

#	Well # screen ID	Coordinates		Screen Depths		Averaged Concentrations [ppb]			
		x [m]	y [m]	z0 [m]	z1 [m]	Time	Observed	Acceptable Range	
								Min	Max
8	R-34	500972	537651	26.73	33.71	2004	5	5	10
						2005	5	5	10
						2006	5	5	10
						2007	5	5	10
						2008	5	5	10
						2009	5	5	10
						2010	5	5	10
						2011	5	5	10
						2012	5	5	10
9	R-35a	500581	539286	69.01	83.98	2008	5	5	15
						2009	5	5	15
						2010	5	5	15
						2011	5	5	15
						2012	5	5	15
10	R-35b	500553	539290	11.15	18.19	2008	5	5	15
						2009	5	5	15
						2010	5	5	15
						2011	5	5	15
						2012	5	5	15
11	R-36	501063	538806	4.86	11.87	2008	5	5	15
						2009	5	5	15
						2010	5	5	15
						2011	5	5	15
						2012	5	5	15
12	R-42	499174	539123	3.66	10.09	2009	950	750	1250
						2010	950	750	1250
						2011	950	750	1250
						2012	950	750	1250
13	R-43#1	499030	539379	3.32	9.63	2009	5	5	15
						2010	5	5	15
						2011	20	10	40
						2012	38	28	58

Table J-4.0-1 (continued)

#	Well # screen ID	Coordinates		Screen Depths		Averaged Concentrations [ppb]			
		x [m]	y [m]	z0 [m]	z1 [m]	Time	Observed	Acceptable Range	
								Min	Max
14	R-43#2	499030	539379	23.20	26.24	2009	5	5	15
						2010	5	5	15
						2011	5	5	15
						2012	5	5	15
15	R-44#1	499891	538615	4.94	7.99	2009	10	5	30
						2010	11	5	31
						2011	12	5	32
						2012	14	5	34
16	R-44#2	499891	538615	32.46	35.48	2009	5	5	15
						2010	5	5	15
						2011	5	5	15
						2012	5	5	15
17	R-45#1	499948	538892	3.59	6.64	2009	12	5	32
						2010	15	5	35
						2011	17	7	37
						2012	20	10	40
18	R-45#2	499948	538892	32.51	38.61	2009	7	5	17
						2010	8	5	18
						2011	9	5	19
						2012	10	5	20
19	R-50#1	499465	538608	3.05	6.10	2010	70	40	100
						2011	85	55	115
						2012	100	70	130
20	R-50#2	499465	538608	32.92	39.62	2010	7	5	20
						2011	7	5	20
						2012	7	5	20
21	R-61#1	498987	538710	7.62	10.67	2012	18	5	38
22	R-61#2	498987	538710	36.58	42.67	2012	5	5	15
23	R-62	498512	539326	4.57	11.28	2012	200	150	250

Note: The calibration ranges include background and anthropogenic chromium concentrations.

Table J-5.2-1
Average Model Parameters Estimated as a Result of the
Model Calibration versus Chromium Concentration Data
Observed at the Regional Monitoring Wells Near Sandia Canyon

Model Parameter	Unit	Average Estimates for the acceptable models	
		Phase I (2009)	Phase II (2012)
Source x coordinate	m	499150	499040
Source y coordinate	m	539000	539182
Source x dimension	m	27	430
Source y dimension	m	468	380
Contaminant flux	kg/yr	18	22
Contaminant-arrival time	yr	1977	1969
Flow Angle	degrees	-7	-34
Horizontal pore velocity	m/yr	23	14
Longitudinal dispersivity	m	1	24
Horizontal transverse dispersivity	m	6	1
Vertical transverse dispersivity	m	1	0.1
Total contaminant mass	kg	550	1100

Appendix K

*Numerical Simulation of Groundwater Flow and
Chromium Transport in the Regional Aquifer beneath
Sandia and Mortandad Canyons*

K-1.0 INTRODUCTION

A numerical model of groundwater flow and contaminant transport in the regional aquifer beneath the Sandia and Mortandad Canyons area is developed to inform and enhance the understanding of the fate and transport of chromium in the environment. This appendix describes the current state of the development of the numerical model and discusses the modeling results. This is a work in progress and a continuation of the model analyses presented in the 2008 Fate and Transport Investigations Update for Chromium Contamination from Sandia Canyon (LANL 2008, 102996).

Flow and transport numerical simulations are applied to predict the migration of chromium in the uppermost portion of the regional aquifer (within the upper 100 m below the regional water table). Groundwater flow and contaminant transport in the unsaturated zone are not part of the current modeling effort. A three-dimensional (3-D) unsaturated zone model was presented in Appendix J of the 2008 Fate and Transport Investigations Update for Chromium Contamination from Sandia Canyon (LANL 2008, 102996). The vadose-zone model analyses demonstrated the potential for 3-D channeling and lateral diversion (along hydrostratigraphic contacts) of the water infiltrating Sandia Canyon before it reaches the regional aquifer.

The effects of geochemical interactions of contaminants with rocks along the flow paths are also not included in the present numerical-model simulations. The potential impact of geochemical interactions of contaminants is analyzed in Appendix J where the analytical model is applied to estimate the impact of chromium reduction and retardation on the contaminant fate and transport in the regional aquifer.

The current goal is to generate a model that is calibrated against existing water-level and concentration observations near the chromium plume. The model targets representation of the long-term water level changes in the regional aquifer and evaluation of their impact on the evolution of the plume. The model currently ignores the seasonal fluctuations in the water levels from municipal pumping effects. The water-supply wells near the plume are not represented explicitly in the model; however, the model is designed to represent the pumping effects as an outflow along the bottom model boundary (discussed further below). In this way, the model is capable of representing the potential impact of water-supply pumping on the vertical extent of the plume.

It is important to contrast the major differences between the model analyses presented in this appendix and in Appendix J of this report. The discussion in Appendix J focuses on evaluating uncertainty associated with model predictions. It also evaluates multiple alternative conceptual models and a large range of conceptual and parameter uncertainties. This is achieved efficiently because the analyses in Appendix J are based on an analytical model allowing for fast computational times of many ($>10^6$) simulations. The analyses presented here apply a 3-D numerical model. Because longer computational times are required to perform a single forward model run, analysis of the uncertainties in model predictions is a challenging task. Currently, model calibration uses a combination of manual (trial and error) and automated optimization techniques. A single model realization is presented in this appendix that demonstrates one solution that is calibrated to field observations. Because of the complexity of the problem, it is expected other models with alternative conceptualization and model parameters can produce a similar or better level of calibration against the observed water level and concentration data (i.e., the solution is nonunique). Thus, it is important to emphasize the modeling results presented here should not be viewed as the only possible prediction of the fate and transport of the contaminant plume in the regional aquifer.

K-2.0 MODEL DOMAIN AND COMPUTATIONAL GRID

The dimensions and design of the computational grid needed for flow and transport simulations at a given site depend on an understanding of the relationships between hydrogeology, contaminant-release history, and site-specific details, such as the locations of monitoring wells and water-supply wells. Also of great importance is the spatial scale of the processes to be modeled and the modeling goals. Sufficient computational-grid resolution is needed to accurately represent wells screens and capture vertical components of the hydraulic gradients.

The computational grid is shown in Figure K-2.0-1. The figure represents the 3-D model domain, computational grid, and locations of the monitoring-well screens included in the model. The computational grid is structured: laterally, it is uniform, and vertically, the grid has higher resolution close to the top of the model and grid spacing increases with depth. The lateral spacing is 50 × 50 m. The vertical spacing varies from about 1 m to 15 m. The grid includes a little less than 100,000 nodes and about 550,000 elements. The grid is designed to provide sufficient computational accuracy and efficiency for the performed model analyses. The model domain extends 4600 m west-east, 3300 m north-south, and 100 m vertically. Note the vertical exaggeration in Figure K-2.0-1 (a factor of ~16) because the model domain has relatively large lateral extent but relatively small vertical extent.

The computer codes Gridder (<https://meshing.lanl.gov/gridder/gridder.html>) and LaGriT (<http://lagrit.lanl.gov>) were used to create the computational grids. The flow and transport simulations were run with the Finite Element Heat and Mass Transfer code ([FEHM] <http://fehm.lanl.gov>) (Zyvoloski et al. 1996, 054421; Zyvoloski et al. 1997, 070147). FEHM was developed by researchers at Los Alamos National Laboratory and is capable of simulating 3-D, time-dependent, multiphase, nonisothermal flow, and multicomponent reactive groundwater transport through porous and fractured media. FEHM has been used in a wide variety of applications. The software is mature, has users throughout the world, and has been certified through the Yucca Mountain Project Software Quality Assurance Program. FEHM is available to the public and operates under various operating systems (Windows, MAC OS X, Linux, etc.).

K-3.0 MODEL CALIBRATION

The model is calibrated against existing water-level and chromium concentration data detected at regional wells R-1, R-33 (2 screens), R-15, R-62, R-43 (2 screens), R-42, R-28, R-61 (2 screens), R-50 (2 screens), R-45 (2 screens), R-44 (2 screens), R-11, R-13, R-35a, R-35b, R-36 and R-34, for a total of 17 wells and 23 screens. The model is designed to simulate water-level changes in the past 5 yr (since 2007) and predict current-day (circa 2012) chromium concentrations. It is important to note that water-level observations are not available for all the wells over the entire simulation period (2007–2012). The water-level calibration targets are defined based on the available water-level measurements. The model uses an increasing number of water-level and concentration calibration targets as those data became available with the drilling of new wells in the Sandia and Mortandad Canyons area. The model is developed to characterize the long-term water-level declines; seasonal fluctuations resulting from water-supply pumping are currently not included. The concentration calibration targets are consistent with the calibration targets implemented for calibration of the analytical contaminant transport model (Appendix J).

K-3.1 Methodology

The model is calibrated using a combination of manual and automated calibration processes. The automated calibration employed the Levenberg-Marquardt optimization algorithm as implemented in the code MADS (<http://mads.lanl.gov>). The objective function subject to minimization is defined as

$$\Phi = [\mathbf{c} - \mathbf{f}(\mathbf{b})]^T \mathbf{W} [\mathbf{c} - \mathbf{f}(\mathbf{b})]$$

where $\mathbf{c}$ is a vector $[N \times 1]$ of optimization targets, $\mathbf{b}$ is a vector $[M \times 1]$ of model parameters, $\mathbf{W}$ is a diagonal weight matrix $[N \times M]$, and $\mathbf{f}$ is the model. If Φ is minimized, the algorithm searches for the maximum-likelihood parameter set $\mathbf{b}$ that provides the best fit between simulated $\mathbf{f}(\mathbf{b})$ and measured $\mathbf{c}$ quantities. The vector of optimization targets includes (1) water-level data and (2) chromium-concentration data. $\mathbf{W}$ represents the relative weight of each optimization target defined subjectively based on the magnitude of the calibration data. The vector $\mathbf{b}$ includes various model parameters considered in the inverse analysis, as described in section K-3.2.

The model development included a series of inverse analyses with different complexity. The final model has on the order of 50 unknown model parameters (outlined in the next section) and about 160 calibration targets.

K-3.2 Model Design

K-3.2.1 Boundary Conditions

The west and east model boundaries are specified-head boundaries forming ambient flow through the model domain, representing the large-scale overall easterly flow from mountain-front recharge to discharge at the Rio Grande to the east. To account for the observed water-level declines at the monitoring wells, the heads along the boundaries decline as well. The initial heads (circa 2007) and annual decline trends along the west and east boundaries are not known and are estimated during model calibration. As a result, the west and east boundaries represent groundwater inflow and outflow, respectively.

North and south model boundaries are no-flow boundaries; they are located sufficiently far from the monitoring wells not to impact groundwater flow and contaminant transport in the area of interest.

Top and bottom boundaries are with spatially variable specified fluxes. The inflow along the top boundary defines aquifer recharge. The outflow along the bottom boundary defines the vertical leakage in the deeper sections of the aquifer impacted by municipal water supply pumping. The fluxes along the top and bottom boundaries are not known and are estimated during model calibration.

The regional aquifer is simulated as confined while, in reality, the aquifer is phreatic (unconfined). Model simulations representing the regional water table as a material boundary are feasible but much more computationally intensive. Given the small magnitude of the water-level fluctuations, the current modeling approach is justified.

Chromium mass flux is carried to the regional aquifer through aquifer infiltration recharge. The mass flux is represented as groundwater infiltration flow with specified contaminant concentration (constant in time). The contaminant concentrations of these infiltration pathways are not known and are estimated during model calibration. The analyses presented in Appendix J are applied to guide the initial locations and lateral dimensions of the contaminant mass arrival zones. The locations and dimensions of the contaminant arrival zones (as wells as locations and dimensions of the infiltration recharge zones) are not known and are estimated during model calibration. Since the infiltration locations and dimensions impact both water-level and concentration-calibration targets, these provide additional constraints in the

calibration process. Consistent with the analyses in Appendix J, different infiltration and contaminant arrival locations can become active at different times. The contaminant concentrations at the arrival zones can vary in time; however, here the analyses are performed assuming fixed concentrations.

An initial steady-state groundwater flow field is calculated for each of the simulations to characterize the flow conditions in 2007; insufficient hydraulic information is available to represent the groundwater flow regime before this date. The model then reproduces the changes in the flow regime based on the transient water-level transient data. The contaminant transport is initiated in 1970 (based on analyses presented Appendix J). For contaminant simulations before 2007, the 2007 groundwater flow field is applied. At the end, the model produces predictions of the water-level and contaminant concentration in 2012. During model inversion, the 2007–2012 model-predicted water levels are matched against the respective water-level data. In addition, 2012 model predicted concentrations are applied in the calibration process.

K-3.2.2 Hydrologic and Transport Properties

The simulations are performed assuming unknown aquifer properties. The grid does not include distinct stratigraphic boundaries although they are known to be present within the model domain. Analyses of water-level responses to water-supply pumping (Appendix G) and during the R-28 pump test (Appendix L) indicate aquifer materials are heterogeneous potentially at scales less than the size of the individual units, and no distinct contrasts exist between different units. Therefore, aquifer permeability is simulated using geostatistical modeling and the pilot-points method. The pilot points are fixed locations where permeabilities are defined during the calibration process. The permeabilities at the pilot points are applied to compute aquifer permeability within the model domain using kriging. The permeabilities at the pilot points are adjusted during model calibration to represent a heterogeneous permeability field that produces groundwater flow and contaminant transport consistent with the observed calibration data. The optimal number of pilot points is defined based on preliminary model analyses (not presented here). The analyses presented below employed 16 pilot points located at the monitoring wells screens (the uppermost screen if the well has two screens). The applied set of pilot points cannot be expected to characterize small-scale aquifer heterogeneity; it is expected only to define potential large-scale structures that control groundwater flow and contaminant transport. No previous information from pumping tests at the monitoring wells is applied to define or constrain the aquifer permeability at the pilot points. The 3-D kriging is performed using the code GSTAT (<http://www.gstat.org>). The 3-D kriging computes permeability values for each node in the model domain representing aquifer heterogeneity.

In addition, heterogeneity in the aquifer permeability is also characterized by two zones with unknown properties and sizes along the west and east boundaries. The permeability and the size of these zones are estimated during model calibration. These zones allow for better characterization of the unknown groundwater flow directions through the model domain. They act as buffer zones that allow some diversion of the ambient groundwater flow to the north or south as well as distribute water in and out of the model domain according to the applied head along the boundaries and the internal geostatistical permeabilities of each node in the domain. Vertical anisotropy of aquifer permeability is assumed to be spatially uniform; the vertical anisotropy ratio is fixed and set equal to 0.01 based on the available site data.

It is important to note the model setup allows for deviations in the groundwater flow directions within the model domain. The groundwater flow is assumed to be predominantly from east to west, which is constrained by the model boundary conditions (see above). However, the combination of (1) buffer zones along constant head boundaries, (2) heterogeneous aquifer properties, and (3) spatially varying fluxes along the top and bottom boundaries creates the opportunity for flow directions that can deviate locally from due east. All the model parameters impacting the local flow directions are estimated during the

model calibration based on the available water-level and concentration data. Given the complexity of the problem, it is expected multiple models will be equally well calibrated against the observed water-level and concentration data (i.e., the solution is nonunique). Thus, it is important to emphasize that the modeling results presented below should not be viewed as the only possible prediction of the groundwater flow directions in the regional aquifer.

Specific storage of the aquifer is assumed to be uniform and unknown; it is estimated during model calibration.

The model uses fixed longitudinal (100 m), transverse lateral (10 m), and transverse vertical (1 m) dispersivities. It is demonstrated in the literature (e.g., Neuman 1990, 090184) that the dispersivity is dependent on the distance of plume migration. Typically, the longitudinal and transverse dispersivities are assumed to be 1/10 and 1/100 of the distance, respectively. The effective porosity characterizing contaminant transport is assumed to be uniform and unknown; it is estimated during model calibration.

K-3.3 Results and Discussion

The calibration targets and obtained model estimates are listed in Tables K-3.3-1 and K-3.3-2. In general, the model predicts with good fidelity the observed water-levels and contaminant concentrations. The largest water-level discrepancies are at R-33, screen 2, and R-35a. Both screens are relatively deep and are impacted strongly by the water-supply pumping at PM-5 and PM-3, respectively. The model relatively accurately predicts the magnitude of the water-level declines at R-33 screen 2 and R-35a observed between 2007 and 2012; however, the model substantially overpredicts the hydraulic head at these two wells. The model also overpredicts the hydraulic head at R-1. R-1 is located upgradient of the study area and close to the model domain boundary; potential processes not represented in the model impact the water levels of this well. The water level at R-11 is slightly underpredicted by the model; this may be an indication for additional infiltration recharge of the regional aquifer in vicinity of R-11. The water levels at the rest of the monitoring wells are relatively well predicted by the model.

The contaminant concentrations are relatively well represented by the model (Table K-3.3-1). Most of the model predicted concentrations are within predefined acceptable ranges. Additional adjustment in the location and strength of the contaminant source is required to better match the R-28, R-50, and R-61 observations.

The estimated model parameters are listed in Table K-3.3-3. For the parameters for which previous data are available (hydraulic conductivity, specific storage, discharge and recharge rates, contaminant concentrations, etc.), the obtained estimates are reasonable (Tables K-3.3-3). The presented model assumes three contaminant-arrival zones with initial estimates about the location and properties of these zone based on the analytical-model results presented in Appendix J. The contaminant-arrival zones are located initially near R-42, R-62, and R-15, respectively. The model is calibrated by adjusting the properties of the contaminant-arrival zones (location, size, recharge flux, and contaminant concentration). The estimated properties of these zones based on model calibration are listed in Table K-3.3-3.

As stated above, it is expected that the solution is nonunique: multiple numerical models with alternative conceptualization and model parameters can be obtained that are consistent with the available data. Therefore, the obtained modeling results are not considered to be the only possible solution of the analyzed problem.

Spatial distributions of the model predicted concentrations in 2012 are presented in Figure K-3.3-1. Figure K-3.3-1(a) shows concentrations along model boundaries. Figures K-3.3-1(b–f) provide 3-D representations of the contaminant plume in the aquifer using a 3-D isosurface representing chromium concentration of 50 ppb and two vertical cross-sections through model domain. The model predicted highest concentration is above 1000 ppb. The contaminant plume predominantly propagates laterally just below the water table. The vertical extent of chromium concentrations exceeding 50 ppb is up to 75 m below the regional water table. The maximum plume depth is observed beneath the infiltration zone near R-42. Figures K-3.3-2 (a–c) provide 3-D representation of the contaminant plume in the aquifer through a series of horizontal cross-section through the model domain at different depths; the figures show the contaminant concentrations at the water table (Figure K-3.3-2a) as well as 25 m and 50 m below the regional water table (Figures K-3.3-2b and K-3.3-2c, respectively). This model predicts the plume migrates downgradient from R-42/R-28 area to the area between R-11 and R-45 and moves toward R-35. The contaminant concentrations along the top of the model decrease to less than 50 ppb downgradient of R-11 and R-45. The model also predicts some southern diversion of the plume migration, which accounts for concentrations observed at R-50.

K-4.0 REFERENCES

The following list includes all documents cited in this appendix. Parenthetical information following each reference provides the author(s), publication date, and ER ID. This information is also included in text citations. ER IDs are assigned by the Environmental Programs Directorate's Records Processing Facility (RPF) and are used to locate the document at the RPF and, where applicable, in the master reference set.

Copies of the master reference set are maintained at the New Mexico Environment Department Hazardous Waste Bureau and the Directorate. The set was developed to ensure that the administrative authority has all material needed to review this document, and it is updated with every document submitted to the administrative authority. Documents previously submitted to the administrative authority are not included.

LANL (Los Alamos National Laboratory), July 2008. "Fate and Transport Investigations Update for Chromium Contamination from Sandia Canyon," Los Alamos National Laboratory document LA-UR-08-4702, Los Alamos, New Mexico. (LANL 2008, 102996)

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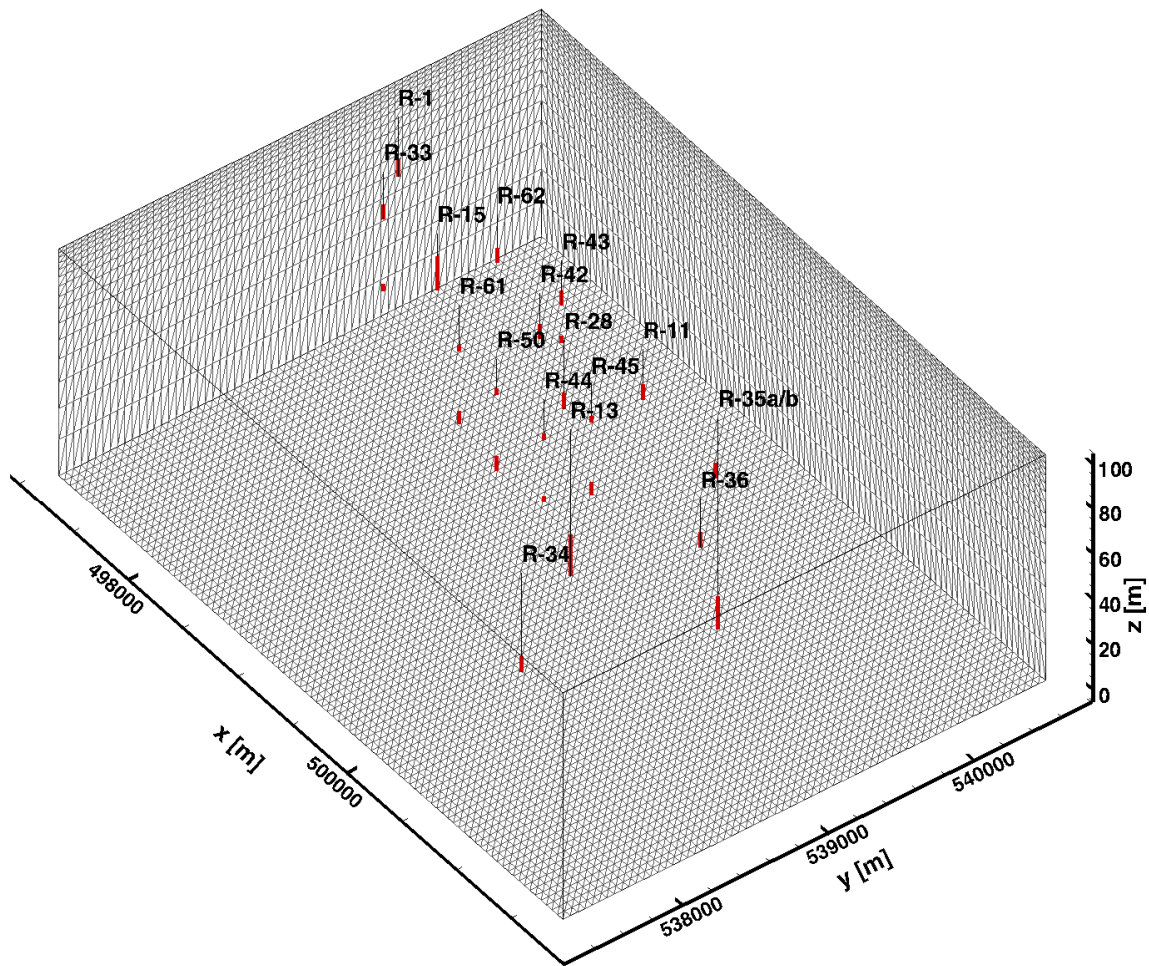
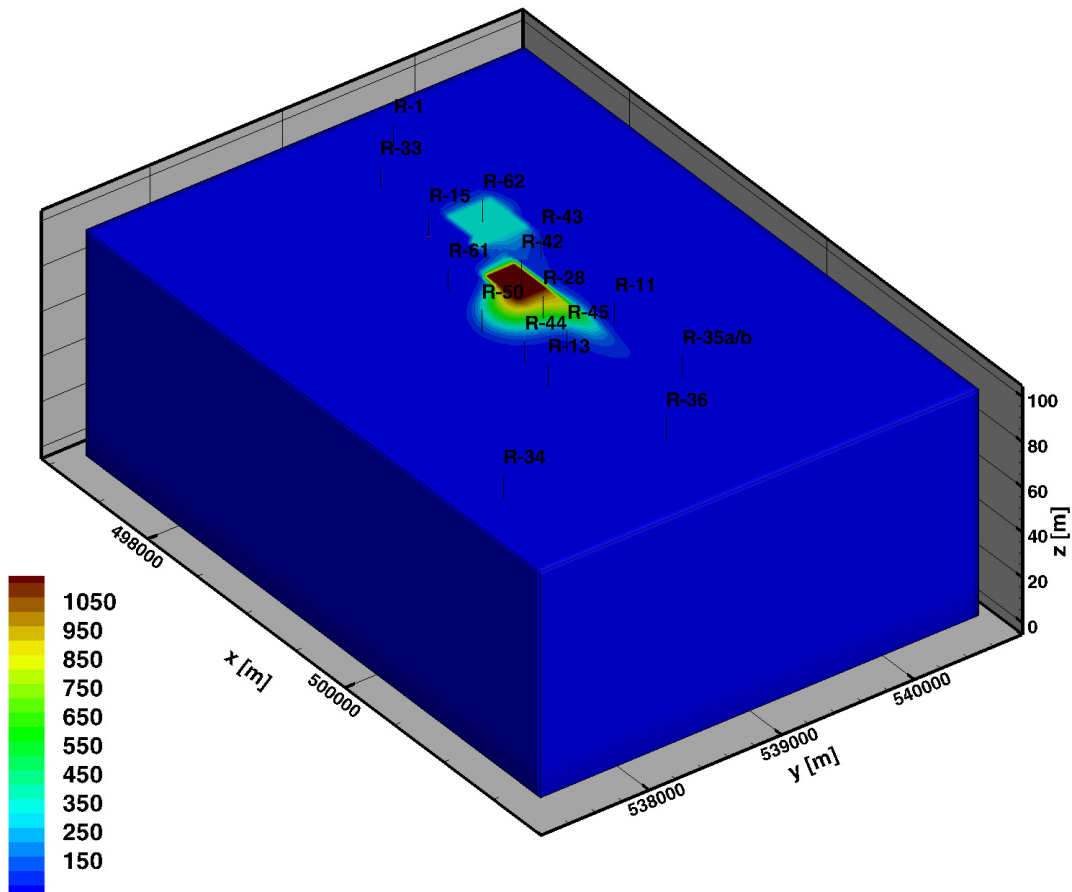
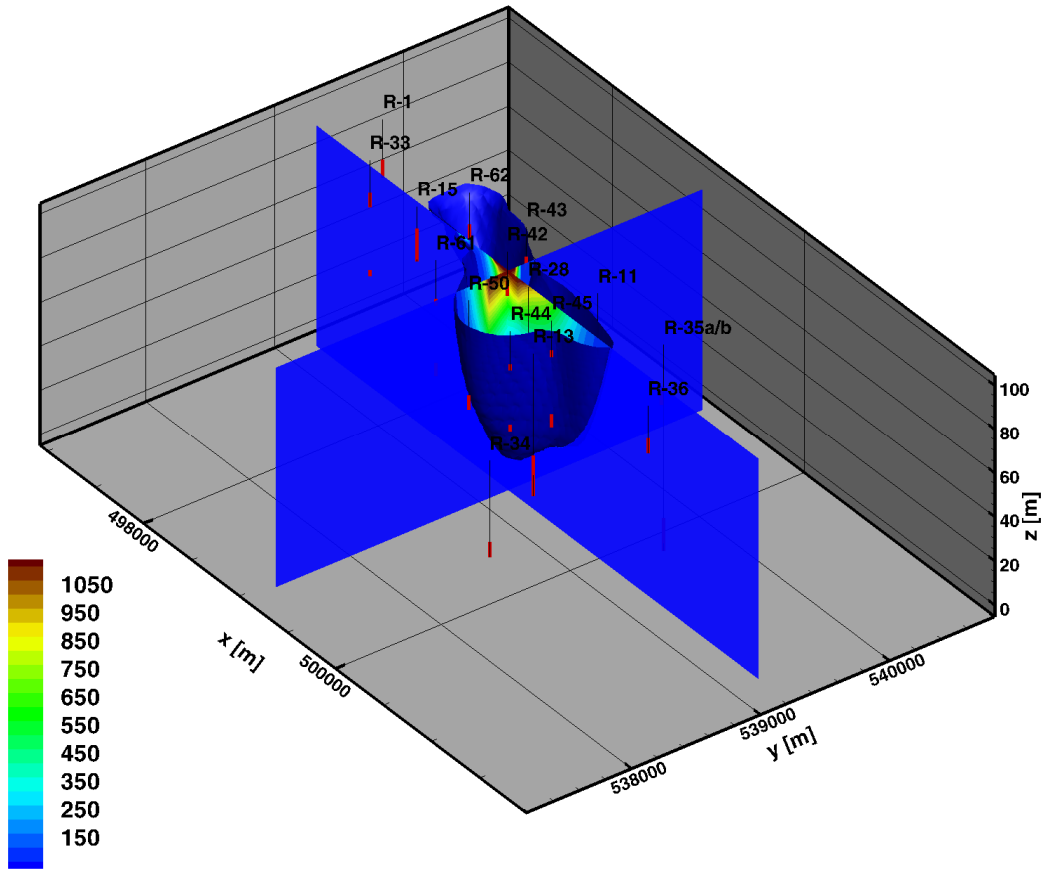


Figure K-2.0-1 The 3-D model domain, computational grid, and locations of the monitoring-well screens



(a)

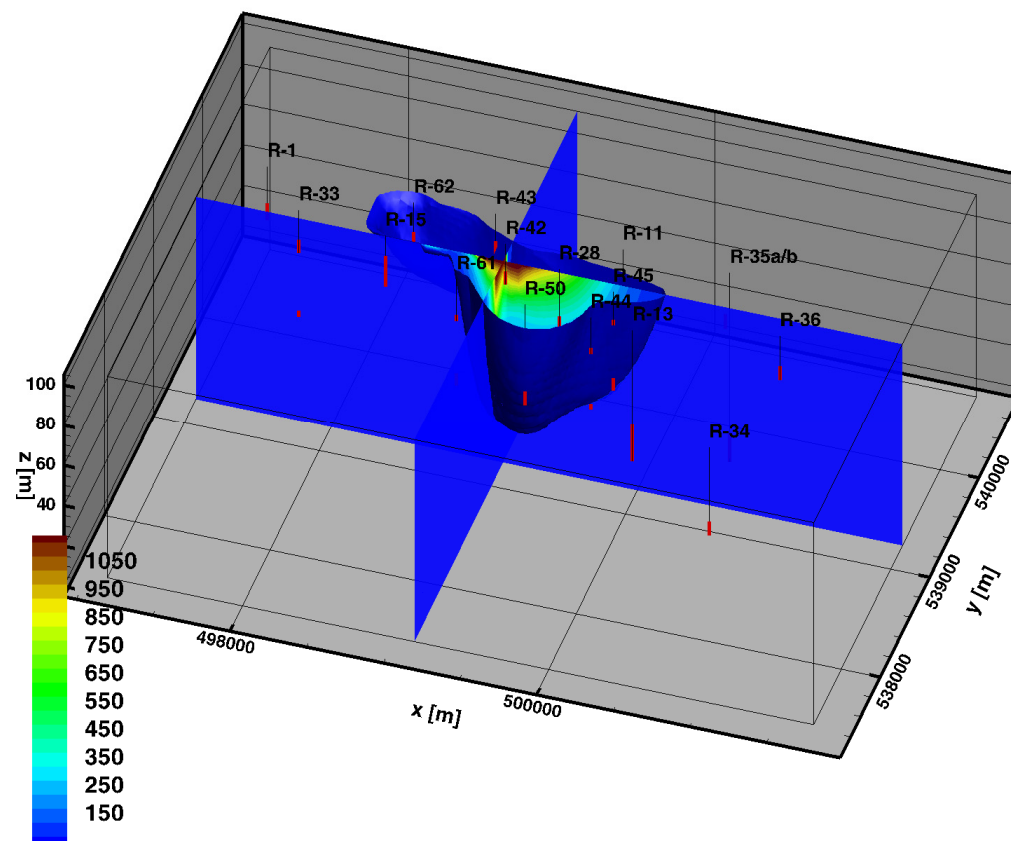
Figure K-3.3-1 Numerical model prediction of 3-D contaminant distribution in 2012: (a) concentrations along model boundaries, (b-f) isosurface of 50 ppb and vertical cross-section through model domain



(b)

Figure K-3.3-1 (continued)

Numerical model prediction of 3-D contaminant distribution in 2012:
 (a) concentrations along model boundaries, (b-f) isosurface of
 50 ppb and vertical cross-section through model domain



(c)

Figure K-3.3-1 (continued)

Numerical model prediction of 3-D contaminant distribution in 2012: (a) concentrations along model boundaries, (b-f) isosurface of 50 ppb and vertical cross-section through model domain.

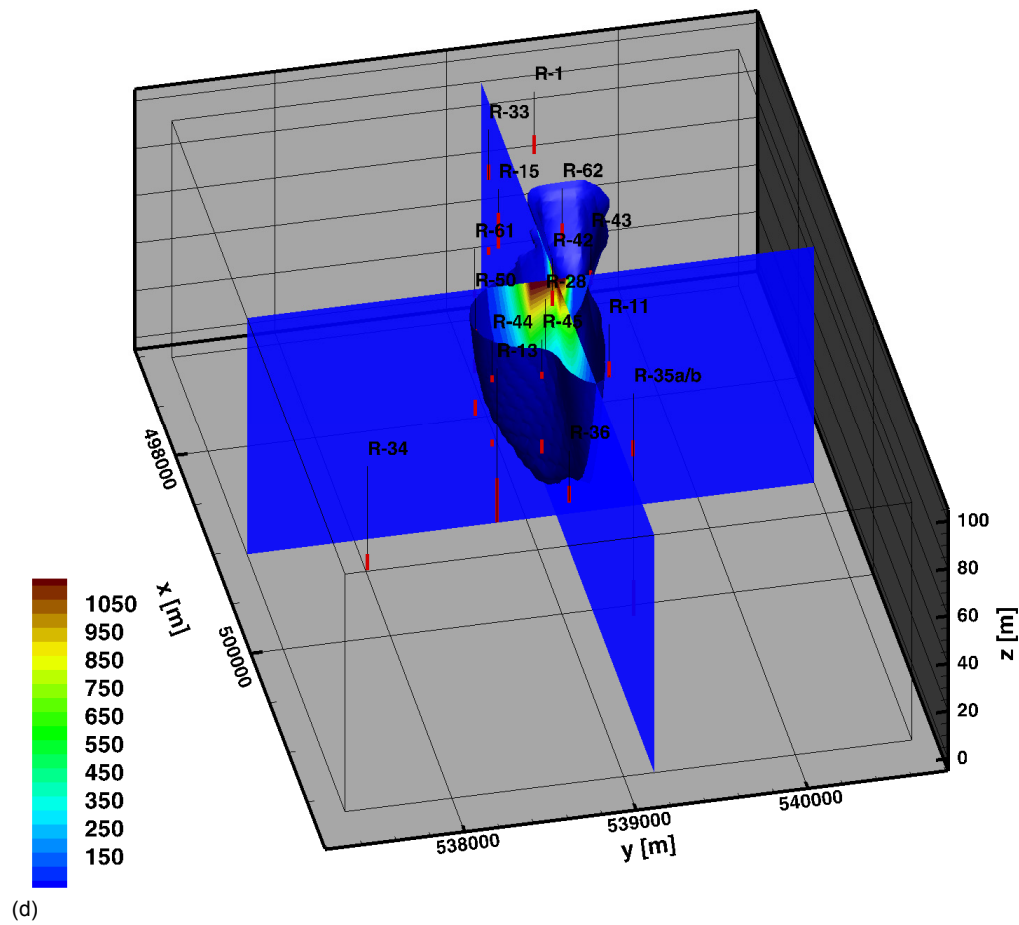
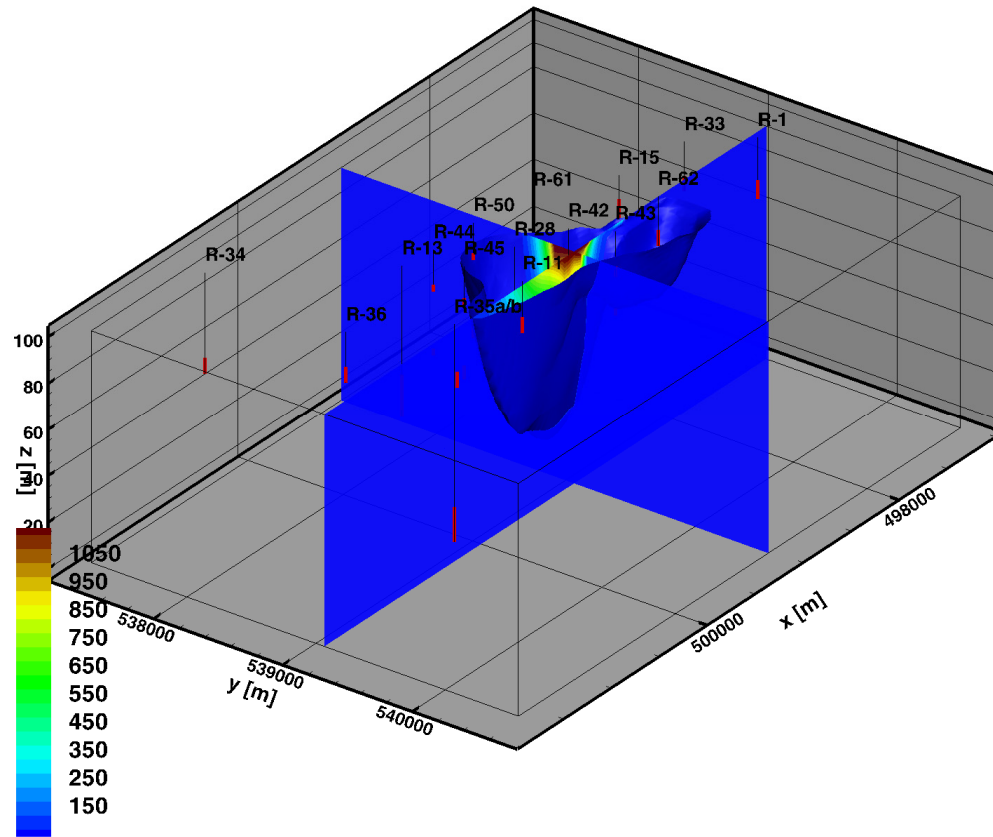


Figure K-3.3-1 (continued)

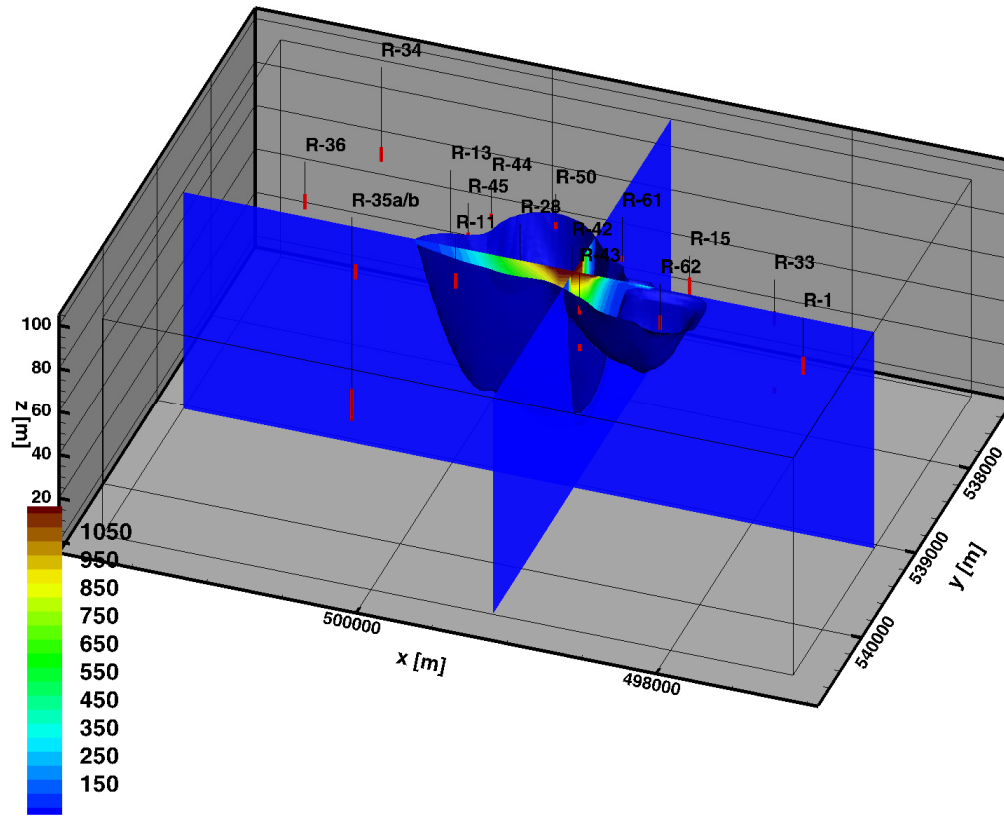
Numerical model prediction of 3-D contaminant distribution in 2012:
 (a) concentrations along model boundaries, (b-f) isosurface of
 50 ppb and vertical cross-section through model domain



(e)

Figure K-3.3-1 (continued)

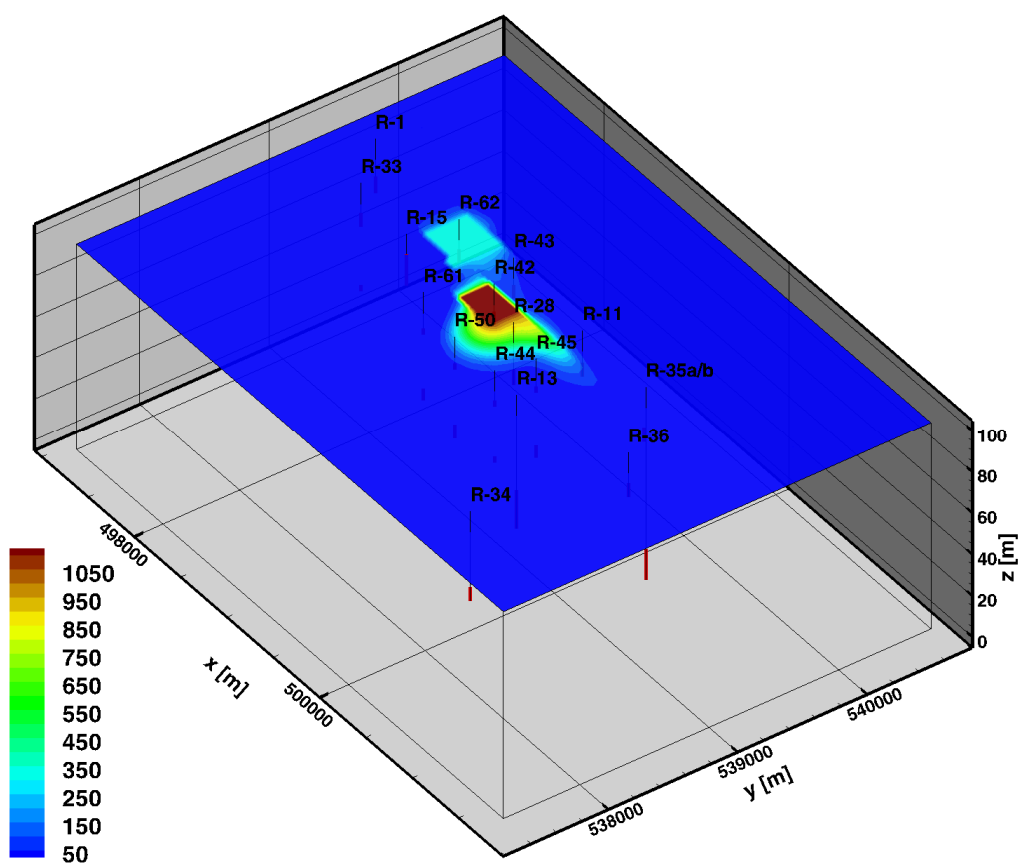
Numerical model prediction of 3-D contaminant distribution in 2012:
 (a) concentrations along model boundaries, (b-f) isosurface of
 50 ppb and vertical cross-section through model domain



(f)

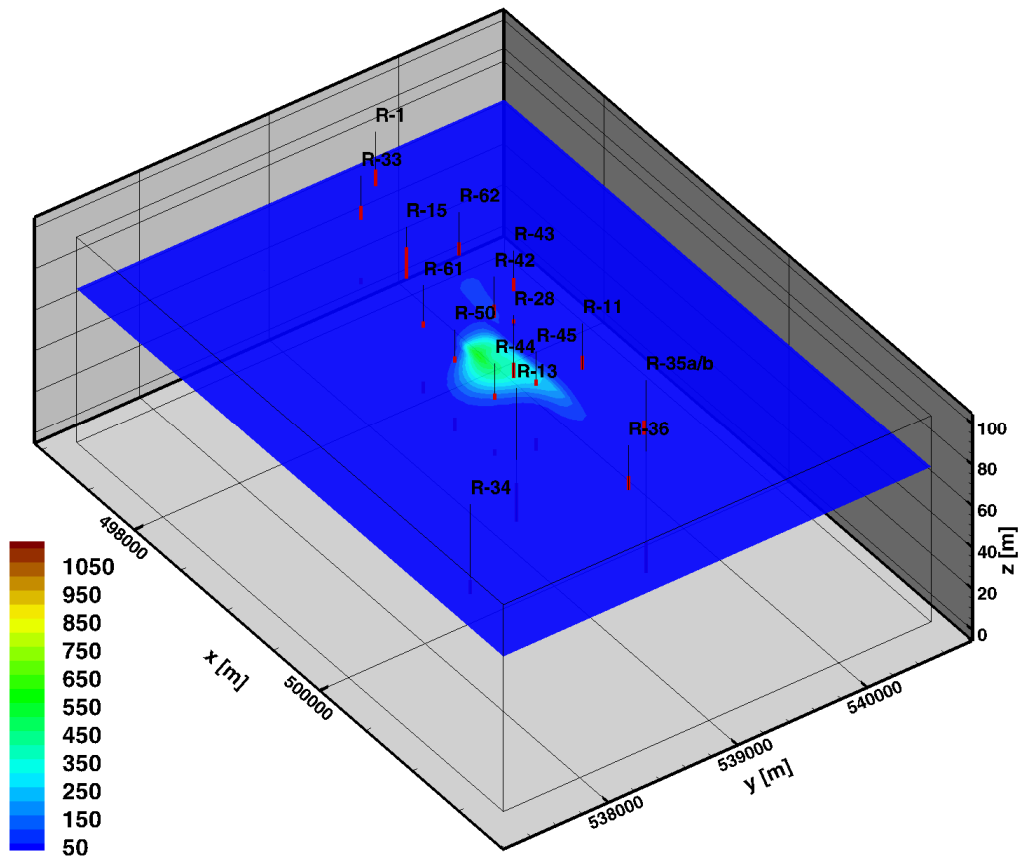
Figure K-3.3-1 (continued)

Numerical model prediction of 3-D contaminant distribution in 2012:
 (a) concentrations along model boundaries, (b-f) isosurface of
 50 ppb and vertical cross-section through model domain



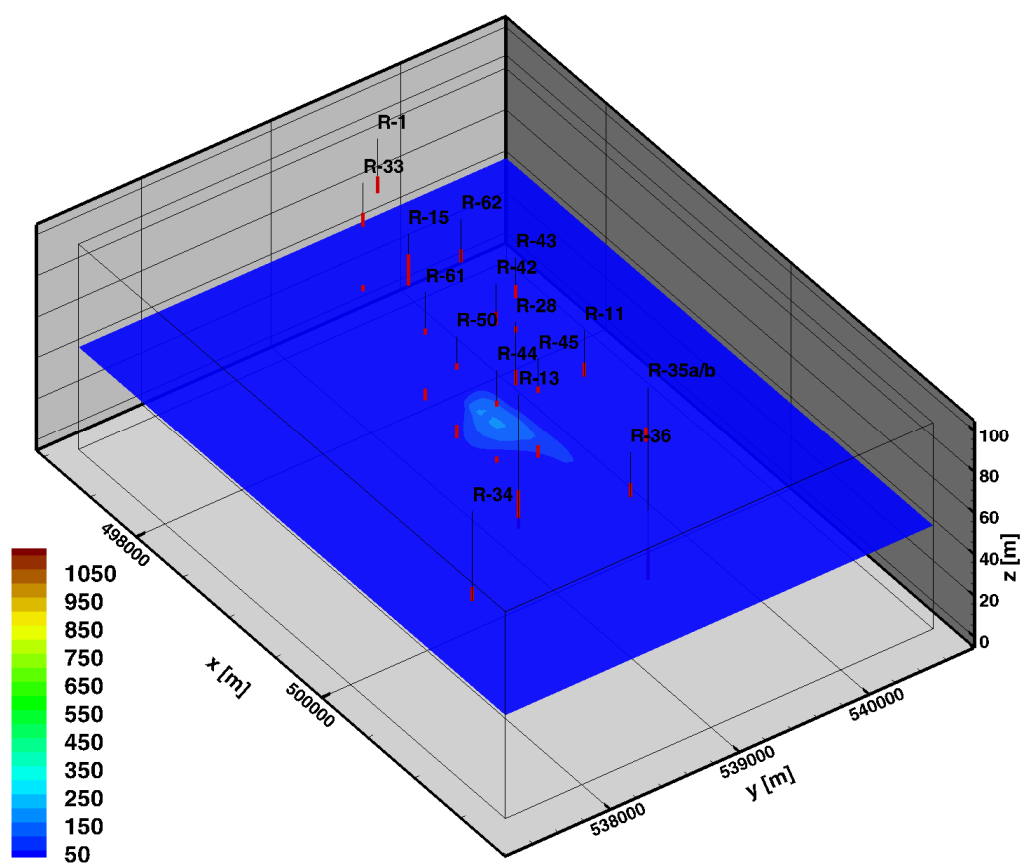
(a) $z=100$ m (at the water table)

Figure K-3.3-2 Numerical model prediction of 3-D contaminant distribution in 2012 concentrations along horizontal cross-section through model domain.



(b) $z = 75$ m (25 m below the water table)

Figure K-3.3-2 (continued) Numerical model prediction of 3-D contaminant distribution in 2012 concentrations along horizontal cross-section through model domain.



(c) z=50 m (50 m below the water table)

Figure K-3.3-2 (continued) Numerical model prediction of 3-D contaminant distribution in 2012 concentrations along horizontal cross-section through model domain.

Table K-3.3-1
Observed and Model-Predicted 2012 Chromium Concentrations

Well/Screen ID	2012 Chromium Concentrations (ppb)			
	Observed	Predicted	Acceptable Range	
			Min	Max
R-1	5	3.8	5	10
R-11	20	18.4	10	40
R-13	5	5.0	5	10
R-15	12	11.3	5	20
R-28	400	325.3	300	500
R-33#1	5	4.9	5	15
R-33#2	5	4.9	5	15
R-34	5	5.0	5	15
R-35b	5	5.5	5	15
R-35a	5	6.6	5	15
R-36	5	2.3	5	15
R-42	950	952.4	750	1250
R-43#1	38	41.1	28	58
R-43#2	5	22.1	5	15
R-44#1	14	7.2	5	34
R-44#2	5	5.7	0	15
R-45#1	20	13.5	10	40
R-45#2	10	7.1	5	20
R-50#1	100	57.2	70	130
R-50#2	7	16.5	5	15
R-61#1	18	5.0	5	38
R-61#2	5	5.0	5	15
R-62	200	196.5	150	250

Table K-3.3-2
Observed and Model Predicted Water Levels for the Period 2007-2012

Well/Screen	Water Level Transients (m)			
	Year	Observed	Predicted	Discrepancy
R-1	2007	1791.84	1793.10	-1.26
R-11	2007	1779.60	1779.34	0.26
R-13	2007	1779.03	1779.06	-0.03
R-15	2007	1783.37	1783.44	-0.07
R-28	2007	1779.54	1779.57	-0.03
R-33#1	2007	1789.73	1789.76	-0.03
R-33#2	2007	1780.49	1789.76	-9.27
R-34	2007	1778.59	1778.56	0.03
R-35b	2007	1779.26	1779.04	0.22
R-35a	2007	1776.89	1779.05	-2.16
R-36	2007		1780.43	
R-42	2007		1779.83	
R-43#1	2007		1779.86	
R-43#2	2007		1779.86	
R-44#1	2007		1779.15	
R-44#2	2007		1779.15	
R-45#1	2007		1779.22	
R-45#2	2007		1779.22	
R-50#1	2007		1779.49	
R-50#2	2007		1779.49	
R-61#1	2007		1780.14	
R-61#2	2007		1780.14	
R-62	2007		1781.29	
R-1	2008	1791.79	1793.00	-1.21
R-11	2008	1779.41	1779.20	0.21
R-13	2008	1778.86	1778.92	-0.06
R-15	2008	1783.27	1783.31	-0.04
R-28	2008	1779.41	1779.43	-0.02
R-33#1	2008	1789.64	1789.65	-0.01
R-33#2	2008	1780.40	1789.65	-9.25
R-34	2008	1778.44	1778.42	0.02
R-35b	2008	1779.09	1778.90	0.19
R-35a	2008	1776.59	1778.91	-2.32
R-36	2008	1780.33	1780.28	0.05
R-42	2008		1779.69	
R-43#1	2008		1779.72	
R-43#2	2008		1779.72	

Table K-3.3-2 (continued)

Well/Screen	Water Level Transients (m)			
	Year	Observed	Predicted	Discrepancy
R-44#1	2008		1779.00	
R-44#2	2008		1779.00	
R-45#1	2008		1779.08	
R-45#2	2008		1779.08	
R-50#1	2008		1779.35	
R-50#2	2008		1779.35	
R-61#1	2008		1780.01	
R-61#2	2008		1780.00	
R-62	2008		1781.15	
R-1	2009	1791.74	1792.89	-1.15
R-11	2009	1779.23	1779.06	0.17
R-13	2009	1778.68	1778.78	-0.10
R-15	2009	1783.17	1783.18	-0.01
R-28	2009	1779.29	1779.29	0.00
R-33#1	2009	1789.54	1789.53	0.01
R-33#2	2009	1780.31	1789.53	-9.22
R-34	2009	1778.28	1778.28	0.00
R-35b	2009	1778.92	1778.76	0.16
R-35a	2009	1776.28	1778.77	-2.49
R-36	2009	1780.16	1780.14	0.02
R-42	2009	1779.74	1779.56	0.18
R-43#1	2009	1779.61	1779.58	0.03
R-43#2	2009	1779.30	1779.58	-0.28
R-44#1	2009	1778.92	1778.87	0.05
R-44#2	2009	1778.84	1778.87	-0.03
R-45#1	2009	1778.87	1778.94	-0.07
R-45#2	2009	1778.86	1778.94	-0.08
R-50#1	2009		1779.22	
R-50#2	2009		1779.22	
R-61#1	2009		1779.87	
R-61#2	2009		1779.87	
R-62	2009		1781.02	
R-1	2010	1791.69	1792.78	-1.09
R-11	2010	1779.05	1778.93	0.12
R-13	2010	1778.51	1778.65	-0.14
R-15	2010	1783.07	1783.06	0.01
R-28	2010	1779.16	1779.16	0.00

Table K-3.3-2 (continued)

Well/Screen	Water Level Transients (m)			
	Year	Observed	Predicted	Discrepancy
R-33#1	2010	1789.45	1789.42	0.03
R-33#2	2010	1780.22	1789.42	-9.20
R-34	2010	1778.12	1778.15	-0.03
R-35b	2010	1778.76	1778.64	0.12
R-35a	2010	1775.98	1778.64	-2.66
R-36	2010	1780.00	1780.01	-0.01
R-42	2010	1779.62	1779.43	0.19
R-43#1	2010	1779.50	1779.45	0.05
R-43#2	2010	1779.20	1779.45	-0.25
R-44#1	2010	1778.80	1778.74	0.06
R-44#2	2010	1778.72	1778.74	-0.02
R-45#1	2010	1778.72	1778.81	-0.09
R-45#2	2010	1778.71	1778.81	-0.10
R-50#1	2010	1779.12	1779.09	0.03
R-50#2	2010	1779.09	1779.09	0.00
R-61#1	2010		1779.74	
R-61#2	2010		1779.74	
R-62	2010		1780.89	
R-1	2011	1791.63	1792.68	-1.05
R-11	2011	1778.87	1778.80	0.07
R-13	2011	1778.34	1778.52	-0.18
R-15	2011	1782.97	1782.94	0.03
R-28	2011	1779.03	1779.03	0.00
R-33#1	2011	1789.36	1789.31	0.05
R-33#2	2011	1780.12	1789.30	-9.18
R-34	2011	1777.96	1778.01	-0.05
R-35b	2011	1778.59	1778.50	0.09
R-35a	2011	1775.67	1778.51	-2.84
R-36	2011	1779.83	1779.88	-0.05
R-42	2011	1779.51	1779.30	0.21
R-43#1	2011	1779.40	1779.32	0.08
R-43#2	2011	1779.10	1779.32	-0.22
R-44#1	2011	1778.68	1778.60	0.08
R-44#2	2011	1778.60	1778.60	0.00
R-45#1	2011	1778.57	1778.68	-0.11
R-45#2	2011	1778.56	1778.68	-0.12
R-50#1	2011	1779.04	1778.95	0.09
R-50#2	2011	1779.00	1778.95	0.05

Table K-3.3-2 (continued)

Well/Screen	Water Level Transients (m)			
	Year	Observed	Predicted	Discrepancy
R-61#1	2011	1779.64	1779.61	0.03
R-61#2	2011	1779.61	1779.61	0.00
R-62	2011	1780.68	1780.76	-0.08
R-1	2012	1791.58	1792.57	-0.99
R-11	2012	1778.69	1778.67	0.02
R-13	2012	1778.17	1778.39	-0.22
R-15	2012	1782.87	1782.81	0.06
R-28	2012	1778.90	1778.90	0.00
R-33#1	2012	1789.27	1789.19	0.08
R-33#2	2012	1780.03	1789.19	-9.16
R-34	2012	1777.80	1777.88	-0.08
R-35b	2012	1778.42	1778.37	0.05
R-35a	2012	1775.37	1778.38	-3.01
R-36	2012	1779.67	1779.75	-0.08
R-42	2012	1779.39	1779.17	0.22
R-43#1	2012	1779.30	1779.19	0.11
R-43#2	2012	1779.00	1779.19	-0.19
R-44#1	2012	1778.56	1778.47	0.09
R-44#2	2012	1778.48	1778.47	0.01
R-45#1	2012	1778.42	1778.55	-0.13
R-45#2	2012	1778.40	1778.55	-0.15
R-50#1	2012	1778.97	1778.82	0.15
R-50#2	2012	1778.91	1778.82	0.09
R-61#1	2012	1779.54	1779.48	0.06
R-61#2	2012	1779.51	1779.48	0.03
R-62	2012	1780.60	1780.64	-0.04

Note: Blank cells indicate no data are available.

Table K-3.3-3
Estimated Model Parameters

Model Parameter	Value
X coordinate of the zone along western boundary (top) [m]	499486.8
X coordinate of the zone along western boundary (bottom) [m]	498039.0
X coordinate of the zone along eastern boundary (top) [m]	501352.0
X coordinate of the zone along eastern boundary (bottom) [m]	501361.3
Specified head along western boundary [m]	1798.6
Annual decline of specified head along western boundary [m]	0.098
Specified head along eastern boundary [m]	1772.1
Annual decline of specified head along eastern boundary [m]	0.147
Hydraulic conductivity along western boundary [m/d]	17.5
Hydraulic conductivity along eastern boundary [m/d]	10.4
Recharge flux near R-36 [m ³ /s]	1.1352
Recharge flux near R-15 [m ³ /s]	0.3583
Recharge flux near R-42 [m ³ /s]	0.3414
Recharge flux near R-62 [m ³ /s]	0.0726
Discharge flux along the bottom boundary near R-1 [m ³ /s]	0.1050
Discharge flux along the bottom boundary near R-35a [m ³ /s]	0.0044
Discharge flux along bottom boundary [m ³ /s]	0.0718
Effective aquifer hydraulic conductivity [m/d]	45.6
Specific storage	0.0022
Effective transport porosity	0.17
Contaminant concentration of infiltration flux near R-42 [ppb]	1165.9
X coordinate of contaminant arrival zone near R-42 [m]	499162.0
Y coordinate of contaminant arrival zone near R-42 [m]	539089.0
X dimension of contaminant arrival zone near R-42 [m]	182.0
Y dimension of contaminant arrival zone near R-42 [m]	127.0
Contaminant concentration of infiltration flux near R-62 [ppb]	321.7
X coordinate of contaminant arrival zone near R-62 [m]	498516.0
Y coordinate of contaminant arrival zone near R-62 [m]	539322.0
X dimension of contaminant arrival zone near R-62 [m]	200.0
Y dimension of contaminant arrival zone near R-62 [m]	200.0
Contaminant concentration of infiltration flux near R-15 [ppb]	12.0
X coordinate of contaminant arrival zone near R-15 [m]	498442.0
Y coordinate of contaminant arrival zone near R-15 [m]	538969.0
X dimension of contaminant arrival zone near R-15 [m]	200.0
Y dimension of contaminant arrival zone near R-15 [m]	200.0

Appendix L

*Hydrogeologic Analysis of the Aquifer Pumping Test
at Regional Well R-28*

L-1.0 INTRODUCTION

This appendix describes the analysis of the regional aquifer pumping test conducted during February and March 2012 at R-28, a regional aquifer well located in Mortandad Canyon. The test on R-28 was conducted to characterize the saturated materials, with a particular emphasis on determining large-scale hydraulic properties of the aquifer in the area of chromium plume in the regional aquifer.

Previous testing of R-28 had been performed in February and March 2004, with pumping periods not exceeding 24 h. Given the short duration of the pumping, pumping drawdowns were not observed in any of the regional (observation) wells near the pumping well. Various technical problems occurred during the 2004 pumping testing that caused some problems with the interpretation of the test data (Kleinfelder 2005, 094042). The new testing effort conducted in 2012 included a brief step-drawdown test and an extended-duration test of 10 d pumping followed by 10 d of recovery. During the testing, water levels were recorded in the pumped well (R-28) and 16 observation wells (R-1, R-11, R-13, R-15, R-33, R-34, R-35a, R-35b, R-36, R-42, R-43, R-44, R-45, R-50, R-61, and R-62). Six of the observation wells were dual-screened wells, bringing the number of monitored observation points to 22. Table L-1.0-1 lists the observation wells and screened intervals monitored during the R-28 tests, along with their approximate distances from R-28. This appendix presents hydrogeological analysis of the 2012 pumping test (section L-2.0) and provides analytical and model evaluations related to the R-28 pumping capture zone (section L-3.0).

L-2.0 ANALYSIS OF AQUIFER PUMPING TEST DATA

L-2.1 Conceptual Hydrogeology

R-28 lies within saturated sands and gravels in the upper portion of the regional aquifer. The well screen is 23.8 ft long, extending from 934.3 to 958.1 ft below ground surface (bgs). The static water level measured on February 14, 2012, before the test was 892.04 ft bgs, a little more than 42 ft above the top of the screen. The brass cap elevation at the well was surveyed at 6728.61 ft above mean sea level (amsl), making the water level elevation 5836.57 ft amsl (Koch and Schmeer 2011, 201566). The proximity of the water table to the top of the well screen suggests the likelihood of unconfined (phreatic) conditions at R-28.

L-2.2 R-28 Testing

R-28 was tested from February 14 to March 6, 2012. On February 14, the pump was installed and a brief 70-min-long step-drawdown test was performed to verify well capacity. Following recovery overnight, the extended-duration test was begun at 9:00 a.m. on February 15 at a discharge rate of 27.7 gallons per minute (gpm). While pumping proceeded, water-level data were downloaded periodically from several observation wells to gauge the response to pumping. Based on the observed response, a final decision was made to extend the pumping test to 10 full days. Pumping continued for 14,400 min until 9:00 a.m. on February 25 when the pump was shut off and recovery began. Recovery measurements were recorded for slightly more than 10 d (14,667 min) until 1:27 p.m. on March 6 when the transducer data were downloaded. The eight listed wells within one-half mile (less than a kilometer) of R-28 (Table L-1.0-1) showed a drawdown response to pumping ranging from a few hundredths to a little more than a tenth of a foot (Table L-2.2-1), while the eight wells more than a half mile away showed no discernible response. Water-level data from the eight nonresponding wells are not included in this appendix.

Figure L-2.2-1 shows a plot of the R-28 pumping rates measured during the 10-d test. The rates ranged from about 27.4 to 28.0 gpm, averaging 27.7 gpm overall. The very low discharge rates shown at 2-d intervals on the plot correspond to brief shutdown periods for refueling the generator. It typically took 4 or 5 min to refuel the generator each time, long enough to affect the discharge rate for the period encompassing the refueling event but not enough to compromise the collected pumping test data. Analytical techniques applied to analyze the pumping test data are capable of accounting for the observed pumping rate variability (Figure L-2.2-1); however, model analyses demonstrated that the brief shutdowns have no impact on the interpretation of the pumping test data.

L-2.3 Pumping Well Data

Figure L-2.3-1 shows a semilog-scale plot of the time-drawdown data from the 10-d pumping test (the data scatter is associated with transducer interference caused by positioning the transducer just above the pump). The data from the first several hours of pumping showed a flat slope, suggesting delayed yield effects resulting from recharge from the unsaturated zone above the regional water table, followed by a slight steepening of the curve at later time. To reduce the noise in the plotted data, a rolling average (using 2.5–3 min windows representing 11 consequent pressure measurements) was performed (Figure L-2.3-2). The data suggested delayed yield persisting for several hours, followed by a slope from which a transmissivity of 40,600 gallons per day (gpd)/ft is computed using Theis curve analysis (Theis 1934-1935, 098241).

The recovery data from the R-28 extended test are shown on Figure L-2.3-3. The data collected at times after the casing storage times (t_C and $t_C/2$) are not representative because of borehole storage effects (t_C and $t_C/2$ are shown on the plot for reference). The data trace shows typical delayed yield response with steep initial and final slopes and a flat intermediate slope. The transmissivity computed from the early slope is 45,700 gpd/ft while the late data suggests a large-scale transmissivity value of 40,500 gpd/ft. The early data is more representative for the aquifer properties near the pumped screen; the late time is more representative of the aquifer properties in a zone impacted by the groundwater pumping. This latter value likely provides the best estimate of the overall large-scale transmissivity of the hydraulically contiguous aquifer in which R-28 is completed. This value is also consistent with the transmissivity computed from the pumping period (Figure L-2.3-2).

In conclusion, the large-scale aquifer transmissivity during the R-28 pumping is estimated to be 40,500 gpd/ft (5410 ft²/d or 503 m²/d). The aquifer area representative for this effective estimate of transmissivity encompasses a three-dimensional region around the well with unknown shape. If it is assumed that the effective aquifer thickness during the R-28 pumping test was about 65 ft (~20 m), the aquifer hydraulic conductivity is 40 ft/d (~25 m/d). In this case, it is assumed that the pumping test impacted a portion of the regional aquifer with an effective thickness of 20 m; this estimate is uncertain, and it is based on a general assessment of the regional aquifer properties suggesting that the portion of the regional aquifer is under phreatic conditions with thickness of about ~100 ft (33 m). It is important to note that the effective thickness of the aquifer during pumping is also impacted by aquifer vertical anisotropy: the higher the vertical anisotropy, the lower the effective aquifer thickness.

L-2.4 Observation Well Data

During the R-28 pumping test, water levels were monitored in 16 wells (R-1, R-11, R-13, R-15, R-33, R-34, R-35a, R-35b, R-36, R-42, R-43, R-44, R-45, R-50, R-61, and R-62), including 22 separate screened intervals, listed in Table L-1.0-1.

Inspection of the observation well hydrographs (e.g., Figures L-2.4-1 through L-2.4-13) shows water-level fluctuations caused by variations in barometric pressure. Because the barometric pressure fluctuations in the hydrographs were substantial, it was necessary to correct the water level data by removing the barometric effect. Each of the hydrographs in Figures L-2.4-1 through L-2.4-13 was corrected for barometric pressure and tidal effects using the BETCO software. BETCO (Barometric and Earth Tide Correction; <http://www.hydrology.uga.edu/rasmussen/BETCO/BETCO.html>) provides a mathematically complex correction algorithm that uses regression deconvolution (Toll and Rasmussen 2007, 104799) to modify the data by accounting for current and antecedent barometric pressure effects. The BETCO-corrected data are shown on each of the figures along with the original data. For each well, it was essentially impossible to detect the drawdown and recovery effect of the R-28 pumping test in the original hydrograph because of the barometric-induced perturbations, but after applying the BETCO correction, the water level response to pumping R-28 can be characterized. Note, however, even the corrected hydrographs still showed substantial effects associated with barometric pressure changes. The BETCO software did not completely eliminate the barometric pressure effects from the corrected hydrographs. The analysis is complicated because barometric pressure effects propagate through the vadose zone (from the ground surface to the regional aquifer) as multiple signals with different travel time and magnitude, making the analysis physically and computationally very challenging.

The estimated total drawdown observed at each of the observation points after 10 d of pumping at R-28 is presented in Table L-2.4-1. The estimated drawdown in the responding observation wells ranged from 0.04 ft to 0.15 ft. Each of the monitoring points less than half a mile from R-28 showed a drawdown response while each of the wells farther away showed no response. The well screens showing a measurable drawdown response included R-11, R-13, R-42, R-43 screens 1 and 2, R-44 screens 1 and 2, R-45 screens 1 and 2, R-50 screens 1 and 2, and R-61 screens 1 and 2. Hydrographs for each of these monitored zones are shown on Figures L-2.4-1 through L-2.4-13, respectively. Since R-28 screen is located relatively deep (~42 ft) below the regional water table, it is not surprising that larger drawdowns are observed in the deep screens of all the nearby monitoring wells with more than one screen (Table L-2.4-1). This is because the R-28 screen is at elevation similar with the elevation of the deep rather the shallow well screens. This is also consistent with a general three-dimensional shape of the zone influence expected in the pumped aquifer.

Note that the hydrographs for R-61 screens 1 and 2 (Figures L-2.4-12 and L-2.4-13, respectively) showed a noisy signal representing apparent data scatter. An additional inspection of the hydrographs showed that, the transducer output toggled every reading or two (15-min intervals) between head values about 0.04 ft apart. Note also that the data from R-45 screen 2 (Figure L-2.4-9) did not appear to respond appropriately, suggesting the possibility of a clogged gauge tube or defective pressure transducer.

The estimated total drawdowns observed at each of the observation points after 10 d of pumping at R-28 (Table L-2.4-1) are plotted on the distance-drawdown graph shown on Figure L-2.4-14. Theis curve matching is used to fit the Theis type curve to the observation well data by fixing the transmissivity at a value of 40,500 gpd/ft (the value obtained from the R-28 recovery analysis) and adjusting the storage coefficient to achieve a match. A reasonable fit is achieved for a storage coefficient value of 0.02. This magnitude suggests unconfined conditions and is consistent with delayed yield effects observed in the pumped well drawdown and recovery data. The reasonable correspondence of the observed data to the Theis type curve provided a measure of corroboration for the transmissivity value obtained from the R-28 recovery data. Thus, the analysis shows a general consistency between the data collected at the pumping and observation wells. This finding may suggest that the portion of the aquifer that was impacted by the R-28 pumping test appears to be relatively uniform without pronounced aquifer anisotropy because the observation-well drawdowns are relatively well correlated with the distance between the pumping and respective observation wells (Figure L-2.4-14). However, because of the very small magnitude of the

observation-well drawdowns, it is difficult to further analyze aquifer heterogeneity and anisotropy. It is very plausible that the pumping test results are predominantly impacted by a large-scale aquifer zone around R-28 that has higher permeability than the rest of the aquifer; as a result, the high permeability zone masks the potential impact of aquifer heterogeneity and anisotropy outside this zone.

Additional comparisons between the data measured in the observation wells (R-11, R-44 screen 1 and R-50 screen 1; the comparisons are not presented here) and the aquifer properties estimated based on the data collected at R-28 demonstrated consistency between the measured drawdown data in the observation wells and estimated aquifer properties based on the observed drawdowns in the pumping well. This is expected because the drawdown curves at the observation wells are not representative of the local aquifer properties near the observation wells but rather of the large scale aquifer properties impacting the groundwater flow during the R-28 pumping test. The analysis of the drawdown data collected at the observation wells also confirmed the delayed yield effects because of recharge from the unsaturated zone above the regional water table.

Hydraulic conductivity values from the R-28 10-d test were compared with those obtained from testing conducted in the same well in 2004 as well as values obtained from pumping tests on several of the observation wells conducted when the wells were installed.

Assuming an aquifer thickness of 23.8 ft (the screen length) and ignoring vertical anisotropy and well partial penetration, the 2004 pumping test analysis (Kleinfelder 2005, 094042) estimated hydraulic conductivity to range between 140 and 160 ft/d; the aquifer transmissivity was about ~26,000 gpd/ft (3500 ft²/d; 320 m²/d). These aquifer permeability estimates are based on the early recovery data (at the beginning of the recovery period) characteristic for aquifer properties in close vicinity of the pumped screen. Additional calculations independent of the drawdown transients and based on the well specific capacity produced a lower limit for conductivity estimates of 73 ft/d (specific capacity calculations can only predict the conductivity is higher than 73 ft/d, but the exact value cannot be computed).

Additional analysis of the water-level transients taking into account (1) the entire recovery record (not only the early data), (2) the aquifer vertical anisotropy, and (3) the partial penetration of the pumping well within aquifer with thickness 400 ft (Kleinfelder 2005, 094042, Figure E-15) produced the following estimates for the aquifer parameters: transmissivity: 48,200 ft²/day; hydraulic conductivity: 121 ft/d; and vertical anisotropy: 0.001. Because these estimates account for the entire recovery record, they are characteristic the aquifer permeability not near the pumped screen but for the zone impacted by the pumping. These estimates of the aquifer properties are more consistent with the analysis of the 2012 R-28 pumping tests rather than with the local permeability estimates based on the early recovery data (above).

Local-scale aquifer hydraulic conductivity estimates were obtained over the years from pumping tests conducted in the observation wells near R-28. Table L-2.4-2 summarizes the results of those tests. Only R-11 showed hydraulic conductivity values similar to those obtained from R-28 while the other wells tended to show somewhat lower values. Therefore, the aquifer is expected to be heterogeneous with local zones of high and low permeability; however, a zone near R-28 is characterized by relatively high permeability. This zone potentially extends to the northeast and includes R-11, which has similar aquifer properties.

In conclusion, the information from the 2012 R-28 pumping test as well as from all the previous short-term pumping test conducted in the study area demonstrates that the aquifer beneath Sandia and Mortandad Canyons is heterogeneous. The aquifer zone around R-28 appears to be more permeable than the rest of the aquifer. The drawdown responses at the pumping and observation wells during the long-term pumping tests at R-28 are primarily influenced by the high permeability zone near R-28.

L-3.0 CAPTURE ZONE ANALYSIS

The capture zone of R-28 during the 2012 pumping test defines the portion of the aquifer from which the groundwater pumped at the well is produced. In general, the capture zones of pumping wells have a three-dimensional shape characterized by three-dimensional structure and properties of the regional groundwater flow during the pumping test. As a result, the R-28 capture zone depends on various hydrogeologic factors:

- R-28 pumping rate and duration
- shape of the regional water table
- aquifer thickness
- spatial and temporal distribution in aquifer flow velocities controlled predominantly by heterogeneity and anisotropy in aquifer properties (permeability, storativity, etc.)
- spatial and temporal variability in aquifer recharge controlled predominantly by heterogeneity and anisotropy in vadose zone properties and spatial and temporal distribution of infiltration along the nearby canyons
- impact of water-supply pumping at the municipal wells near R-28 (O-4, PM-3, PM-5, PM-4, and PM-2); the water-supply pumping causes small changes in the water levels measured at R-28 and other nearby wells (Appendix G); as a result, it is expected water-supply pumping has negligible impact on the R-28 capture zone

All these factors are uncertain and not well defined for the R-28 site. Therefore, the capture zone estimates are uncertain as well.

It is important to emphasize aquifer recharge can be important for estimating the R-28 capture zone. In general, the aquifer recharge across the Pajarito Plateau is small (less than 1 mm/yr) and this recharge flux is not expected to influence substantially the shape of the capture zones of pumping wells (in this case, the regional water table can be approximately represented as a no flow boundary). However, higher recharge rates near R-28 from focused recharge along Sandia Canyon and, to a lesser extent, Mortandad Canyon can substantially influence the shape of the R-28 capture zone. To take into account the infiltration recharge, the water table needs to be represented as a material boundary with spatially (and potentially temporally) varying recharge flux representing the variability in aquifer recharge.

The most important information about the R-28 capture zone is obtained during the R-28 pumping test. The pumping test also provided information about the zone of pumping influence, which is almost circular with a radius of about 750–1000 m (less than a mile).

As discussed in section L-2.0, R-28 was pumped at a rate of about 27.7 gpm (~1.75 l/s; 151 m³/d) during the pumping test. The large-scale aquifer transmissivity in the vicinity of R-28 is estimated to be about 40,500 gpd/ft (~503 m²/d) based on the observed pumping response at R-28. This transmissivity estimate is consistent with the pumping drawdowns at the nearby monitoring wells.

The thickness of the aquifer impacted during the R-28 pumping test is not known. It is expected the aquifer thickness exceeds substantially the screen length (24 ft; 7.3 m). R-28 screen is located about 46 ft (14 m) below the top of the regional aquifer. If it is assumed that the effective aquifer thickness during the R-28 pumping test was about 65 ft (~20 m), the aquifer hydraulic conductivity is 80 ft/d (~25 m/d).

The aquifer appears to be unconfined (phreatic) with the regional water table elevation defined approximately by the hydraulic heads observed in the monitoring wells (the water table elevation is approximate because the R-28 well screen does not straddle the water table; most of the well screens near R-28 are located at depths below the water table).

Evaluation of the impact of the hydrogeologic uncertainties on the capture zone estimates can be performed using different theoretical and computational techniques. The capture zone of R-28 can be also evaluated using assumptions and simplification of the actual groundwater flow in the aquifer.

The drawdown curves observed during the R-28 pumping test show temporarily drawdown stabilization. This temporarily drawdown stabilization is expected to be caused by delayed yield from the vadose zone (phreatic aquifer effects) and leakage for the deeper hydrostratigraphic units (leaky aquifer). The temporarily drawdown stabilization may also be caused by lateral boundary effects.

L-3.1 Capture zone estimate based on the pumped volume

The capture zone can be estimated based on the volume of water pumped at R-28. This approach allows for better approximation of the capture zone size at early times when the pumping period is relatively short (less than 10–100 d).

In this case, the capture zone is assumed to have a cylindrical shape with a constant vertical height H (dependent on the well-screen length) and time-varying horizontal radius R . To account for the three-dimensional component of groundwater flow near the well screen, the vertical height H is assumed to be approximately 1.5 times the screen length ($H = 36$ ft or about 11 m). Here the vertical height H does not represent the aquifer thickness but rather the height of the capture zone, which is assumed to be dependent on the screen length. The cylinder radius can be computed using the following formula:

$$R = \sqrt{\frac{Q_p t}{\pi \phi_s H}}$$

where Q_p is the pumping rate, t is pumping duration, and ϕ_s is the water storage porosity. If the total water-filled porosity is assumed to be 0.3 (water filled porosity is larger than the effective transport porosity applied below) and the pumping rate is 27.7 gpm (151 m³/d), the size of the capture zone changes in time as presented in Table L-3.1-1. Based on the results in the table, the capture zone around R-28 after 10 d of pumping has a radius of 12 m (~36 ft) around the well.

This capture zone estimate ignores the ambient groundwater flow in the aquifer. The groundwater flow impacts the shape of the capture zone. The lateral extent of the capture zone cannot be expected to be circular around the well. The capture zone will be elongated upgradient and shortened downgradient from the well. As a result, more groundwater is expected to be captured from the upgradient aquifer zones.

L-3.2 Capture zone estimate based on ambient aquifer flow

The capture zone can be estimated based on the width of groundwater flow within which the ambient groundwater flux is equal to the pumping rate (Figure L-3.2-1). In this case, it is assumed the groundwater flow in an aquifer with lateral constant head or flux boundaries, the cone of water-level depression and the capture zone from pumping grows in the upgradient direction until it reaches a width within which the ambient groundwater flow rate is equal to the pumping rate (Figure L-3.2-1). This approach allows for better approximation of the capture zone size at late times when the pumping period is relatively long

allowing establishment of a quasi-steady-state flow regime near the pumping well. The width of the capture zone perpendicular to the groundwater flow direction becomes a constant in time once the flow reaches a quasi-steady state.

Assuming uniform confined groundwater flow conditions, the flow rate Q_A through a vertical section in the regional aquifer with a horizontal width W and thickness M can be computed as:

$$Q_A = IkMW = ITW$$

In this case, the vertical aquifer thickness M is uncertain; the information about the vertical thickness is implicitly characterized through transmissivity T . It is important to note that here M is the effective aquifer thickness representative of the zone contributing the groundwater flow toward the pumping well (R-28). The width W of a section that has a flow rate equivalent to the rate of pumping at R-28, Q_P , is computed as

$$W = \frac{Q_P}{IT}$$

The ambient groundwater flow in the aquifer near R-28 has a hydraulic gradient of about 0.001 (with an uncertainty range from 0.0005 to 0.002; see Appendix G for additional analyses on the hydraulic gradient near R-28). The capture zone width for different pumping rates is presented in Table L-3.2-1. For pumping rate of 27.7 gpm (~1.74 L/s; 151 m³/d), the width of R-28 capture zone upgradient from the well is about 300 m perpendicular to the groundwater flow direction. Note that the capture width adjacent to R-28 is exactly half of the upgradient width, or about 150 m.

The maximum length of capture in the downgradient direction, L_0 , from the pumping well (Figure L-3.2-1) can be expressed as follows:

$$L_0 = \frac{Q_P}{2\pi TI}$$

The maximum length of capture in the downgradient direction, L_0 , for different pumping rates is presented in Table L-3.2-2. For pumping rate of 27.7 gpm (~1.75 L/s; 151 m³/d), the length of R-28 capture zone in the downgradient direction, L_0 , is about 48 m.

Once the equilibrium between the pumping and ambient flow rates has been established, R-28 will be capturing the groundwater flowing toward R-28. The width of the groundwater flow captured by R-28 is defined by W (Figure L-3.2-1). The length L of the capture zone upgradient from R-28 (Figure L-3.2-1) depends on groundwater flow pore velocity and duration of pumping.

The ambient groundwater flow pore velocity v_A can be computed using the following equation:

$$v_A = \frac{IT}{M\phi_T} = \frac{Ik}{\phi_T}$$

where ϕ_T is the effective transport porosity. If it assumed the effective transport porosity, ϕ_T , is 0.2 (effective transport porosity is less than the total water-filled porosity applied above), the groundwater flow pore velocity v_A is equal to 0.063 m/d. Note that the groundwater flow velocity will be higher close to the pumping well; however, this can be ignored. As a result, the computed approximate length of the capture zone represents a lower bound estimate.

The approximate length L of the capture zone upgradient from R-28 can be computed as:

$$L = v_A t_P$$

The length of the upgradient capture zone will be 0.63 m, 6.3 m, and 63 m, if the well is pumped for 10, 100, and 1000 d, respectively. If the groundwater velocities are higher (e.g., the hydraulic gradients are higher), the capture zone length will be larger.

For the analyses presented above, it is instructive to estimate how fast the pumping-induced gradient changes reach equilibrium, which indicates when the equilibrium between the pumping and ambient flow rates will be established. This equilibrium is achieved when a quasi-steady-state (a steady hydraulic-gradient) flow regime is established in the vicinity of R-28. The quasi-steady-state commences when the following inequality is satisfied:

$$0.1 \leq \frac{r^2 S}{4Tt}$$

where S is storage coefficient, r is a radial distance away from the pumping well, and t is time since the pumping started. The storage coefficient S is assumed of to be equal to 0.02 based on analysis of R-28 pumping test data (Figure L-2.4-14); the value is characteristic of unconfined conditions. At a given distance r , a quasi-steady-state regime, is established for times greater than t_{QSS} :

$$t_{QSS} \geq 2.5 \frac{r^2 S}{T}$$

Table L-3.2-2 lists the values for t_{QSS} for different radial distances from the pumping well. For example, if $r = 150$ m (corresponding to the estimated capture zone width of 300 m), t_{QSS} will be equal to about 2 d. Note that significant pumping-induced gradient changes occur much earlier than t_{QSS} ; they just do not reach their maximum levels until after that time.

At a given time t since the pumping started, a quasi-steady-state regime is established within a zone with radius r_{QSS} :

$$r_{QSS} \leq \sqrt{\frac{0.4Tt}{S}}$$

Table L-3.2-3 defines the radius r_{QSS} within which quasi-steady-state regime is established after a different pumping durations at R-28. For example, if $t = 10$ d, r_{QSS} will be equal to about 300 m. Note that pumping-induced gradient changes occur far beyond r_{QSS} ; they just have not reached their maximum levels beyond this distance.

This analysis confirms that the quasi-steady-state regime will be established relatively fast once R-28 pumping commences. Because of the relatively short period pumping period during the R-28 pumping test (10 d), most of the pumped water originated from the aquifer in close vicinity to R-28.

L-3.3 Capture zone estimate based on numerical flow model

Application of a numerical model such as U.S. Geological Survey (USGS) ModFlow or Finite Element Heat and Mass Transfer code (FEHM) allows for more accurate estimation of the R-28 capture zone taking into account the actual aquifer geometry. A simple 3-D model is created using the USGS ModFlow

and ModPath codes as implemented in GMS Version 6.5 (Groundwater Modeling System; <http://www.aquaveo.com>) to represent the ambient flow through the aquifer and the potential focused recharge created by the infiltration along the canyons. This model is similar to the more complicated FEHM model discussed in Appendix K. The model accounts for the partial penetration of the pumping well, the aquifer vertical anisotropy and the three-dimensional structure of the groundwater flow.

The model is setup to represent the ambient groundwater flow in the study area. The model also accounts for aquifer recharge: distributed recharge (1 mm/yr) throughout model domain and a small area of focused recharge (1 m/yr) 1 km upgradient from R-28. The aquifer hydraulic conductivity is uniform (~25 m/d) with vertical anisotropy of 1/10.

Obtained modeling results are presented in Figure L-3.3-1. The predicted distribution of steady-state hydraulic heads is represented by colored contour lines (0.125-m contour intervals). The predicted capture zone during long-term pumping at R-28 is shown with a series of dark blue lines originating at the R-28 screen.

The results demonstrate the three-dimensional shape of the long-term capture zone, which is influenced by screen depth, vertical aquifer anisotropy, aquifer recharge and flow velocity.

L-3.4 Caveats in the Capture Zone Analyses

The partial penetration of the aquifer by the pumping well screen is not explicitly accounted for in the analytical analyses. The screen of the pumping well R-28 does not penetrate the entire thickness of the aquifer. The partial penetration causes three-dimensional groundwater flow effects that are difficult to evaluate using analytical techniques. If the partial penetration effects are slight, the resulting capture zone may penetrate the entire aquifer thickness. On the other hand, if the partial penetration effects are severe, the resulting capture zone will fail to extend through the full thickness of the aquifer. The partial penetration effects are expected to be exacerbated by the observed pronounced vertical heterogeneity (layering) of the Miocene sediments pumped by R-28.

The presented numerical techniques explicitly represent the partial penetration of the pumping screen. The numerical analyses are performed with numerical resolution and accuracy sufficient for representative estimation of the R-28 capture zone. In the model analyses, model domain (lateral boundaries and aquifer thickness) is defined to be sufficiently large so the model boundaries do not impact the groundwater flow near the pumping well.

The presented numerical and analytical analyses ignored the impact of heterogeneity assuming that the medium is uniform. It is reasonable to assume the medium is relatively uniform (especially laterally, along the flow directions) at the scale (within) the estimated capture zones. Still, medium heterogeneity is expected to affect the capture zone boundary, which in reality will have a more complicated shape than the schematic representation in Figure L-3.2-1. Numerical model analyses presented in Appendix K take into account the impact of aquifer heterogeneity on the groundwater flow near R-28.

L-4.0 REFERENCES

The following list includes all documents cited in this appendix. Parenthetical information following each reference provides the author(s), publication date, and ER ID. This information is also included in text citations. ER IDs are assigned by the Environmental Programs Directorate's Records Processing Facility (RPF) and are used to locate the document at the RPF and, where applicable, in the master reference set.

Copies of the master reference set are maintained at the New Mexico Environment Department Hazardous Waste Bureau and the Directorate. The set was developed to ensure that the administrative authority has all material needed to review this document, and it is updated with every document submitted to the administrative authority. Documents previously submitted to the administrative authority are not included.

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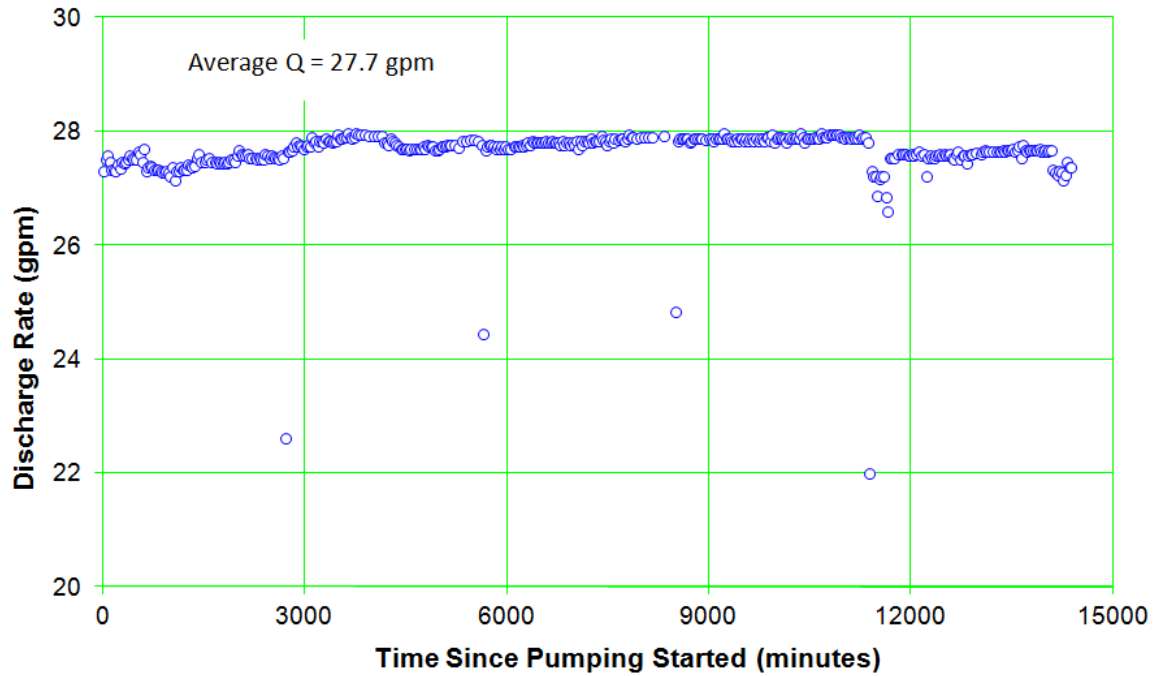


Figure L-2.2-1 Measured pumping rate during R-28 pumping test

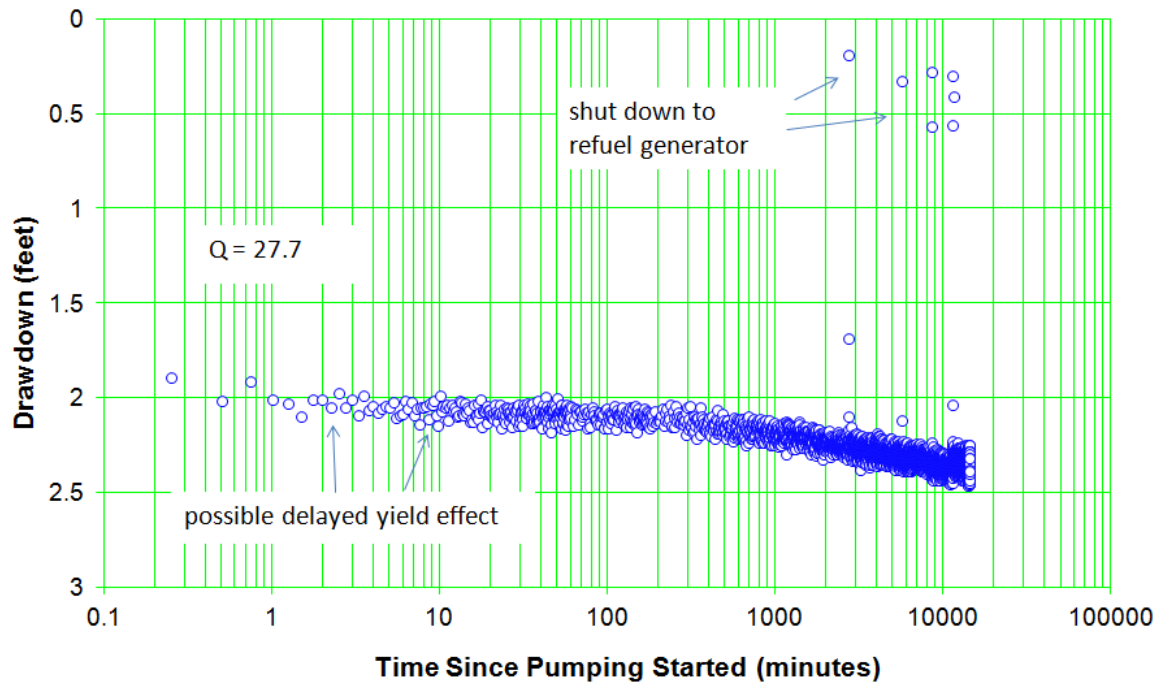


Figure L-2.3-1 Measured drawdown at well R-28 during the pumping test

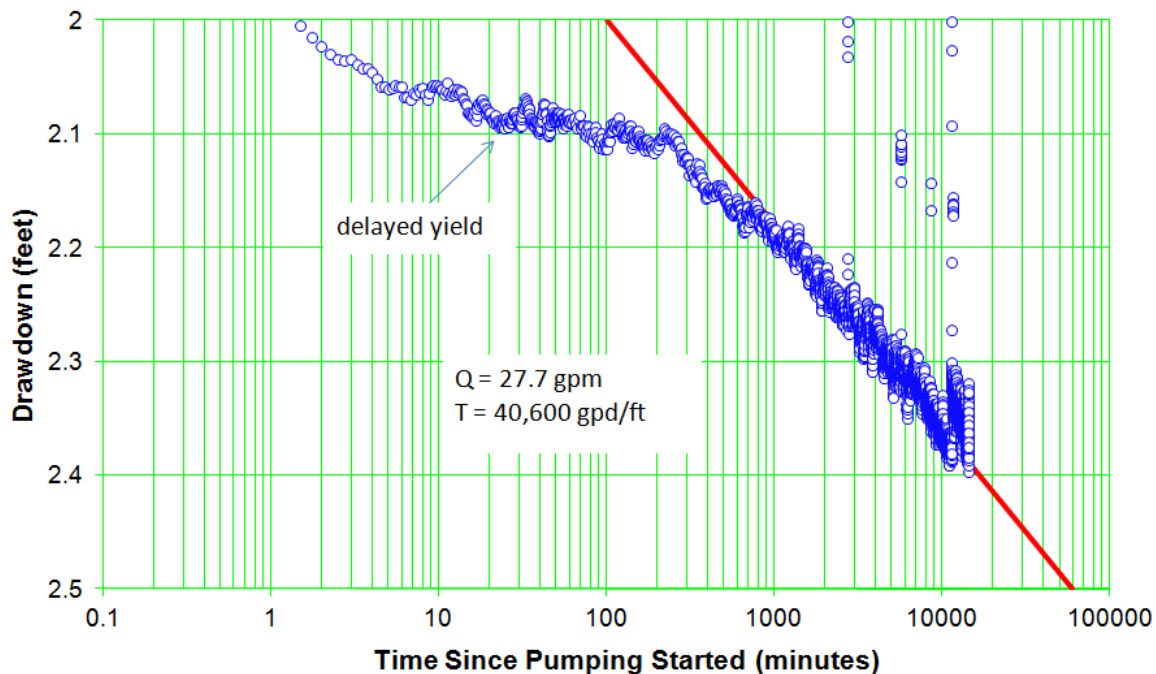


Figure L-2.3-2 Rolling averaged drawdown at R-28 during the pumping test

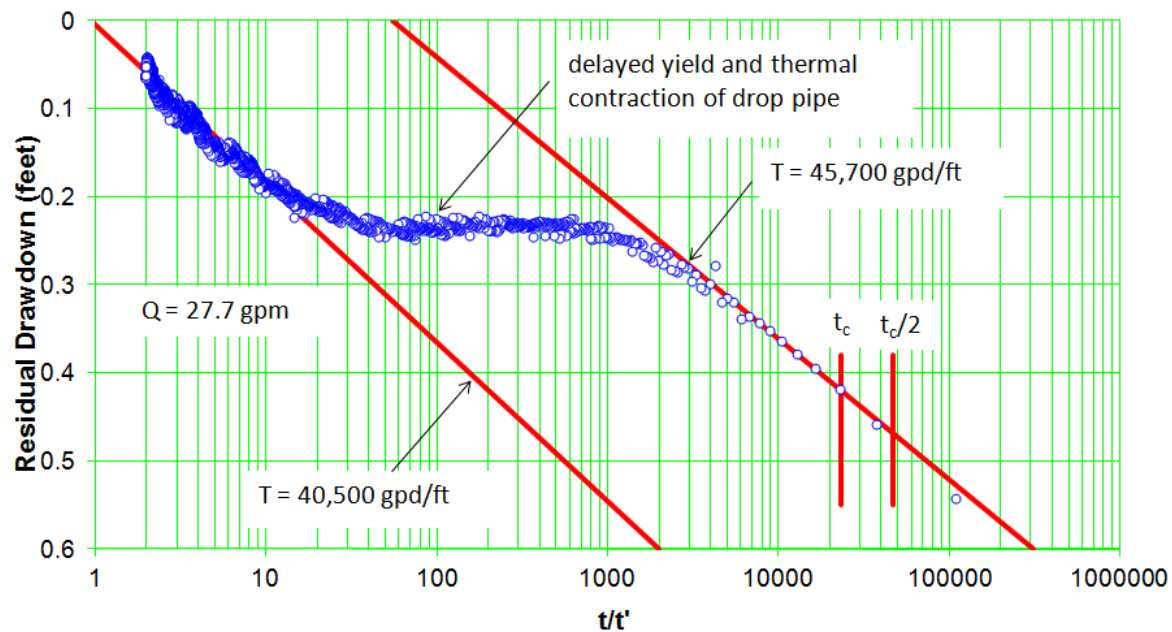


Figure L-2.3-3 Drawdown recovery at R-28 after the pumping is terminated

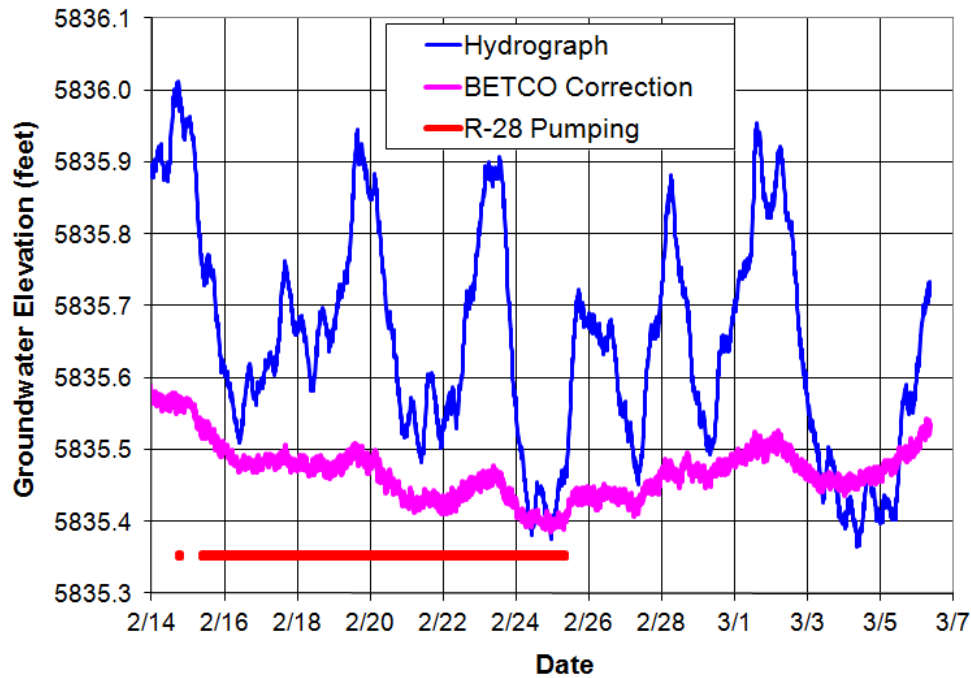


Figure L-2.4-1 Well R-11 hydrograph during the R-28 pumping test

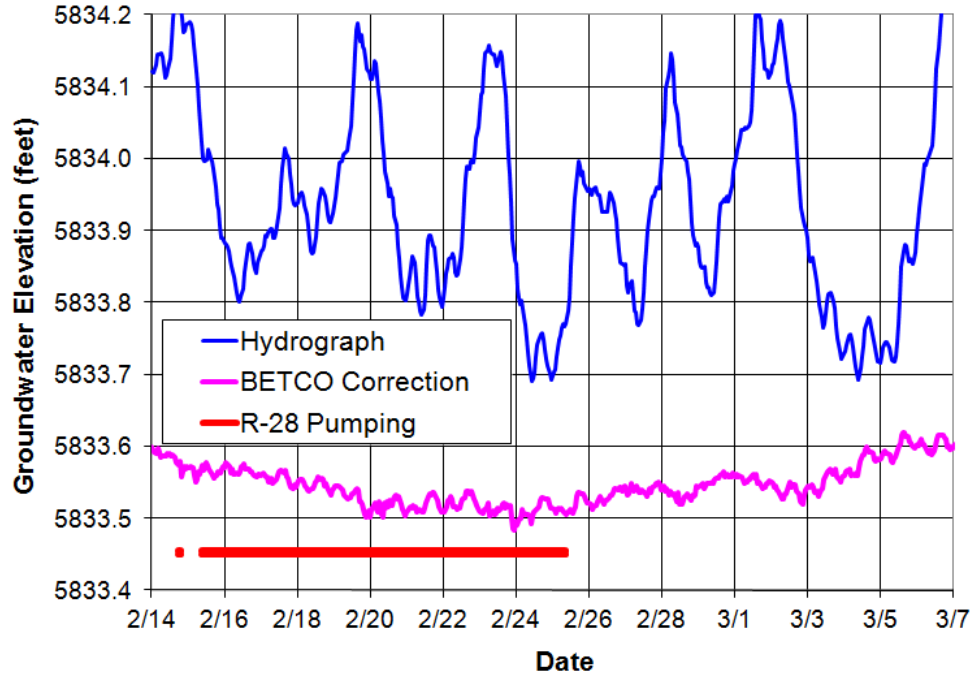


Figure L-2.4-2 Well R-13 hydrograph during the R-28 pumping test

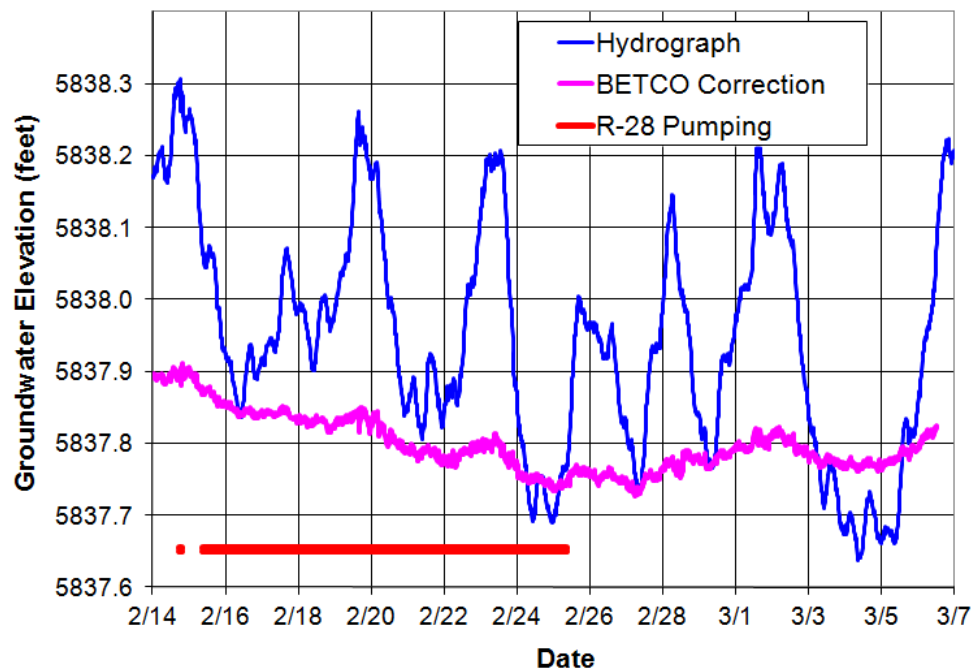


Figure L-2.4-3 Well R-42 hydrograph during the R-28 pumping test

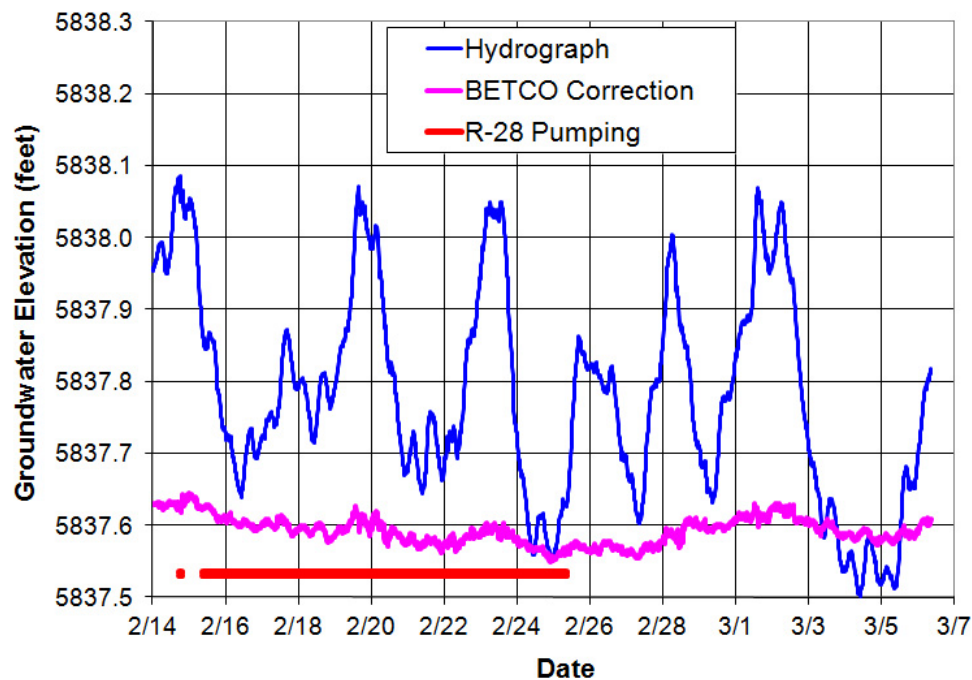


Figure L-2.4-4 Well R-43 screen 1 hydrograph during the R-28 pumping test

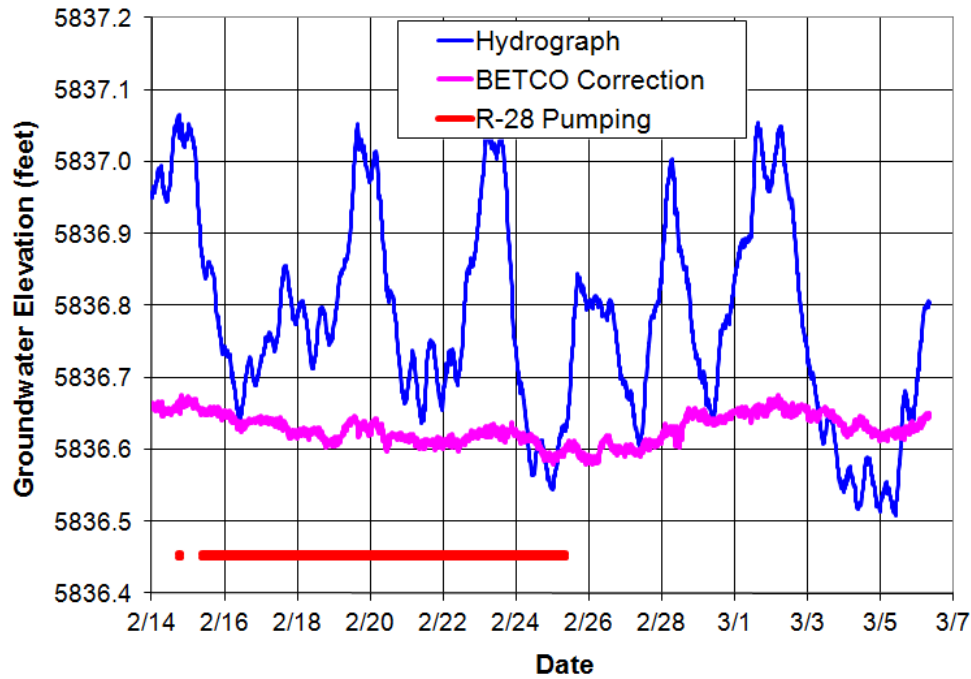


Figure L-2.4-5 Well R-43 screen 2 hydrograph during the R-28 pumping test

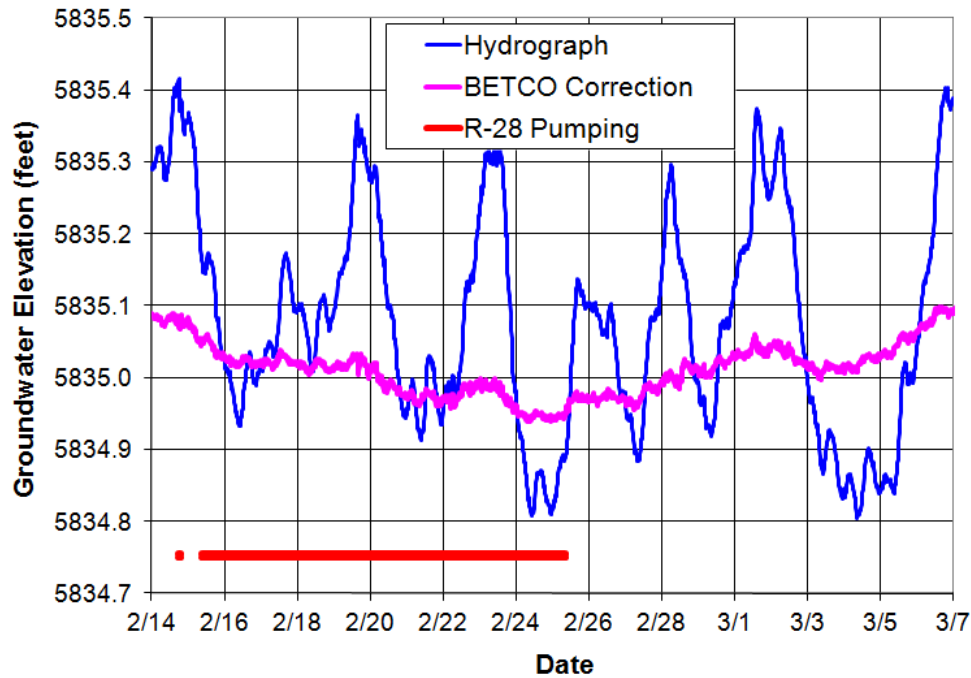


Figure L-2.4-6 Well R-44 screen 1 hydrograph during the R-28 pumping test

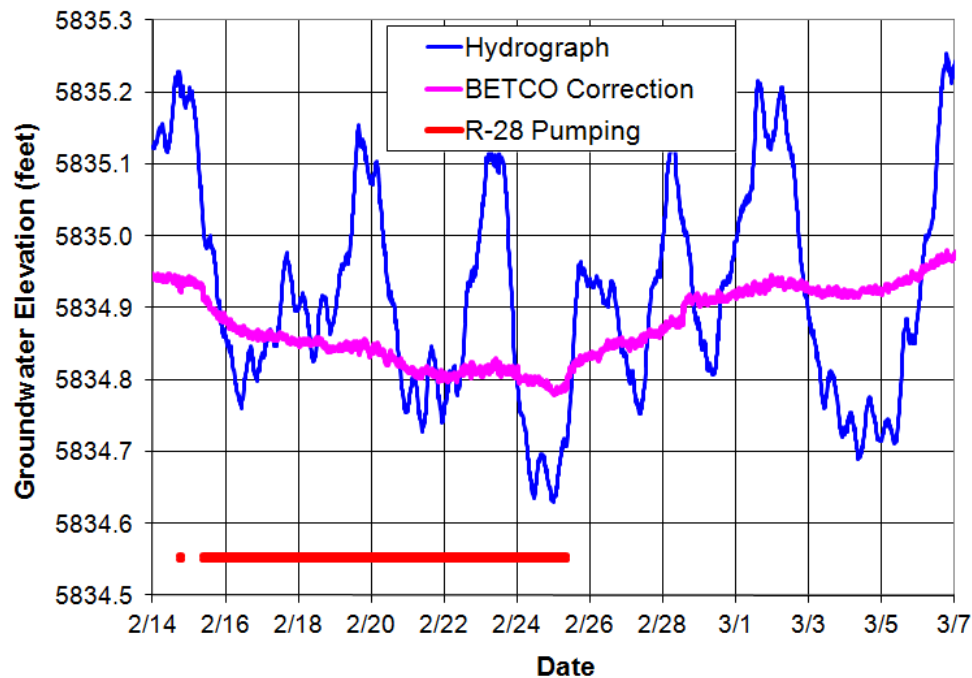


Figure L-2.4-7 Well R-44 screen 2 hydrograph during the R-28 pumping test

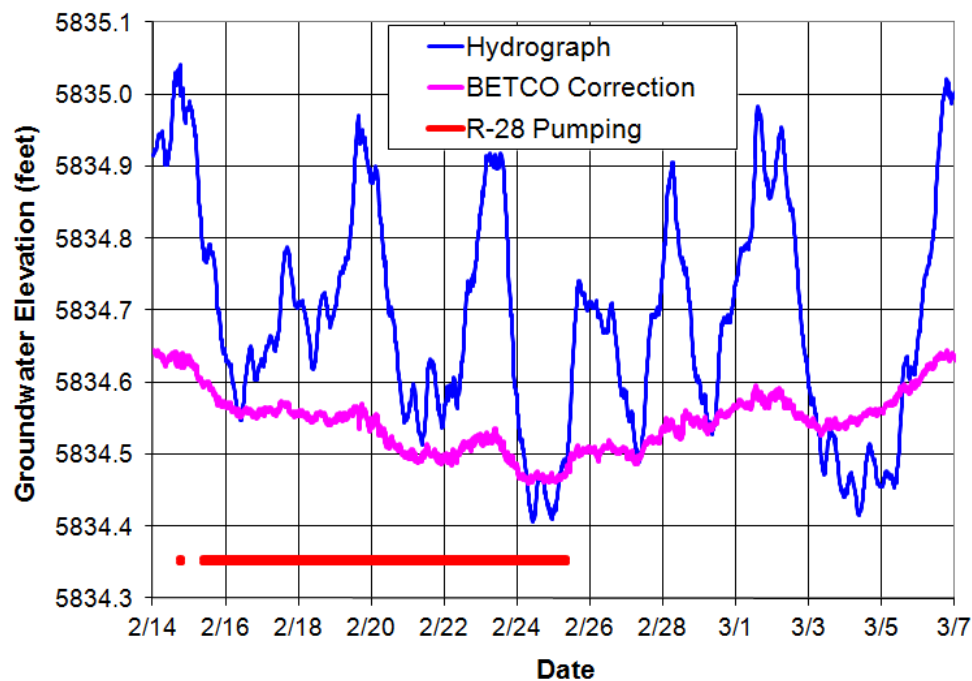


Figure L-2.4-8 Well R-45 screen 1 hydrograph during the R-28 pumping test

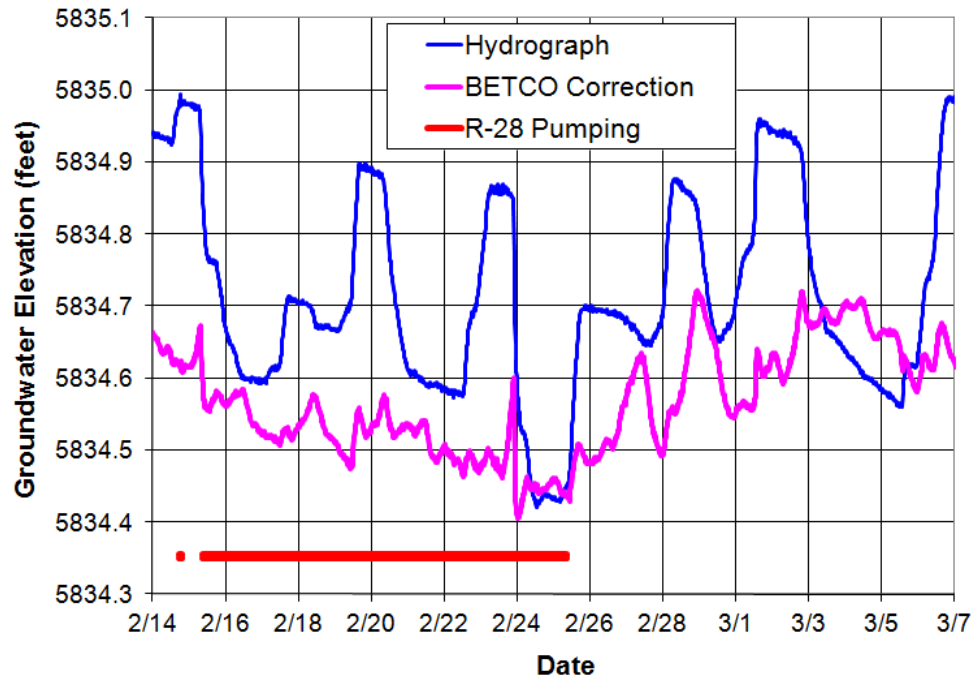


Figure L-2.4-9 Well R-45 screen 2 hydrograph during the R-28 pumping test

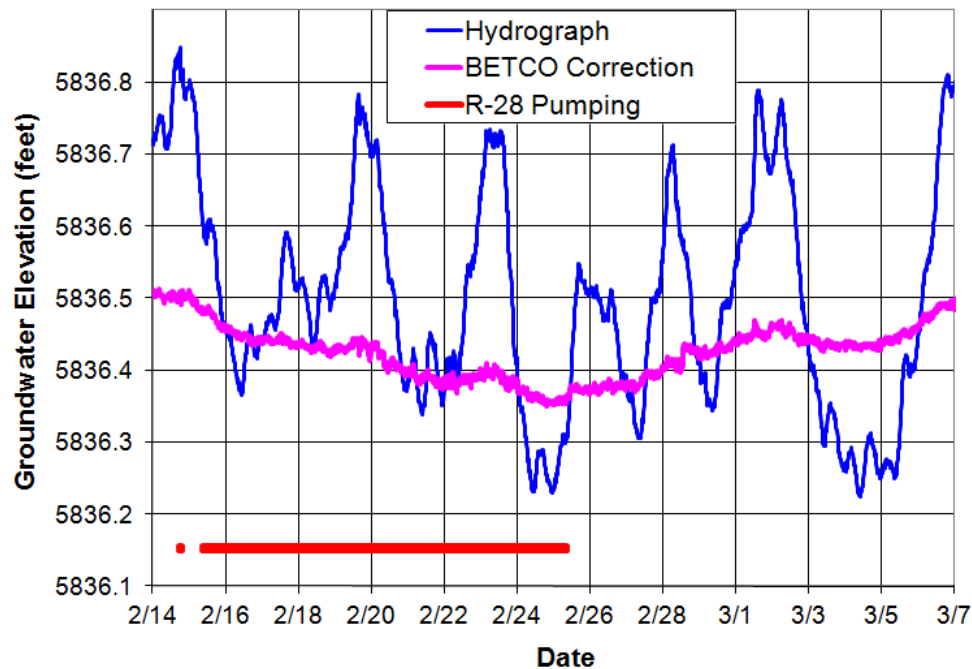


Figure L-2.4-10 Well R-50 screen 1 hydrograph during the R-28 pumping test

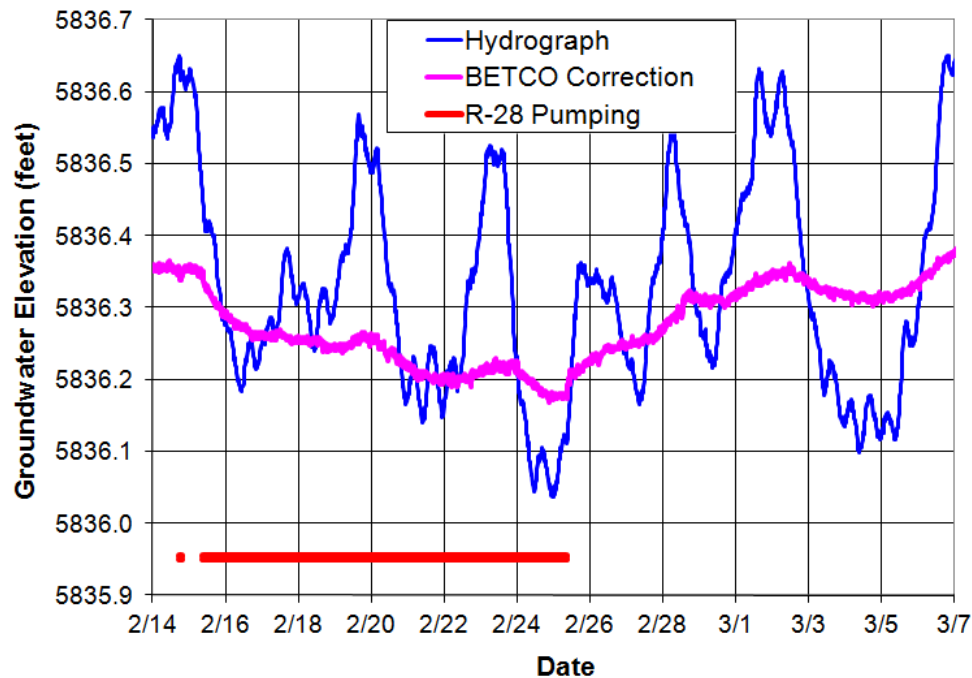


Figure L-2.4-11 Well R-50 screen 2 hydrograph during the R-28 pumping test

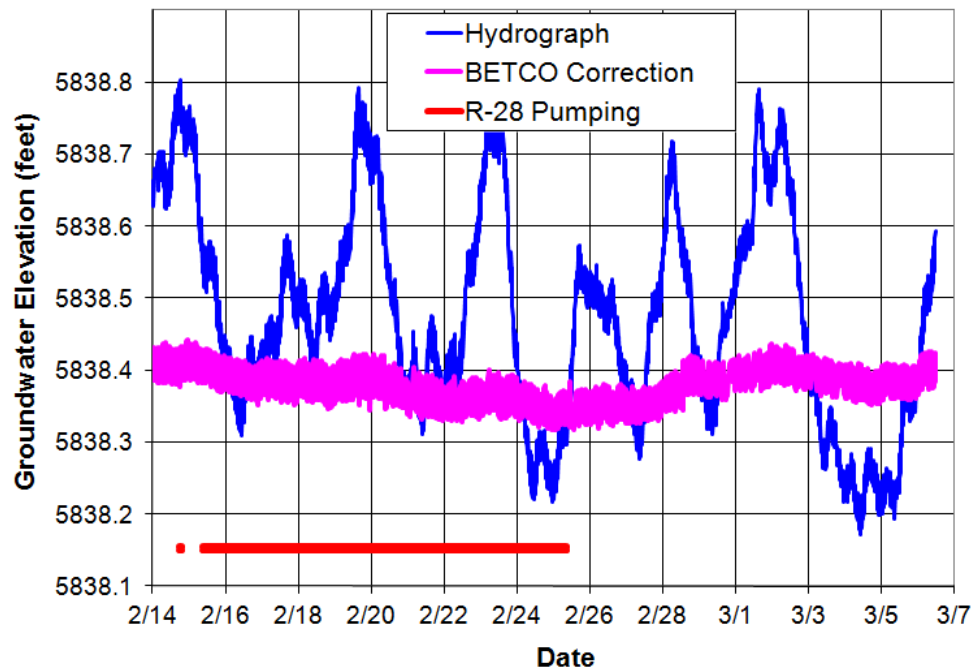


Figure L-2.4-12 Well R-61 screen 1 hydrograph during the R-28 pumping test

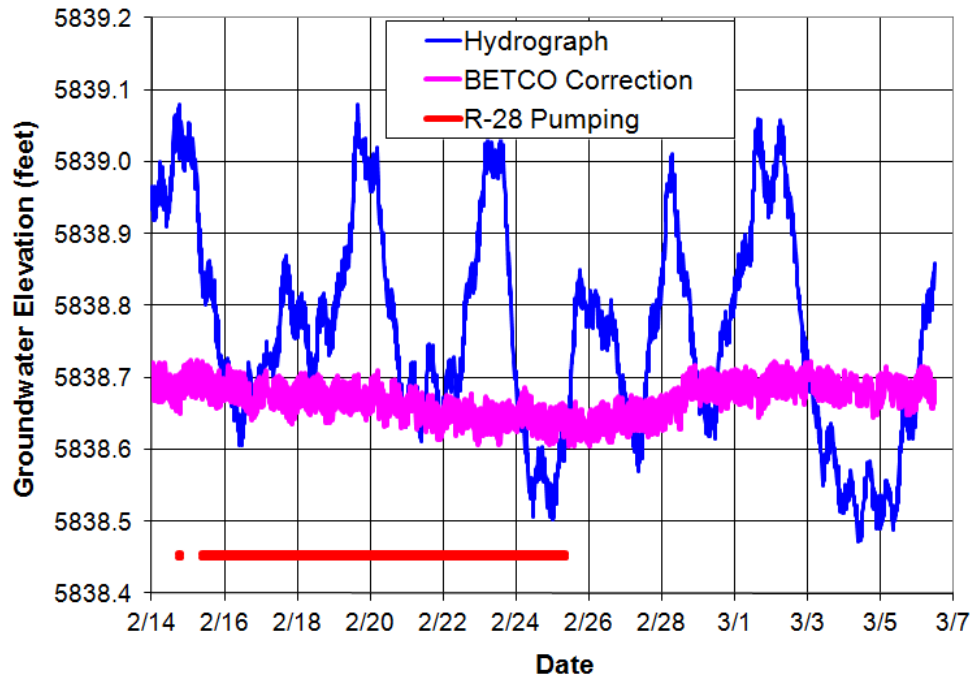


Figure L-2.4-13 Well R-61 screen 2 hydrograph during the R-28 pumping test

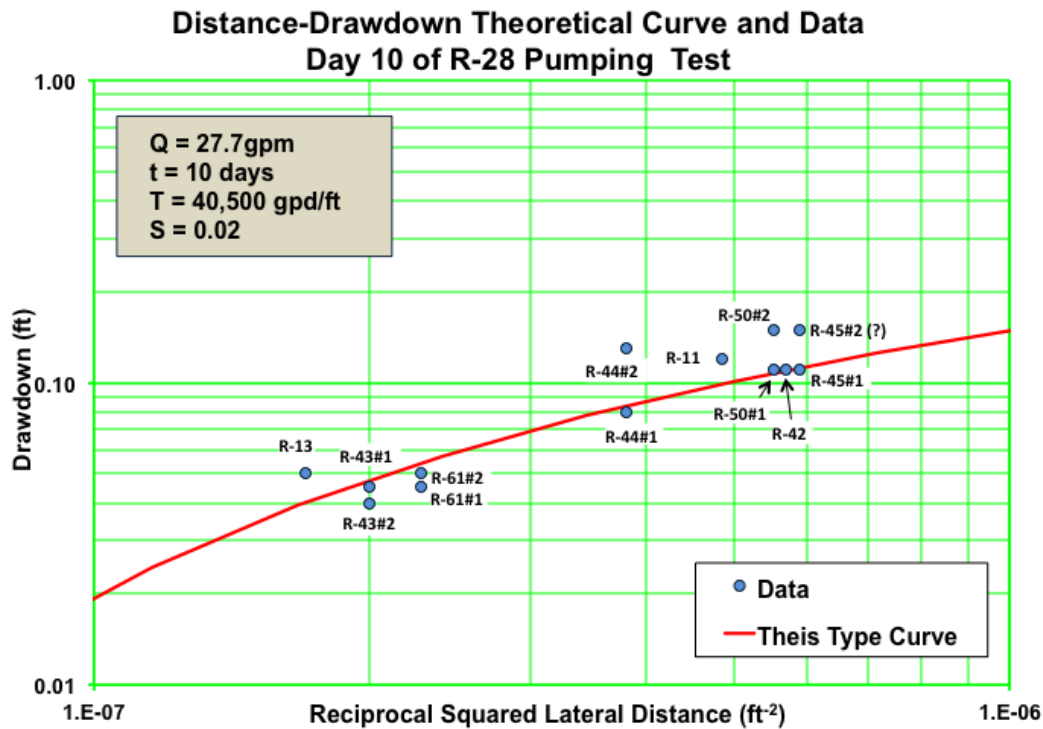


Figure L-2.4-14 Distance-drawdown Theis theoretical curve and drawdown data after 10 d of R-28 pumping

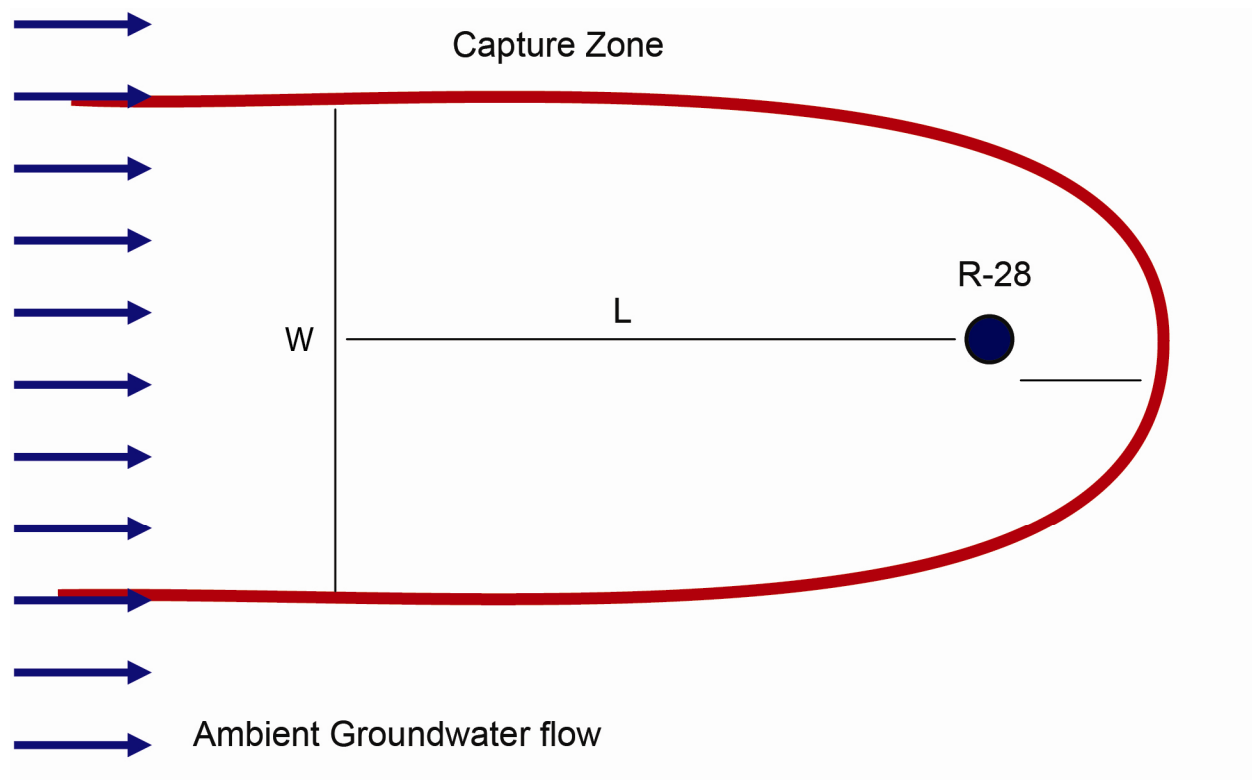


Figure L-3.2-1 Schematic representation of estimated capture zone at R-28 taking into ambient groundwater flow through the regional aquifer

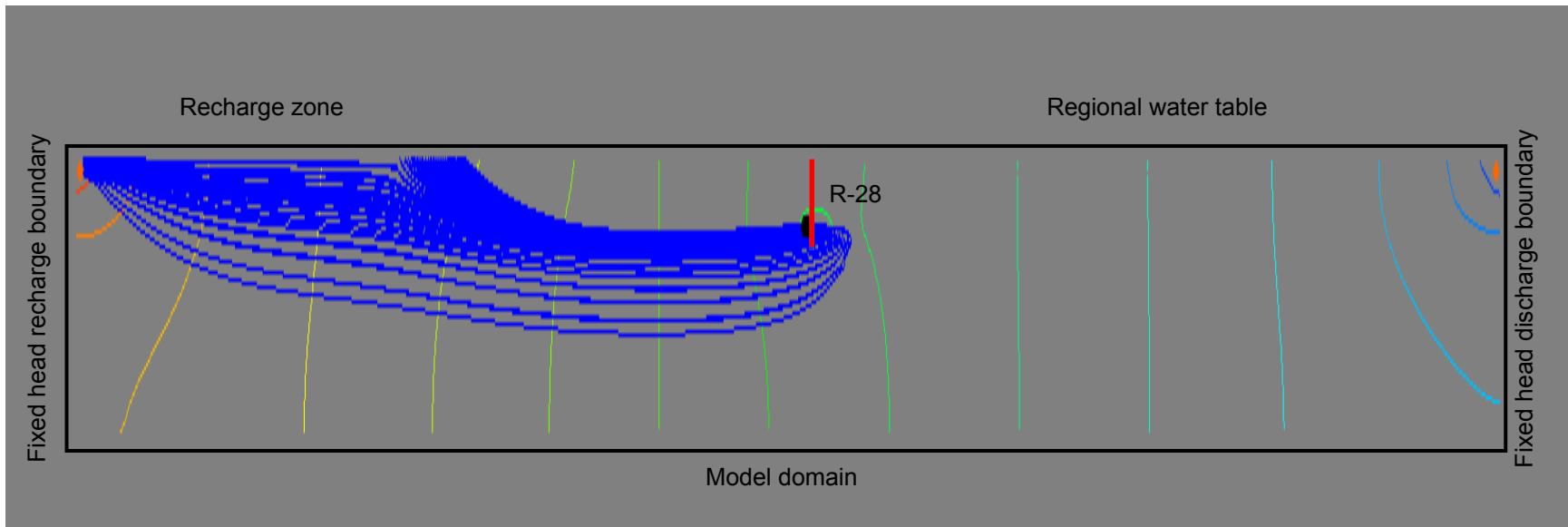


Figure L-3.3-1 Numerical simulation of the capture zone (dark blue lines represent groundwater flowpaths from the R-28 screen towards the aquifer recharge zone) during long term pumping at R-28 using (Groundwater Modeling System [GMS] utilizing USGS ModFlow and ModPath codes); colored contour lines represent hydraulic heads (0.125-m contour intervals).

**Table L-1.0-1
Observation Wells**

Well	Distance from R-28 (ft)
R-1	6750
R-11	1435
R-13	2425
R-15	3680
R-33 Screen 1	5590
R-33 Screen 2	5590
R-34	6325
R-35a	3470
R-35b	3470
R-36	4960
R-42	1325
R-43 Screen 1	2235
R-43 Screen 2	2235
R-44 Screen 1	1620
R-44 Screen 2	1620
R-45 Screen 1	1300
R-45 Screen 2	1300
R-50 Screen 1	1345
R-50 Screen 2	1345
R-61 Screen 1	2095
R-61 Screen 2	2095
R-62	3610

**Table L-2.4-1
Drawdown Data at Observation Wells after 10 Days of R-28 Pumping**

Well	Distance from R-28 (ft)	Drawdown (ft)
R-11	1440	0.12
R-13	2425	0.05
R-42	1325	0.11
R-43 Screen 1	2235	0.04
R-43 Screen 2	2235	0.045
R-44 Screen 1	1620	0.08
R-44 Screen 2	1620	0.13
R-45 Screen 1	1300	0.11
R-45 Screen 2	1300	0.15
R-50 Screen 1	1345	0.11
R-50 Screen 2	1345	0.15
R-61 Screen 1	2095	0.045
R-61 Screen 2	2095	0.05

Table L-2.4-2
Hydraulic Conductivity Estimates
Obtained from Previous Pumping-Test Analyses

Well	Distance from R-28 (ft)	k (ft/d)
R-28	0	120-160
R-11	1440	73-160
R-42	2425	10
R-43 Screen 1	1325	10
R-43 Screen 2	2235	10
R-44 Screen 1	2235	50
R-44 Screen 2	1620	11
R-45 Screen 1	1620	41
R-45 Screen 2	1300	21
R-50 Screen 1	1345	2
R-50 Screen 2	1345	9
R-61 Screen 1	2095	2
R-61 Screen 2	2095	8

Note: R-28 estimate is based on the 2004 pumping test analysis.

Table L-3.1-1
Capture Zone Radius r_{CZ} for
Different Pumping Durations at R-28

t [d]	r_{CZ} [m]
1	3.82
2	5.40
5	8.54
10	12.08
20	17.09
50	27.02
100	38.21

Table L-3.2-1
Capture Zone Width W and Maximum
Downgradient Length L_o for Different Pumping Rates at R-28

Q [gpm]	W [m]	L_o [m]
10	109	17
20	217	35
27.7	301	48
50	543	86
100	1086	173

Table L-3.2-2
Time t_{QSS} to Reach Quasi-Steady-State
Regime at a Given Distance from R-28

r [m]	t_{QSS} [d]
1	0.0001
2	0.0004
5	0.0025
10	0.0100
20	0.0398
50	0.2490
100	0.9960
200	3.9841
500	24.9004
1000	99.6016

Table L-3.2-3
Radius r_{QSS} within which
Quasi-Steady-State Regime is
Established for Different Pumping Durations at R-28

t [d]	r_{QSS} [m]
1	100.2
2	141.7
5	224.1
10	316.9
100	1002.0

Appendix M

Hydrogeologic Cross-Sections along and across Sandia Canyon

M-1.0 INTRODUCTION

The hydrogeology of the subsurface near Sandia Canyon plays an important role in controlling groundwater flow in the vadose and saturated zones (including perched zones and the regional aquifer). Groundwater-flow properties of the subsurface are defined by the matrix and fracture properties of canyon-bottom alluvium, mesa-top soils, and underlying Pleistocene to Miocene bedrock. The bedrock unit that hosts stream canyons and alluvial fill is the Tshirege Member of the Bandelier Tuff, up to a point east of core hole SCC-5 where Sandia Canyon cuts into deeper units (Cerro Toledo interval, Otowi Member of the Bandelier Tuff, and east of well R-10, Cerros del Rio lavas [Figure 7.2-1 of the Phase II investigation report]). Hydrostratigraphic units of the vadose zone beneath the Bandelier Tuff include Puye Formation fanglomerates, Cerros del Rio lavas or (to the west) dacite lavas of the Tschicoma Formation, pumiceous sediments of the upper Santa Fe Group, and deeper sands and gravels of the Santa Fe Group.

The top of regional saturation beneath middle and lower Sandia Canyon occurs in pumiceous sediments of the upper Santa Fe Group in the vicinity of wells R-43 and R-11, in Puye Formation between well R-11 and municipal supply well PM-3, and in deeper sands and gravels and intercalated basalts of the Santa Fe Group between well PM-3 and the Rio Grande. No deep wells have been drilled to characterize the regional aquifer beneath upper Sandia Canyon, but the top of regional saturation probably occurs primarily in the Puye Formation and pumiceous sediments of the upper Santa Fe Group.

In this appendix, a set of three cross-sections is used to illustrate the relationships between hydrostratigraphic units, the top of regional saturation, and known or suspected perched-intermediate zones. The cross-sections and their locations are shown in Figure M-1.0-1. These cross-sections are based on well that were in place in 2009.

M-2.0 EAST-WEST SECTION LINE A-A'

This cross-section extends down the axis of Sandia Canyon from well SCI-1 to well PM-3 (Figure M-1.0-1). The western part of this section includes the hypothesized major zone of infiltration for surface water and alluvial groundwater into underlying bedrock units of the vadose zone beneath the canyon floor. The eastern part of the cross-section is located the area where surface water and alluvial groundwater become rare to absent in a downcanyon direction, thus delineating the eastern extent of infiltration into the vadose zone. Two known perched-intermediate groundwater zones occur in this part of Sandia Canyon: an upper one in the Puye Formation (Tpf) above Cerros del Rio basalt at well SCI-1, and a lower one in the lower part of the Cerros del Rio basalt at SCI-2 (Figure M-1.0-1). The hydrogeology of the upper perched zone is described in this section, and the lower perched zone is described in section M-3.0 for Line B-B'.

Basalt stratigraphy beneath Sandia Canyon is partly defined borehole gamma logs that respond to changes in the chemistry of the basalts, specifically their uranium, thorium, and potassium contents. The basalt stratigraphy in Sandia Canyon is relatively simple with a thin package of low-gamma basalt overlying a thicker package of high-gamma basalt (Figure M-1.0-1). X-ray fluorescence analyses indicate the basalts with low gamma activities are chemically classified as tholeiites, and those with high-gamma activities are alkali basalts. The broad low-gamma and high-gamma basalt packages defined by the geophysical logs are themselves made up of stacked lavas that consist of multiple flow units separated by interflow breccias. Flow interiors are made up of dense, variably fractured impermeable rock. Under saturated conditions, groundwater flow in these lava interiors is controlled by fractures, with hydraulic conductivity determined by aperture dimensions, fracture density, interconnectivity, and the presence of

fracture-filling minerals. Porous flow is expected to dominate groundwater flow in the interflow zones made up of highly porous breccias, clinker, cinder deposits, and sedimentary deposits. Both nonfractured flow interiors and clay-filled fractured zones are expected to have very low saturated permeability. Zones with significant connected open fractures, lava tubes, and interflow zones are expected to have higher saturated permeability and low porosity, a combination of properties that can lead to very fast travel times. Flowpaths within these basalts are highly uncertain because the complex internal stratigraphy of these rocks.

The upper zone of intermediate saturation at SCI-1 is approximately 22 ft thick. The perching layer for this zone appears to be the top of the Cerros del Rio basalt. A local dip in the upper basalt surface in the vicinity of SCI-2 may focus infiltration from the perched zone into deeper bedrock units in this area. The top of the Cerros del Rio basalt also acts as a perching horizon at wells MCOI-4 and MCOBT-4.4 in Mortandad Canyon, suggesting this contact has favorable characteristics for perching groundwater over a wide area. A structure contour map presented in Appendix H of the Fate and Transport Modeling Report for Chromium Contamination from Sandia Canyon (LANL 2007, 098938, Figure H-2) shows the upper surface of the Cerros del Rio basalt near SCI-1 generally dips west towards well R-1 in Mortandad Canyon. Small variations in the surface of the Cerros del Rio basalt from erosion and the lateral abutment of basalt flows may result in southwesterly groundwater pathways, towards wells MCOI-4 and MCOBT-4.4 in Mortandad Canyon.

The top of regional saturation in cross section A-A' occurs mostly within pumiceous sediments of the upper Santa Fe Group in the area west of well R-11. To the east, between wells R-11 and PM-3, the top of regional saturation occurs within fanglomerate deposits of the Puye Formation.

M-3.0 NORTHWEST-SOUTHEAST SECTION B-B'

This cross-section extends from well SCI-1 in Sandia Canyon towards the south-southeast towards well R-42 in Mortandad Canyon, then turns towards southeastward to well R-28, and ends at well R-13 (Figure M-1.0-1). The western part of this section includes the hypothesized major zone of contaminant infiltration in Sandia Canyon and the portion of the regional aquifer containing the highest concentrations of chromium beneath Mortandad Canyon (wells R-28 and R-42). The line of section is parallel or subparallel to the dominant groundwater flow direction in the regional aquifer in this area.

The deep perched zone beneath Sandia Canyon at SCI-2 occurs in fractured lavas and interflow breccias of the Cerros del Rio basalt (Figure M-1.0-1). Compared to Sandia Canyon, the basalts beneath Mortandad Canyon are characterized more complex interfingering of high- and low-gamma basalt that probably reflects a more complex flow stratigraphy. The perched zone at SCI-2 is approximately 100 ft thick and occurs in the thick basal high-gamma basalt that has an apparent southerly dip towards Mortandad Canyon. Cuttings and borehole videos show this basalt is made up of multiple lava flows separated by blocky interflow breccias. The lava flows making up the basal high-gamma basalt were deposited over a south to south-southeast dipping surface that developed on top of the Puye Formation during the Pliocene (LANL 2007, 098938, Figure H-3). The nature of the perching horizon at the base of these basalts is poorly understood but may include relatively impermeable sedimentary rocks of the Puye Formation and clay-altered flow-base volcanic sediments at the base of the Cerros del Rio basalt. Beneath Sandia Canyon in the vicinity of SCI-2, groundwater contained the lower part of the Cerros del Rio basalt may follow the dip of basal high-gamma basalt towards the south and south-southeast. Lack of perched water in the Cerros del Rio basalt at R-28 and R-42 in Mortandad Canyon may indicate perched groundwater drained from the basalts and infiltrated the underlying Puye Formation, eventually reaching the regional aquifer in the area between SCI-2 and R-28 and R-42.

Figure M-3.0-1 contains rose diagrams showing the azimuths of bedding dips for regional aquifer rocks in wells R-11, R-13, and R-28. The data represent bedding measurements made from open borehole, oriented Formation Microimager logs conducted by Schlumberger, Inc. These well logs show the orientation of Miocene pumiceous beds in the upper part of the aquifer in the area near the chromium entry point from the vadose zone near well R-28 and along downgradient groundwater pathways. The Miocene pumiceous beds provide the best orientation data in the logs because of their well-stratified nature. Unfortunately, similar data for the underlying Miocene riverine deposits for this area are not available, and bedding data for the overlying Puye Formation are generally too noisy to produce consistent results. As Figure M-3.0-1 shows, bedding in the uppermost Miocene pumiceous sediments strike N72E and dip about 5.7° towards the south-southeast. Groundwater flowing easterly or east-southeasterly near the water table in the vicinity of wells R-42 and R-43 will flow through these highly stratified dipping deposits. Although the predominant direction of groundwater flow is controlled by water-table gradients, contrasting hydrologic properties of dipping strata along the flow path will probably result in some lateral diversion of the advective groundwater flow and potentially enhanced dispersion of contaminant transport along bedding planes towards the east-northeast and west-southwest. Bedding of strata may also cause vertical diversion of the advective groundwater flow as groundwater may follow highly permeable beds dipping towards the south-southeast. On the other hand, the bedding stratification is also expected to impede vertical dispersion of contaminants. The vertical extent of the contaminant plumes probably does not go much deeper than 100 to 150 ft into the aquifer based water-level responses to municipal pumping and the distribution of chromium in monitoring wells. Modeling of contaminant transport in Appendix L incorporates the heterogeneity imposed dipping strata in the regional aquifer by the increasing the dispersivity in the flow model.

M-4.0 NORTH-SOUTH SECTION LINE C-C'

This north-south cross-section extends from the mesa north of Sandia Canyon south to mesa south of Mortandad Canyon. The cross-section includes the major zone of infiltration in Sandia Canyon near SCI-1 and shows the regional water table cutting up section from Miocene sands and gravels on the north to Miocene pumiceous sediments and the Puye Formation to the south.

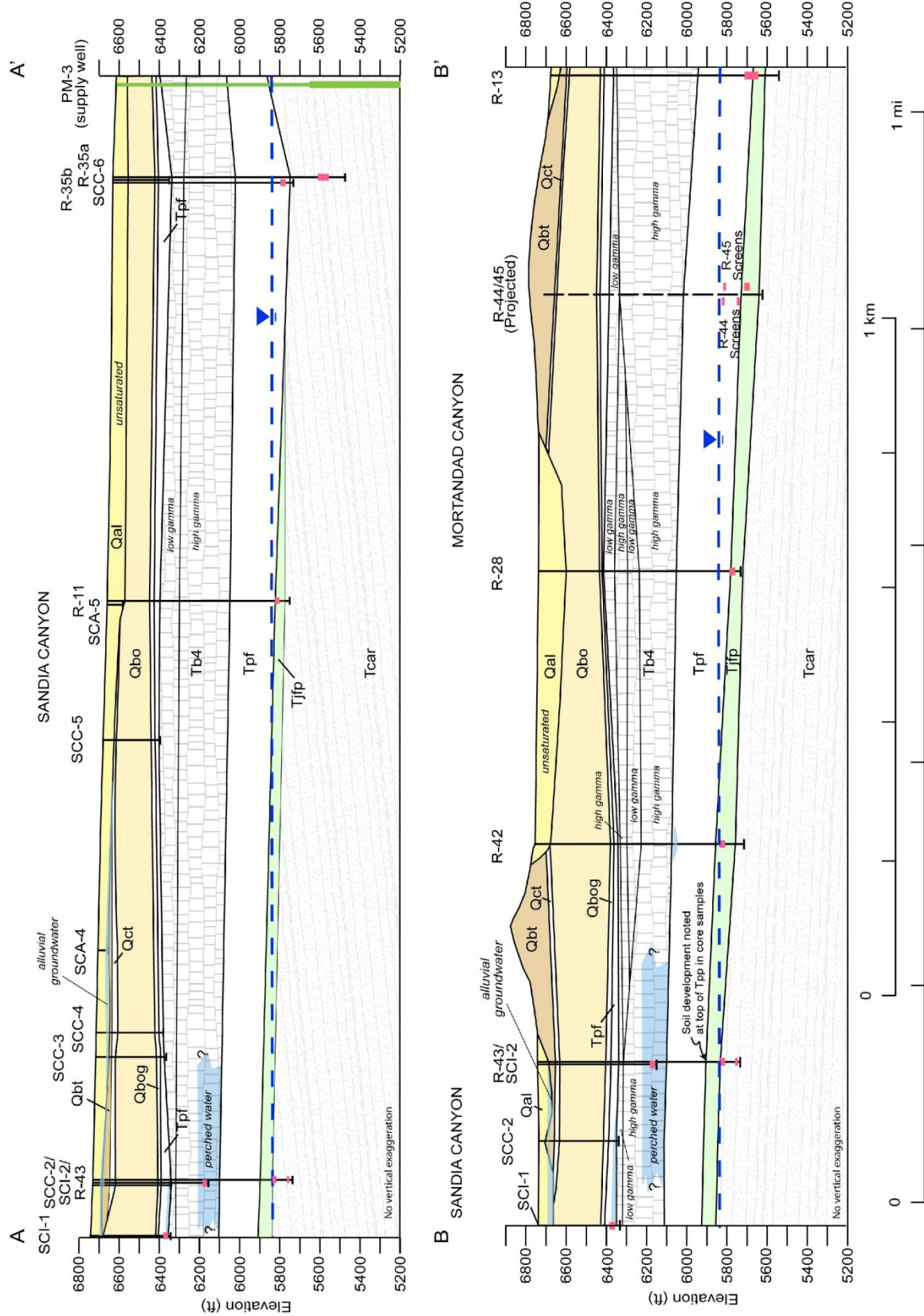
The perched groundwater in Cerros del Rio basalt at SCI-2 beneath Sandia Canyon follows the dip of the basal high-gamma basalt to the south towards Mortandad Canyon (Figure M-1.0-1). Perched groundwater was absent when core hole MCOBT-8.5 was drilled, indicating this zone dies out before reaching Mortandad Canyon in a southerly direction. Similar zones of perched groundwater 20 to 40 ft thick occur near the base of the Cerros del Rio basalts at wells MCOI-5 and MCOI-6 in Mortandad Canyon, west of section C-C', indicating this setting is generally favorable for the formation of perched groundwater zones. The MCOI-5 and MCOI-6 perched groundwater probably receives local recharge from surface water and alluvial groundwater in middle Mortandad Canyon area.

M-5.0 REFERENCE

The following list includes all documents cited in this appendix. Parenthetical information following each reference provides the author(s), publication date, and ER ID. This information is also included in text citations. ER IDs are assigned by the Environmental Programs Directorate's Records Processing Facility (RPF) and are used to locate the document at the RPF and, where applicable, in the master reference set.

Copies of the master reference set are maintained at the New Mexico Environment Department Hazardous Waste Bureau and the Directorate. The set was developed to ensure that the administrative authority has all material needed to review this document, and it is updated with every document submitted to the administrative authority. Documents previously submitted to the administrative authority are not included.

LANL (Los Alamos National Laboratory), September 2007. "Fate and Transport Modeling Report for Chromium Contamination from Sandia Canyon," Los Alamos National Laboratory document LA-UR-07-6018, Los Alamos, New Mexico. (LANL 2007, 098938)



Note: Locations of cross-sections and the legend of symbols are on the next page.

Figure M-1.0-1 Geologic cross-sections for Sandia and Mortandad Canyons

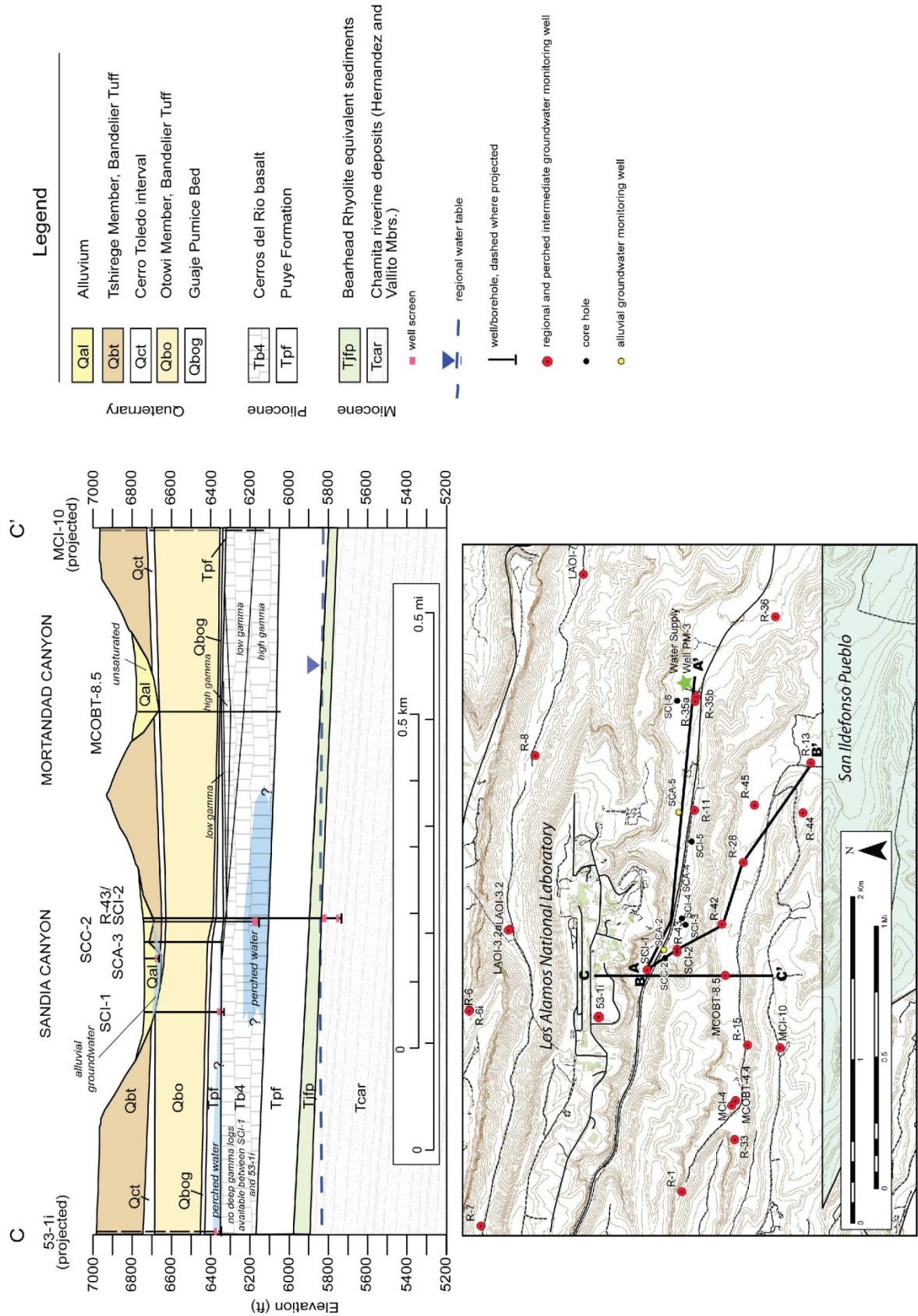


Figure M-1.0-1 (continued) Geologic cross-sections for Sandia and Mortandad Canyons

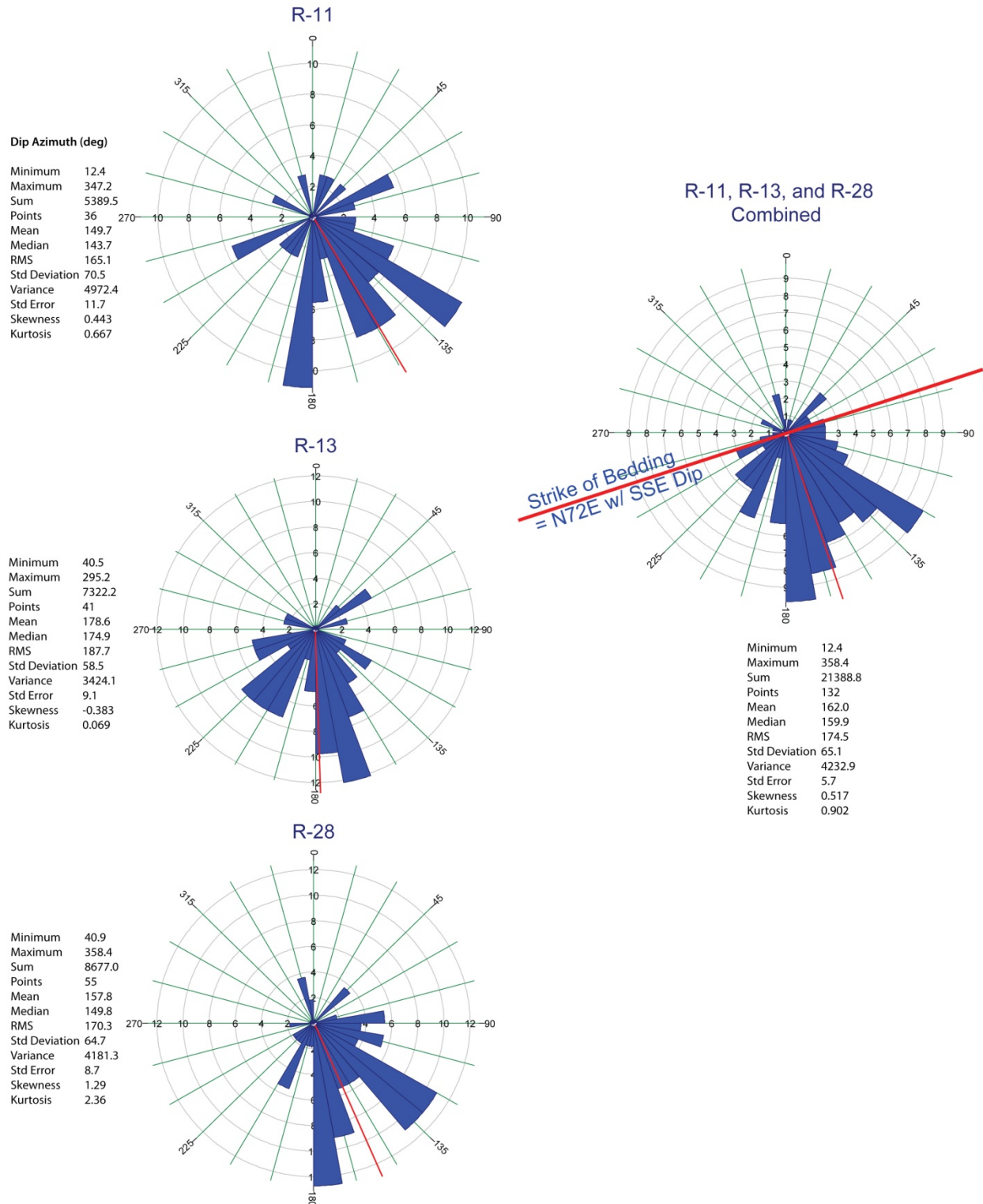


Figure M-3.0-1 Bedding azimuths determined from open borehole Formation Microimager logs for Miocene pumiceous sediments in wells R-11, R-13, and R-28

Appendix N

*Cross-Reference of New Mexico Environment Department
Approvals with Modifications to the Sandia Canyon
Phase II Investigation Report*

N-1.0 INTRODUCTION

This appendix includes cross-reference tables that address comments Los Alamos National Laboratory (LANL) received in the New Mexico Environment Department's (NMED's) approval with modification for the Investigation Report for Sandia Canyon (NMED 2010, 108683) and the approval with modifications on the Phase II Investigation Work Plan for Sandia Canyon (NMED 2011, 111518).

Table N-1.0-1
Cross-Reference to NMED's Approval with Modification
for the Sandia Canyon Investigation Report and the Sandia Canyon Phase II Investigation Report

NMED Comment	Summary of NMED Requirement	Summary of Actions Taken or Other Comment Resolutions
1	<p>Per the February 9, 2010, Approval with Modification letter for the Sandia Canyon investigation report (NMED 2010, 108683), produce a Phase II Sandia Canyon investigation work plan that includes details of additional groundwater monitoring wells, methodology for more rigorous analysis of existing and to-be-acquired contaminant and hydrochemical data, and procedures for comprehensive examination of physical aspects of aquifer interconnectivity.</p> <p>Replace the current report with a Phase II investigation report that synthesizes information from the Phase I and Phase II investigations.</p>	<p>A Phase II Investigation Work Plan for Sandia Canyon (LANL 2010, 110480) was submitted to NMED on July 30, 2010. The work plan included the details of additional work as directed by NMED.</p> <p>A Phase II investigation report for Sandia Canyon is issued here. The report describes work done to satisfy the Phase II work plan and additional work as directed by NMED in its Approval with Modification Phase II Investigation Work Plan for Sandia Canyon (NMED 2011, 111518)</p>
2	<p>Install two perched-intermediate wells to the base of the Cerros del Rio basalt. Core and sample boreholes for percent moisture, anions, cations, and chemicals of potential concern (COPCs).</p> <p>Prepare an additional work plan if either of the two planned wells encounters chromium at concentrations greater than the maximum value in the regional aquifer.</p>	<p>Boreholes were drilled for proposed intermediate wells SCI-3 and SCI-4. These boreholes were not completed because insufficient perched water was encountered to complete them as wells. See discussion in sections 3.2.1 and 4.2.1.</p>
3	<p>To define vertical and western extents of the chromium plume in the regional aquifer,</p> <ul style="list-style-type: none"> • Install a dual-screen well at depths of 150 ft and 300 ft below the water table in the regional aquifer at well R-28 to define the vertical extent of contamination. • Install a second dual-screen well west of well R-42 on the mesa separating Sandia and Mortandad Canyons. 	<p>Regional wells R-61 and R-62 were drilled to satisfy these requirements. These are described in sections 3.2.2 and 4.2.2 of the Phase II IR.</p> <p>Water samples from these wells are described in sections 6 and 7.2, and Appendix D of the Phase II IR.</p>

Table N-1.0-1 (continued)

NMED Comment	Summary of NMED Requirement	Summary of Actions Taken or Other Comment Resolutions
4	Use a heat-pulse flow meter, colloidal borescope, or other NMED-approved method to measure the vertical and horizontal groundwater flow velocities and directions in all regional and perched-intermediate wells in the vicinity of the chromium plume and develop a three-dimensional (3-D) flownet model for the regional aquifer in the vicinity of the chromium plume.	Per agreement with NMED, the downhole instrumentation was not installed because it is incompatible with the downhole sampling systems. Instead, a pump test in R-28 and 3-D modeling were performed to satisfy this requirement. The R-28 pump test is described in sections 3.2.3 and 4.2.3; the results are provided in Appendix L. Appendix K describes the 3-D model and its results.
5	Revise the conceptual model for surface water transport and vertical infiltration pathways in the Phase II investigation report.	The conceptual model text in section 7.2.2 was revised to include the processes described.
6	Expand the analysis to include examination of trends and distributions of stable isotopes and contaminant tracers such as chlorate and bromide and present the refined analysis in the Phase II investigation report.	Further analyses of chromium, nitrate, oxygen, and sulfur isotopes are included in Appendixes H and I. Further analyses of other tracers and contaminants are included in Appendix D.
7	In July 1994, after the primary chromium release period ended, samples of surface water collected at stations SCS-2 and SCS-3 were found to contain 760 ppb and 17 ppb chromium. These analyses were not included in the investigation report. Investigate whether this release represents a distinct release from that which occurred during the 1956–1972 period and evaluate whether the present release is the source of chromium at SCI-2. Present this evaluation in the Phase II investigation report.	The 1994 Environmental Surveillance Report (ESR) (LANL 1996, 054769) lists the SCS-2 sample with 760 ppb chromium and the SCS-3 sample with 17 ppb (Table VI-7). The ESR notes that the SCS-2 sample was incorrectly identified as filtered. However, it was a nonfiltered sample that was analyzed using hydrofluoric acid digestion. The ESR states this sample has a high metal content because of suspected sampling or analytical problems. The ESR also noted that neither upstream nor downstream samples collected on the same day have elevated metal concentrations. No discussion is included in the Phase II investigation report because of these analytical problems.
8	To determine the moisture conditions beneath the wetland, LANL must perform a geophysical survey and install one boring a depth of 200 ft (bgs), preferably in the area of the highest conductivity. Conduct a surface-based direct current– (DC-) resistivity geophysical survey in the vicinity of the Sandia Canyon wetland and use the survey results to identify the most likely area of infiltration beneath the wetlands. Drill a core hole to the 200-ft depth and characterize the core for moisture, anions, cations, and COPCs; present the data collected from this investigation in the Phase II report.	The Laboratory conducted a DC resistivity survey of the Sandia Canyon wetland area as described in sections 3.2.7 and 4.2.7. The geophysics report is included in Appendix E. The geophysics results alone cannot be used to determine whether observed conductivity anomalies are infiltration pathways for chromium. Additional insights from modeling are used in the Phase II report to assess whether infiltration beneath the wetland is important to the nature and extent of chromium in the regional aquifer. Modeling studies presented in Appendixes J and K indicate the observed distribution of chromium in the regional aquifer cannot be caused by a significant chromium pathway transmitting chromium from the wetland area to the regional aquifer. However, a small chromium flux that generates near-background concentrations downgradient is feasible.

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NMED Comment	Summary of NMED Requirement	Summary of Actions Taken or Other Comment Resolutions
8 (cont.)		Because these results coupled with the earlier surface water balance studies performed in Sandia Canyon (summarized in the Phase I investigation report) indicated little infiltration in the wetland area, LANL does not recommend the drilling of the 200-ft-depth corehole.
9	Install a perched-intermediate well at R-10/R-10a and present data collected from this investigation in the Phase II report.	Perched-intermediate well R-10i has not yet been installed. Currently, the well is scheduled to be completed by January 20, 2014. See sections 3.2.1 and 4.2.1.
10	Review data from sediment sampling stations and from the Rio Grande to assess the possibility of sediment transport from Sandia Canyon to the Rio Grande. Address this possible transport in the Phase II investigation report.	Sections 7.1.1, 7.1.2.4, 7.1.4.3, and (especially) 7.1.7 address potential sediment transport to the Rio Grande.
11	A large alluvial fan deposit located 2000 ft east of PM-3 may have caused damming of floodwaters on the canyon floor and deposition of sediments onto the nearby floodplain. Collect surface and subsurface sediment samples from these deposits and analyze them for a full suite of inorganic and organic chemicals; report the result in the Phase II investigation report.	Sediment reach S-5EC was investigated and the results are reported in sections 3.1, 4.1, and 7.1, and Appendixes B and D.
12	The risk assessment is incomplete because the investigation on which it is based is incomplete. Include an updated risk assessment in the Phase II investigation report. 12a. Estimations of exposure point concentrations must be revised to incorporate regression on order statistics method for handling non-detects in datasets.	Supplemental data collection relevant to the risk assessments was conducted in one additional sediment investigation reach and also included three years of surface water sampling. These additional data have been evaluated both qualitatively and quantitatively. Additional information on these supplemental data is provided in section 8.4. 12a. LANL concurs that robust methods are available for handling nondetects. However, the risks were characterized based on the full detection limit in the Phase I investigation report (LANL 2009, 107453, Tables 8.1-5 to 8.1-8, 8.1-10, and 8.1-12). The detection limit replaced with zero scenario was provided as additional information to illustrate those cases where there are no detects for a chemicals of potential ecological concern in a reach or at a location. No changes to the risk assessment are needed to address this comment. LANL also agrees to not use any sort of simple substitution method in future risk assessments.

NMED Comment	Summary of NMED Requirement	Summary of Actions Taken or Other Comment Resolutions
12 (cont.)	<p>12b. Revise the assessment to include an evaluation of potential risk to avian receptors.</p> <p>12c. The Permittees must clarify the issue of soil screening values.</p> <p>12d. The Permittees must revise the assessments to include an evaluation of the subsistence hunting scenario.</p>	<p>12b. The potential for ecological risks for the dioxin-like properties of PCBs was evaluated as a supplemental calculation for the Phase I IR (LANL 2009, 107453, Table 8.1-13). Table 8.1.13 presented the TCDD (tetrachlorodibenzodioxin[2,3,7,8-]) hazard quotient (HQ) values for the shrew based on the TCDD-equivalent concentration (TEC) mammal. As a point of comparison the TCDD HQ values for the robin (invertivore diet) can be calculated using the avian TRV noted in this comment. LANL had calculated a soil ecological screening level (ESL) for the robin (invertivore diet) as 4.6e-6 mg/kg in ECORISK Database Version 2.0 (LANL 2003, 080117). Using this ESL and the maximum TEC bird concentration (0.00123 mg/kg from CASA-08-13548) the avian HQ would be 300. Therefore, the potential for adverse effects on birds as well as mammals would be possible based on the polychlorinated biphenyl (PCB) congener sample results. The potential for adverse effects on both birds and mammals was also noted for PCBs based on the Aroclor sample results. The original conclusions for the Phase I investigation report ecological risk assessment noted that PCBs have the potential for adverse effects on the terrestrial environment. This conclusion is unchanged based on the additional information provided in response to this comment.</p> <p>12c. Although the Phase I investigation report referred to Region 6 and Region 9 soil screening values, only NMED and U.S. Environmental Protection Agency regional soil screening values were used in this report. Therefore, no changes to the tables or calculations are needed to respond to this comment.</p> <p>12d. A review of the COPCs indicates no bioaccumulative sediment COPCs were identified in reaches S-6W and S-6E located on Pueblo of San Ildefonso lands. However, two PAHs were detected in water collected on Pueblo of San Ildefonso lands, specifically from Sandia Spring. The PAHs were detected in the original sample but not the field duplicate (both samples were collected on September 24, 2001). No polycyclic aromatic hydrocarbons (PAHs) were detected in the other 11 samples collected from Sandia Spring. Given the lack of bioaccumulative chemicals in sediment on Pueblo lands there is no need to evaluate a hunting scenario.</p>

Table N-1.0-1 (continued)

NMED Comment	Summary of NMED Requirement	Summary of Actions Taken or Other Comment Resolutions
12 (cont)	12e. Updates to the NMED screening levels for the PAH must be considered as part of the revisions to this report.	12e. LANL has considered the potential impact of using the December 2009 NMED screening levels compared with the August 2009 NMED screening levels that were used in the Phase I IR. There would be no change to the human health risk assessment other than to somewhat reduce the sum of fractions calculated for the initial risk screening. For example, the benzo(a)pyrene residential soil screening level was 0.481 mg/kg (August 2009 version), and the December 2009 soil screening value for this chemical was 0.621 mg/kg. Site-specific risks were calculated using the LANL recreational SSLs, which have not been updated since the September 2009 publication of the Phase I IR.
13	The report contains numerous inaccuracies, omissions, and internal inconsistencies.	This comment was made about the Phase I report and is not applicable to the Phase II report.

Table N-1.0-2

**Cross-Reference to NMED's Approval with Modification for the Sandia Canyon
Phase II Investigation Work Plan and the Sandia Canyon Phase II Investigation Report**

NMED Comment	Summary of NMED Requirement	Summary of Actions Taken or other Comment Resolutions
1	Stabilize the eastern end of the wetland in reach S-2 and submit a work plan for stabilizing the wetland and headcut; include proposal for post-stabilization contaminant monitoring and a maintenance program for all structures.	LANL prepared the Work Plan and Final Design for Stabilization of the Sandia Canyon Wetland (LANL 2011, 207053) in response to requirements set forth by NMED. A work plan has been approved by NMED, and installation of the grade-control structure is due for completion in 2013. The proposed work is summarized in the Phase II report.
2	Based on NMED's review of available information and data regarding contamination in the regional aquifer beneath Sandia and Mortandad Canyons, Conceptual Model 3, proposed by LANL, seems to be the most accurate of the three presented in the Phase II work plan. Conduct an investigation to determine the nature and vertical and lateral extent of contamination within the chromium plume. If additional monitoring wells are deemed necessary, the number and location must be based on data from proposed well R-61 and R-62 along with other nearby wells.	A revised conceptual model based on an assessment of Phase 1 and Phase II data is presented in section 7.2 of the Phase II report. The Phase II report presents information that defines nature and extent sufficient to support proceeding to the corrective measures evaluation phase.

Table N-1.0-2 (continued)

NMED Comment	Summary of NMED Requirement	Summary of Actions Taken or other Comment Resolutions
3	Add more profiles to the DC-resistivity surveys in upper Sandia Canyon to properly delineate lateral contrast and configure the survey to allow for determination of the role of near-vertical features beneath the wetland. Submit the final scope for survey to NMED for approval 20 d before work is implemented.	The additional DC resistivity profiles were run after agreement with NMED on the additional lines. A separate report on the results of the geophysics survey is included in the Phase II report (Appendix E) and incorporated into the conceptual model in section 7.2.
4	When LANL collects additional sediment data, the location and depth of the sediment samples collected must be based on the results of the post-1942 geomorphic units. Add 10 more sediment samples to reach S-5EC with locations and depths based on mapping of post-1942 geomorphic units; Notify NMED 15 d before sampling in reach S-5EC.	Information from the additional sediment investigation is presented in section 7.1.
5	NMED does not agree with LANL's assertion that monitoring data from existing dual-screen wells provide "good evidence" that the vertical extent of chromium is constrained. Install a deep-screened, dual-screen well to define vertical extent if work performed under the plan does not reduce this uncertainty to an acceptable level.	Information provided in multiple sections of this report present a case that vertical extent of contamination in the regional aquifer is sufficiently constrained to support proceeding to the corrective measures evaluation phase.

N-2.0 REFERENCES

The following list includes all documents cited in this appendix. Parenthetical information following each reference provides the author(s), publication date, and ER ID. This information is also included in text citations. ER IDs are assigned by the Environmental Programs Directorate's Records Processing Facility (RPF) and are used to locate the document at the RPF and, where applicable, in the master reference set.

Copies of the master reference set are maintained at the NMED Hazardous Waste Bureau and the Directorate. The set was developed to ensure that the administrative authority has all material needed to review this document, and it is updated with every document submitted to the administrative authority. Documents previously submitted to the administrative authority are not included.

LANL (Los Alamos National Laboratory), July 1996. "Environmental Surveillance at Los Alamos During 1994," Los Alamos National Laboratory report LA-13047-ENV, Los Alamos, New Mexico. (LANL 1996, 054769)

LANL (Los Alamos National Laboratory), November 2003. "Ecorisk Database (Release 2.0)," on CD, Los Alamos National Laboratory, Los Alamos, New Mexico. (LANL 2003, 080117)

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