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EXECUTIVE SUMMARY

This report examines the history of groundwater-quality data collected at well R-61 and provides an assessment whether groundwater data from R-61 currently represent the contaminant plumes at its location. The assessment concludes that R-61 screen 1 (R-61 S1) is currently capable of providing usable data. Although conditions related to drilling and subsequent redevelopment are still present immediately around the well screen, modified sampling protocol can achieve usable data for the contaminant plumes at well R-61. R-61 screen 2 is not assessed in this report and is recommended for abandonment.

The primary purpose for drilling and installing well R-61 was to further define the nature and extent of chromium contamination in the regional aquifer beneath Mortandad Canyon. Data from well R-61 currently meet this objective and can be used in conjunction with data from other wells in the monitoring network to monitor the temporal and spatial evolution of the chromium and perchlorate plumes and to provide key information needed to evaluate potential remedial strategies.

The well was redeveloped in 2012 to improve the water yield of R-61 S1 and to mitigate reducing conditions that had developed in both screen intervals. The redevelopment activities resulted in a significant improvement in the aquifer yield for R-61 S1. This screen now shows negligible drawdown, even during extended purges. Because the affected zone around the well screen appears limited to a short radial distance from the borehole wall, usable data for key constituents can be obtained by pulling water from beyond this zone through extended purging before sampling. Although secondary, newly formed phosphate minerals may persist in the formation surrounding the screen, they do not appear to adversely affect the usability of concentrations for the key constituents.

Los Alamos National Laboratory recommends that R-61 S1 be retained in the monitoring network as a single-screen well. The sampling protocol for collecting groundwater samples at the well should use extended purging and a variety of field measurements to assess stability and representativeness of groundwater samples. Trigger levels of specific indicators of deteriorating conditions should be defined that would initiate maintenance actions if necessary. R-61 S1 will be placed on a watch list included in the Interim Facility-Wide Groundwater Monitoring Plan to facilitate tracking of changes in conditions at the well.

CONTENTS

1.0 INTRODUCTION 1

2.0 CHRONOLOGY OF KEY FIELD ACTIVITIES 2

3.0 CONCEPTUAL MODEL 3

4.0 EVALUATION OF PRESENT-DAY DATA FROM R-61 S1 4

- 4.1 Assessment Approach 4
- 4.2 Evaluation of Current Condition in R-61 S1 5
- 4.3 Field Data 8
- 4.4 Characterization of Redox State of Groundwater 9
- 4.5 Evaluation of Chromium Reactions with Reactive-Mineral Surfaces 11
- 4.6 Chromium Speciation and Stable Isotopes 12

5.0 SUMMARY 14

6.0 REFERENCES 15

Figures

Figure 1.0-1 Location of well R-61 19

Figure 3.0-1 Conceptual cross-section of R-61 screen 1 showing how parts of the aquifer next to the well are affected by drilling fluids and redevelopment efforts 20

Figure 4.2-1 Trilinear plot showing major-ion chemistry of groundwater from R-61 S1 relative to nearby monitoring wells and reequilibration trends for R-61 S1 following redevelopment 21

Figure 4.2-2 Trilinear plot showing reequilibration of major-ion chemistry of groundwater for R-61 S1 during extended purge events conducted following redevelopment 22

Figure 4.2-3 Schoeller plots of geochemical data collected during sampling of R-61 S1: (a) major ions and perchlorate and (b) trace metals 23

Figure 4.2-4 Concentrations of major ions for well R-61 S1 and other wells in the Chromium Investigation monitoring group: (a) sodium, (b) chloride, (c) sulfate, (d) potassium, (e) total phosphate, and (f) calcium 24

Figure 4.2-5 Concentrations of chromium, perchlorate, and nitrate for well R-61 S1 and other wells in the Chromium Investigation monitoring group 26

Figure 4.3-1 Field parameters monitored during purging of R-61 S1: (a) dissolved oxygen, (b) specific conductance, (c) pH, (d) ORP, (e) temperature, (f) turbidity, (g) discharge rate, and (h) water level 27

Figure 4.3-2 Final field parameters for samples collected at R-61 S1 under the IFGMP 28

Figure 4.5-1 Absence of correlation between filtered concentrations of chromium at R-61 S1 with low concentrations of (a) iron and (b) manganese 29

Figure 4.6-1 Correlation between concentrations of chromium in filtered and unfiltered samples collected during extended purges of R-61 S1 30

Figure 4.6-2 Temporal trends of chromium concentrations in samples from R-61 S1 during extended purges 31

Figure 4.6-3 Stable chromium isotopes and hexavalent chromium concentrations in time-series samples collected from R-61 S1 during extended purge events 32

Tables

Table 4.1-1 Sampling Events Included in the Evaluation of R-61 S1 33
Table 4.1-2 Sampling Events at R-61 S2 34
Table 4.2-1 Laboratory pH, Major-Ion, and Silica Concentrations in Groundwater Samples from R-61 S1 35
Table 4.2-2 Laboratory pH, Major-Ion, and Silica Concentrations in Groundwater Samples from R-61 S2 36
Table 4.2-3 Total Organic Carbon, Perchlorate, and Trace-Metal Concentrations in Groundwater Samples from R-61 S1 37
Table 4.2-4 Total Organic Carbon, Perchlorate, and Trace-Metal Concentrations in Groundwater Samples from R-61 S2 38
Table 4.3-1 Field Parameters Measured at R-61 S1 39
Table 4.3-2 Field Parameters Measured at R-61 S2 40
Table 4.4-1 Concentrations of Redox Couples in Groundwater Samples from R-61 S1 41
Table 4.4-2 Concentrations of Redox Couples in Groundwater Samples from R-61 S2 42
Table 4.4-3 Standard Electrode Potentials for Pertinent Reduction Half-Reactions at 25°C 43
Table 4.6-1 Hexavalent Chromium Concentrations and Chromium Isotopes in Groundwater at Other Regional Wells Near the Periphery of the Chromium Plume 44
Table 4.6-2 Hexavalent Chromium Concentrations and Chromium Isotopes in Groundwater at R-61 S1 45

Appendixes

Appendix A Physical and Hydrologic Attributes of Well R-61
Appendix B Water-Quality Data (on CD included with this document)

1.0 INTRODUCTION

This report evaluates the present capability of regional aquifer well R-61 to provide groundwater samples for key contaminants present in groundwater beneath Mortandad Canyon at Los Alamos National Laboratory (LANL or the Laboratory). Well R-61 currently exhibits geochemical conditions that affect concentrations for certain classes of constituents in both of its screened intervals. This condition led to a requirement from the New Mexico Environment Department (NMED) to replace the well and to provide a work plan to NMED by June 14, 2013 (NMED 2013, 522648). A subsequent letter from the Laboratory requested an extension to the due date for the work plan to September 30, 2013, to allow time for a technical evaluation of the adequacy of the current data for well R-61 (LANL 2013, 241946). NMED approved the extension request (NMED 2013, 522733) and has since clarified that the requirement for a replacement work plan is deferred pending NMED's review of this report.

Well R-61 is located on the mesa top south of Mortandad Canyon within the Laboratory's Technical Area 05 (TA-05) in Los Alamos County, New Mexico (Figure 1.0-1). The primary purpose for drilling and installing well R-61 was to further define the nature and extent of chromium (Cr) in the regional aquifer beneath Mortandad Canyon. The well's location was selected to define the southwestern extent of a potential southerly flow path for the main part of the Cr plume (LANL 2010, 110998).

Groundwater samples collected from the well indicate the main part of the Cr contaminant plume is located north and east of well R-61 and that, in conjunction with other regional aquifer wells in the monitoring network, well R-61 defines the southern extent of the Cr plume. Groundwater samples taken at well R-61 indicate the well also supports monitoring of a separate perchlorate (ClO_4) plume that originates farther to the west in Mortandad Canyon. More detailed information about these plumes is presented in investigation reports for Sandia Canyon submitted to NMED (LANL 2009, 107453; LANL 2012, 228624). As with other dual-screen wells in the monitoring network, contaminants are present in the uppermost part of the regional aquifer, but not at depth. Water levels from the two screens in well R-61 have also been used to evaluate pumping effects from nearby municipal supply wells and to construct the water table map for the area. Data collected during drilling indicate the absence of perched aquifers beneath this part of Mortandad Canyon.

Well R-61 is currently being used in conjunction with other wells in the network to monitor the temporal and spatial evolution of the Cr and ClO_4 contaminant plumes. The well was redeveloped in 2012 to improve the water yield of the upper screen and to mitigate reducing conditions which had developed in both screen intervals. The key objective of this report is assess whether well R-61 screen 1 (R-61 S1), in particular, is capable of providing data that sufficiently represent the Cr and ClO_4 plumes at the location of the well and that support the path forward for groundwater remediation and monitoring. Well R-61 is part of the Chromium Investigation monitoring group as described in the Interim Facility-Wide Groundwater Monitoring Plan (IFGMP) (LANL 2013, 241962) that includes 15 regional aquifer wells that monitor groundwater within and around the Cr contaminant plume. Groundwater monitoring and decisions about remedial alternatives are based on the data synthesized from all of the wells in the monitoring network. The approach is consistent with that used in various network evaluations in which the evaluation is conducted to determine if wells provide data for specific network objectives (LANL 2010, 109947; LANL 2012, 213573).

Section 2.0 summarizes field activities at well R-61 that are relevant to its present-day suitability for providing groundwater monitoring data. Section 3.0 presents a conceptual model that illustrates the spatial extents of drilling-related effects to the borehole wall and chemical effects to the formation near R-61 S1 as a result of redevelopment activities. Section 4.0 briefly describes the protocol, geochemical tools, and general types of data available and applies the protocol to recent water-quality data from well R-61, focusing on the uppermost screen, R-61 S1. Section 5.0 summarizes the findings and presents recommendations for future activities at well R-61. Appendix A summarizes physical and hydrologic attributes of well R-61. The analytical results presented in this report were compiled from the Laboratory's environmental database and are included in Appendix B (on CD); these data are also available to the public at the Intellus New Mexico database (available at www.intellusnm.com). Other documents and records referenced in this report are on file at the Laboratory's Records Processing Facility (RPF).

2.0 CHRONOLOGY OF KEY FIELD ACTIVITIES

Well R-61 was installed to monitor water quality in the regional aquifer and to help characterize contaminant concentrations and trends in distal portions of two plumes known to exist in the area (LANL 2011, 206492; Kulis 2012, 227669). The R-61 borehole was drilled using fluid-assisted air-rotary methods. Drilling fluids included compressed air, municipal water, and a mixture of municipal water with Baroid brand AQF-2 foaming agent. The well was completed on May 3, 2011, at a total depth (TD) of 1251.6 ft below ground surface (bgs) with two screened intervals. The upper screen (10.0 ft long) was set from 1125.0 to 1135.0 ft bgs near the top of the regional aquifer, and the lower screen (20.6 ft long) was set from 1220.4 to 1241.0 ft bgs within the regional aquifer. Following final well development activities, a Baski manufactured dual-zone sampling system was installed in the well to isolate and allow discrete sampling of the screened intervals. More detailed information about well drilling, completion, and development is compiled in Appendix A.

Quarterly sampling began at well R-61 under the 2011 IFGMP (LANL 2011, 208811), with the first sample being collected from R-61 S1 at the end of the aquifer test on May 20, 2011. However, within months after completion and initial development, field parameters and water-quality data for well R-61 indicated reducing conditions had developed in the vicinity of both screens. A low yield of R-61 S1, manifest by large drawdowns (up to 15 ft) during pumping tests conducted at <2 gallons per minute (gpm) (LANL 2013, 239229, Appendix A), was also observed.

Plans for well redevelopment were presented in the "Work Plan for Redevelopment of Monitoring Well R-61" (LANL 2012, 221454) that was approved by NMED on July 10, 2012 (NMED 2012, 520923). A proposed revision to the work plan for redevelopment of R-61 was submitted to, and approved by, NMED on August 30, 2012 (Kulis 2012, 227669). Redevelopment activities were undertaken at well R-61 between September 4 and October 29, 2012 (LANL 2013, 239229). Field activities conducted as part of the redevelopment included specific capacity testing, removal of the dedicated Baski sampling system, video logging, introduction of well-development chemicals and physical redevelopment, purging with temporary pumping assemblies and sampling, reinstallation of the sampling system, and purging and sampling.

Three separate chemical treatments were selected for the well-development phase of this activity (LANL 2013, 239229). The first treatment chemical was a caustic solution of potassium hydroxide (KOH) and Johnson Screens Nu-Well 320 biocaustic dispersant. The purpose of this treatment was to enhance the solubility of minerals, biological debris, and hydrocarbon residues. The second treatment was a bioacid polymer solution of Nu-Well 120 liquid (phosphoric) acid and Nu-Well 310 bioacid dispersant. The purpose of this treatment was to break down any biofilm that might be present, disperse mineral salts, and further enhance removal of hydrocarbon chemicals. The final treatment was a chlorine solution of sodium hypochlorite (NaOCl) and Nu-Well 410 chlorine enhancer. The purpose of this treatment was to sanitize the well screens and filter packs and promote additional removal of iron (Fe) and manganese (Mn) scale, biofilm, and hydrocarbons.

Following completion of redevelopment activities, the sampling system for well R-61 was reinstalled between October 18 and October 21, 2012, and additional pumping was conducted sequentially in each screen. The remainder of this report examines geochemical characteristics of groundwater samples collected from well R-61 following redevelopment, and it evaluates the usability of present-day water quality data for R-61 S1.

3.0 CONCEPTUAL MODEL

Figure 3.0-1 depicts a conceptual model showing how parts of the aquifer next to R-61 S1 are affected by residual drilling products and chemicals introduced during redevelopment activities. The discussion below presents the basis for the conceptual model.

The regional aquifer at R-61 was drilled by advancing 12-in. drill casing using a downhole underreaming hammer (LANL 2011, 206492). Fluids introduced into the borehole during drilling included compressed air, municipal water, and AQF-2 drilling foam to remove cuttings. Hammer oil was injected into the compressed air introduced into the borehole during drilling to lubricate the hammer bit. The addition of AQF-2 to the drilling fluid for well R-61 ceased when the borehole reached a depth of 1992 ft bgs, approximately 109 ft above the regional aquifer water table.

During drilling, approximately 3762 gal. of potable water was added below the regional aquifer water table. An additional 20,165 gal. was added during installation of the annular fill materials below the water table. Approximately 23,927 gal. of potable water was introduced below the water table during drilling and construction, over approximately 165 vertical feet of strata next to the borehole wall. The well was developed between May 4 and 15, 2011 (LANL 2011, 206492). Initially, approximately 1075 gal. of composite groundwater from both screens was removed during bailing activities to remove formation fines from the filter packs and the well sump. Each screened interval was then developed individually, using a submersible pump with an inflatable packer to isolate the two screens. At R-61 S1, approximately 2992 gal. was removed during development, and an additional 1931 gal. was pumped during the aquifer test. At R-61 S2, approximately 8308 gal. was removed during development and an additional 29,939 gal. was pumped during the aquifer test.

Reducing conditions were present in the completed well after the Baski sampling system was installed from July 26 to 28, 2011, two and a half months after completion. Reducing conditions indicate some residual drilling fluid remained trapped in the formation around the well screen, leading to increased microbial activity.

The chemical consequences of small amounts of residual AQF-2 that may have been carried downhole after cessation of use are generally minimal because its soluble constituents (e.g., Na and sulfate [SO_4]) are readily flushed from the formation during development and subsequent sampling events. The less soluble organic constituents in AQF-2 biodegrade within a few months in oxic groundwater. In contrast with AQF-2 characteristics, hammer oil is insoluble and is designed to adhere to formation solids to reduce friction on the hammer bit. For this reason, the use of hammer drilling is generally discouraged in the screened interval if possible. The highly adhesive nature of hammer oil prevents it from penetrating more than a few centimeters beyond the borehole wall, although deeper penetration can occur in washouts and highly permeable zones (depicted as light green areas next to the borehole in Figure 3.0-1).

Redevelopment efforts were largely successful in restoring well yield and more oxidizing conditions in the screened interval. However, small amounts of residual drilling products remain, likely trapped in low-permeability strata, and continue to affect the water quality of groundwater samples. The geochemical evaluation presented in section 4.0 supports the finding that the lingering geochemical effects on constituents of interest at well R-61 can be largely overcome by conducting extended purges before sampling, which draws water at greater distances from the well from where it is not affected by pockets of residual drilling products. The blue-dashed contour lines In Figure 3.0-1 schematically show the portions of the aquifer contributing to water samples taken after 3, 6, and 12 casing volumes (CV) are purged from the well.

4.0 EVALUATION OF PRESENT-DAY DATA FROM R-61 S1

An immediate effect of the redevelopment activities was a significant improvement in the aquifer yield for R-61 S1. This screen now shows negligible drawdown when the well is sampled, even during extended purges, and has subsequently sustained improved yield to the present day, nearly one and a half years after redevelopment. However, water-quality data after redevelopment show the groundwater chemistry in the immediate vicinities of both screens is affected by the residual effects of the chemicals used for redevelopment. These geochemical effects persist even after several extended purge events. Section 4.0 addresses the question of whether concentrations of key contaminants are usable for project decisions under current conditions around the well screen. Data for R-61 S2 are included to provide perspective on the manifestation of reducing conditions present in that screen interval.

4.1 Assessment Approach

This report focuses its evaluation on the present-day capability of well R-61 to sufficiently represent the plumes (primarily Cr and ClO_4 and secondarily NO_3) at that location in light of the conditions after redevelopment. Geochemical factors that could potentially affect the representativeness of water-quality data for these constituents include reducing conditions, pH, the formation of soluble complexes with phosphate, and adsorption/desorption from reactive mineral surfaces. The evaluation is based on water-quality data for sampling events occurring after redevelopment (Table 4.1-1 for R-61 S1; comparable information for R-61 S2 is presented in Table 4.1-2).

The following sections examine multiple lines of evidence for this evaluation.

- Section 4.2 identifies classes of constituents that may not be representative of formation water in the screen intervals by examining temporal trends in constituent concentrations and by comparing concentrations at R-61 S1 to site-specific background values and to concentrations in other wells in settings similar to that of R-61 S1. Graphical tools used for the comparison include a Piper (trilinear) diagram, Schoeller plots of major ions and trace metals, and temporal concentration trends for key constituents.
- Section 4.3 examines temporal trends in field parameters monitored during purging as one basis for determining the effectiveness of extended purging to provide representative samples of the key monitored constituents.
- Section 4.4 characterizes redox conditions in the screen intervals using a variety of redox indicators measured in the field and in analytical facilities. Apparent oxidation-reduction potential (Eh) values calculated from these data sets are compared against one another to support a conceptual model about the type and extent of redox conditions that prevail in the vicinity of the screen.
- Section 4.5 considers how geochemical effects of redevelopment chemicals could affect interactions of Cr with reactive mineral surfaces in the screened interval.

- Section 4.6 presents data for Cr concentrations and Cr isotope signatures to evaluate Cr speciation at R-61 S1 during recent extended purge events. The Cr isotope data are also used as an additional means to evaluate whether reducing conditions are present or are otherwise affecting Cr concentrations.

4.2 Evaluation of Current Condition in R-61 S1

This section compares the major element chemistry of groundwater sampled at R-61 S1 with that found in nearby wells. The purpose of this comparison is to identify classes of constituents that appear to be impacted by current geochemical conditions in the vicinity of the screen interval. This preliminary step sets the stage for more in-depth examination of geochemical processes that can account for the observed effects at R-61 S1. An important part of the evaluation is the comparison of geochemical data at R-61 S1 with data from other wells in the vicinity of well R-61. Wells selected for this comparison (R-15, R-44 S1, R-45 S1, and R-50 S1 [Figure 1.0-1]) have well screens near the regional aquifer water table and are situated along the southern periphery of the Cr plume beneath Mortandad Canyon. Well R-13 is also included as a local background well for the Cr and ClO_4 contaminant plumes. Analytical data for these additional wells are also included in Appendix B.

Tables 4.2-1 and 4.2-2 summarize analytical data for common inorganic ions in groundwater at R-61 S1 and R-61 S2, respectively. Tables 4.2-3 and 4.2-4 summarize data for trace metals in groundwater from R-61 S1 and R-61 S2. The data for R-61 S1 are examined for stability and for significant differences from background concentrations and contaminant trends using several standard graphical techniques.

Trilinear Diagrams (Piper plots)

Figure 4.2-1 characterizes major-ion chemistry at R-61 S1 relative to the chemistry at other local regional monitoring wells on a trilinear diagram, also called a Piper plot. In this diagram, major ions are plotted as percentages of meq/L in two base triangles. Total concentrations of cations and anions (expressed in meq/L) are each set equal to 100%, and the data points in the two triangles are projected onto an adjacent diamond-shaped grid. The main purposes of the Piper plot are to show clustering of data points to indicate samples with similar compositions and to illustrate temporal trends in geochemistry that result from groundwater mixing or reequilibration at a specific location—in this case, R-61 S1.

The Piper plot in Figure 4.2-1 includes samples collected from R-61 S1 and other select monitoring wells. The major-ion chemistry of R-61 S1 at the end of the aquifer test on May 20, 2011, is plotted with a red star; this sample is closest to being representative of pre-drilling groundwater (with a caveat about Na concentrations noted below). Following the injection of treatment chemicals, including KOH, during redevelopment activities (Section 2.0), relative proportions of cations in the water samples shifted significantly to higher proportions of the major monovalent cations, Na + K, relative to the major divalent cations, calcium (Ca) + magnesium (Mg). The magnitude of this shift is shown by the orange square symbol representing the first sample collected after redevelopment on November 15, 2012. Subsequently, the proportions of major cations in each quarterly sample have recovered steadily to the extent that the two most recent samples (shown by a pink square for November 15, 2013, and black star for January 23, 2014) are nearly indistinguishable from that for the aquifer test sample on May 20, 2011. The cation trend observed on the Piper diagram during serial sampling of R-61 S1 is likely the result of cation-exchange reactions on mineral surfaces. The anions show a less pronounced trend because they are less affected by ion-exchange processes.

Figure 4.2-2 illustrates these same steadily improving geochemical trends occurring at R-61 S1 during each of five extended purge events conducted in 2013 and 2014. The plot includes samples collected at the end of each day during a 5-d purge event in late April and early May 2013, as well as sets of time-series samples collected at 3, 6, 9 and 12 CV during four 1-d purge events. As in Figure 4.2-1, the groundwater attains stable major-ion chemistry after purging 3 CV to 6 CV for the two most recent sampling events, such that the last two samples in each time-series set plot on top of each other on the figure. It is noted that samples collected at R-61 S1 under the IFGMP (Figure 4.2-1) were collected at either 3 CV or 6 CV, in accordance with requirements in EP-DIV-SOP-20032, Groundwater Sampling. Time-series samples were collected throughout these extended purges, including after the IFGMP samples had been collected, as part of a special study (Table 4.1-1). However, because stability in the relative proportions of major ions present in the samples is attained by 3 CV or 6 CV in each purge event, the IFGMP samples plot at nearly the same position in Figure 4.2-1 as the 12-CV time-series sample for that event in Figure 4.2-2.

Schoeller Plots

Effects of redevelopment chemicals on relative proportions of the major anions included on a trilinear plot (carbonate alkalinity, SO_4, and Cl) are comparatively minor for R-61 S1. However, this graphical tool cannot address chemical effects on other major anions in the screened interval, notably, NO_3, ClO_4, and phosphate (PO_4), nor is it useful for identifying effects on trace metals. For this purpose, a more detailed picture of the classes of constituents affected by residual conditions in R-61 S1 after redevelopment emerges in the set of temporal fingerprints of inorganic constituents at R-61 S1 depicted on a Schoeller plot (Figure 4.2-3). Schoeller plots are semilogarithmic diagrams originally developed to represent major ion analyses in meq/L and to show different hydrochemical water types on the same diagram. This type of graphical representation has the advantage that, unlike the trilinear diagram, actual sample concentrations are displayed and compared. The modified Schoeller plot used for the assessment represents results in units of mg/L or µg/L.

The upper plot in Figure 4.2-3 shows concentrations of major ions and ClO_4 in R-61 S1, and the lower plot shows concentrations of trace metals. Geochemical fingerprints are shown for five samples collected from R-61 S1: the sample collected after the aquifer test on May 20, 2011 (plotted as a red line) and the four most recent quarterly monitoring samples collected after redevelopment. The gray-shaded band on each plot shows the 5th to 95th percentile range of background concentrations for these naturally occurring inorganic constituents in a similar hydrogeologic setting. The development and use of these background values were first described in a report titled “Reliability Assessment of Well R-47i” (LANL 2011, 201564), in which groundwater background values were derived from data for deep wells screened in the Puye Formation or the Cerro Toledo interval. This set of background values can be viewed as representative of deep groundwater underlying the central Pajarito Plateau in an area roughly bounded by Mortandad and Water Canyons and has been used in several recent NMED-approved reports (e.g., LANL 2012, 228624; LANL 2012, 213573). The 5th and 95th percentile concentrations calculated from this data set are included on the Schoeller plots in Figure 4.2-3 to facilitate quick visual identification of possible excursions from background geochemical conditions.

For major ions and ClO_4, the most significant excursions from background concentrations after redevelopment [Figure 4.2-3(a)] are summarized below:

- An elevated concentration of Na in the aquifer-test sample (May 20, 2011) can be attributed to a small component of residual Na released from the bentonite clay seal or from drilling foaming agent AQF-2. This observation is a common but relatively short-lived effect in many newly constructed monitoring wells. In all samples after redevelopment, Na concentrations have attained levels representative of pre-drilling groundwater.

- Elevated but stable (or slightly increasing) concentrations of SO_4, Cl, NO_3, and ClO_4 are attributable to Sandia and Mortandad contaminant sources.
- Elevated but decreasing concentrations of K and PO_4 (as Total P) in samples after redevelopment are attributable to residual chemical products associated with redevelopment. The slow rate at which concentrations of these constituents decrease over time indicates their mobility may be limited by mineralogical controls or ion-exchange reactions.

For trace metals, the most significant excursions from background concentrations after redevelopment [Figure 4.2-3(b)] are summarized below:

- Elevated concentrations of Mn, molybdenum (Mo), and zinc (Zn) in the aquifer-test sample (May 20, 2011) are likely associated with placement of the bentonite clay seal, from which these trace metals may be released as soluble anions (MoO_4^{2-}) or attached to suspended clay colloids (Mn^{2+}, Zn^{2+}) as the bentonite settles and compacts (LANL 2007, 096330, Table A-10). In recent samples, concentrations of Mo and Zn are within the range of local background.
- Dissolved Mn and Fe concentrations remain slightly elevated above local background levels in recent samples. The implications of this observation for the oxidation state of Cr are evaluated in section 4.5.
- Elevated and slightly increasing concentrations of Cr are attributable to Sandia and Mortandad contaminant sources.
- Negligibly low concentrations of uranium (U) in samples collected after redevelopment are attributable to co-precipitation or surface complexation with PO_4–bearing minerals that formed from mixing of phosphoric acid chemicals with native groundwater.

Temporal Trends in Concentrations

Concentrations of constituents plotted over time for R-61 S1 and nearby wells provide a visual tool for distinguishing the residual effects of drilling, construction, and redevelopment materials from those attributable to the presence of contaminant plumes in the area. Concentration trends at R-13 and other local monitoring wells beneath Mortandad Canyon along the periphery of the Cr plume are used to establish bounds on concentrations that could be expected to be present at R-61 S1.

Figure 4.2-4 depicts trends for selected major ions and phosphate, which are not contaminants of concern. The following observations are noted for this figure:

- In Figures 4.2-4a–c, concentrations of Na, Cl, and SO_4 in samples collected at R-61 S1 after redevelopment fall within the range established by local background groundwater (R-13) and other local monitoring wells beneath Mortandad Canyon along the periphery of the Cr plume at which Cr concentrations are less than 30 µg/L. Consistency with these nearby wells provides evidence that Na, Cl, and SO_4 concentrations at the present day are representative of groundwater at R-61 S1.
- In contrast, in Figures 4.2-4d–e, K and phosphate (PO_4) are persistently elevated in all samples from R-61 S1 after redevelopment, orders of magnitude above concentrations observed at other local monitoring wells (Figures 4.2-4d and 4.2-4e). These excursions at R-61 S1 can be attributed to residual concentrations of KOH and phosphoric acid chemical treatments used during redevelopment.

- Finally, Figure 4.2-4f shows that calcium concentrations at R-61 S1 after redevelopment are persistently lower than at other local wells, which is attributed to interactions with PO_4-bearing precipitates. Although not plotted, uranium concentrations are similarly impacted at R-61 S1.

Figure 4.2-5a–c plots concentrations of three local contaminants of concern—Cr, ClO_4, and NO_3. The following observations are noted for this figure:

- As with Na, Cl, and SO_4, concentrations of Cr in samples collected at R-61 S1 after redevelopment fall within the range established by local background groundwater (R-13) and other local wells at which Cr concentrations are less than 30 µg/L.
- The presence of the ClO_4 plume is manifested at R-61 S1 by present-day concentrations of ClO_4 similar to those at R-15, whereas concentrations of this contaminant are near background levels at the other wells shown in Figure 4.2-5.
- In every case, concentrations of Cr and the cocontaminants at R-61 S1 fall within the bounded regions of these plots and show a consistent relationship to trends at other nearby regional monitoring wells.

In summary, a variety of graphical data presentations provides lines of evidence that current geochemical effects appear to be limited to two categories of constituents, both of which could be attributed to the residual effects of redevelopment chemicals:

- constituents introduced as redevelopment chemical products and that cannot be flushed readily from the screen interval (K and PO_4) and
- sequestering of bivalent cations (notably Ca) and U from the formation of surface complexation or coprecipitation with PO_4-bearing minerals.

There is no compelling evidence in the preceding evaluation that concentrations of Cr, ClO_4, or NO_3 are impacted significantly by conditions at R-61 S1 after redevelopment.

4.3 Field Data

This section presents time-series data for field parameters monitored during purging before sample collection at R-61 S1. The field parameter data are presented to identify trends during purging and to assess whether stable values were attained by the end of purging. Time-series field-parameter data are presented for recent sampling events at R-61 S1 after redevelopment—the 3-CV purge on May 17, 2013, and 12 CV extended purges on July 15, 2013, November 15, 2013, and January 23, 2014 (Figure 4.3-1). Figure 4.3-2 and Table 4.3-2 present final field parameters for samples collected at R-61 S1 under the IFGMP, starting with the end of the aquifer test in May 2011 and extending to January 23, 2014. Examination of these data yields the following observations.

- Minimal water-level drawdown during purging has been sustained throughout the sampling events after redevelopment, including multiday extended purges (Figure 4.3-1h; Figure 4.3-2g), indicating hydraulic conditions that affect drawdown during purging and that existed shortly after the well was completed have improved following redevelopment;
- Final field parameter values for dissolved oxygen (DO) and oxidation-reduction potential (ORP), show significant improvement after redevelopment and fall within the range of background values for regional groundwater, compared to values observed for sampling events conducted before redevelopment (Figure 4.3-2a, Figure 4.3-2d); and

- The pH values remain consistently lower in recent samples and below the range of background values for regional groundwater compared with values observed following the aquifer test and in other samples collected before redevelopment (Figure 4.3-2c). The decrease in pH is attributed to the pH-buffering effect of PO_4 minerals precipitated in the vicinity of the screened interval.

4.4 Characterization of Redox State of Groundwater

This section examines redox conditions in the regional aquifer in the vicinity of R-61 and discusses how these conditions may affect the speciation of Cr in groundwater around the well. Field parameters and concentrations of redox-sensitive trace metals and nonmetals are used to assess redox conditions in current water samples collected at R-61 S1.

Under conditions typical of the local regional aquifer, dissolved Cr is expected to be present predominantly as the oxidized hexavalent species, CrO_4^{2-}, which is highly mobile. Reduced trivalent Cr species such as chromium hydroxide [$Cr(OH)_3$] are relatively insoluble. At the end of the aquifer test at R-61 S1 on May 20, 2011, field data [Eh = +0.51 volt (V) and pH 7.5, Table 4.3-1] indicate the predominance of dissolved Cr as CrO_4^{2-}. As reducing conditions developed in the screen interval during the next few months, Eh determined from ORP data dropped to +0.18 V (February 7, 2012; Table 4-3.1), indicating the predominance of Cr as the reduced trivalent species. Following redevelopment, conditions near the screened interval once again became more oxidizing (Eh = +0.36 V on January 23, 2014, Table 4.3-1) but also slightly acidic (pH 6.7), under which Cr(III) would be the most stable species (if kinetic rates of the reduction reaction are not considered; see section 4.5).

Prediction of Cr oxidation states from ORP measurements, however, is inappropriate when nonequilibrium conditions are present in the groundwater. This section examines geochemical lines of evidence concerning redox conditions, and identifies those indicators most relevant for dissolved Cr. Apparent redox conditions in R-61 S1 are characterized not only using field measurements of DO and ORP (Table 4.3-1) but also laboratory measurements of redox-sensitive species of trace metals (Fe and Mn) and nonmetals (N and S) (Table 4.4-1; corresponding data for R-61 S2 are shown in Table 4.4-2). Potentially relevant redox reactions involving these redox species are listed in Table 4.4-3. The standard electrode potentials listed for each reaction in Table 4.4-3 are used to calculate apparent Eh values (discussed below) from the measured concentrations listed in Table 4.4-1.

Key observations about these data are listed below:

Redox-sensitive trace metals (Mn and Fe)

- *Manganese* is detected in every filtered sample from R-61 S1. Calculations presented here assume the concentrations are the reduced species, Mn(II), in equilibrium with a Mn(IV/III) or Mn(IV) oxide mineral. Concentrations indicate apparent Eh values below +0.73 V for samples after redevelopment. Measurable concentrations of dissolved Mn(II) in groundwater indicate a potential for reductive dissolution of MnO_2. Mn(IV) in MnO_2 is an important mechanism for oxidizing any dissolved Cr(III) to Cr(VI) and thus for maintaining Cr(VI) as the dominant oxidation state in formation water. This mechanism for maintaining Cr(VI) in solution would be ineffective in parts of the formation in which Mn-reducing conditions were present. Caveats that apply to this interpretation are presented in section 4.5.

- *Iron* is also detected in every filtered sample from R-61 S1. Assuming the concentrations are the reduced species, Fe(II), in equilibrium with amorphous or poorly crystallized $Fe(OH)_3$ precipitated near the screen, apparent Eh values calculated for the Fe(III)/Fe(II) redox couple are less than +0.25 V. At these Eh values, a simple model might indicate that only Cr(III) would be present in the groundwater. However, a number of other factors present around the well screen appear to control observed speciation, as discussed in sections 4.5 and 4.6.

Field parameters (DO and ORP)

- *Dissolved oxygen* is detected in every sample from each screen, resulting in a narrow range of Eh values averaging +0.81 V for samples after redevelopment. However, this result is not relevant to ensuring that Cr(VI) is the stable oxidation state because DO is not an effective oxidizing agent for Cr(III).
- *Eh values* calculated from field ORP data at R-61 S1 trend upward during extended purge events conducted after redevelopment and approach a plateau value, suggesting conditions become more oxidizing as more water is pumped (Table 4.3-1 and Figure 4.3-1[d]).

Redox-sensitive nonmetals (N and S)

- *Nitrate* is detected in every sample analyzed from three most recent extended purge events at R-61 S1, indicating apparent Eh values extending above +0.48 V for samples after redevelopment. However, like DO, this result is not relevant to the question of Cr oxidation state because neither NO_3 nor nitrite (NO_2) are oxidizing agents for Cr(III).
- During the extended purge event on July 15, 2013, *sulfide* is detected only in filtered samples collected from the screens in the pre–1 CV and the 1 CV samples. No sulfide is detected in subsequent filtered samples. Thus, SO_4-reducing conditions and associated sulfide minerals might be present but appear to be limited to the immediate vicinity of the screens. This result is relevant to the Cr oxidation state immediately adjacent to the screen because Cr(VI) can be reduced by sulfide, but this potential effect is limited to the early part of purging.

Caveats about the interpretation of Eh values

The wide disparity observed in the Eh values calculated using different redox couples highlights limitations of such an approach, which include the following.

- ORP is a qualitative measurement in that many factors, such as availability of information on redox pairs that are present, or reaction kinetics in solution, limit its interpretation. ORP is best used for comparative measurements over time. The ORP probe measures an average of the redox couples to which it is sensitive. It is relatively insensitive to DO, NO_3, NO_2, and SO_4. In the case of R-61 S1, the probe appears to be responding primarily to Mn and Fe redox couples based on the observation that Eh values calculated from the ORP data for R-61 S1 (+0.35 V on January 23, 2014) fall between the upper bounds of the ranges calculated from the data for $Fe(OH)_3/Fe^{2+}$ (+0.25 V) and MnO_2/Mn^{2+} (+0.73 V).
- Most natural waters do not achieve redox equilibrium. In general, no single value of Eh can be used to represent the redox state. Instead, there is a distinct value for each redox couple in the system. The variation among the resulting values of Eh provides a qualitative indication of the extent of disequilibrium in a system.

- Formation of complexes of Fe(II), Fe(III), and Mn(III/IV) with solid or aqueous ligands (especially PO_4 at well R-61) significantly affects redox reactions by either inhibiting or enhancing the kinetics of reactions in which these species are involved (Lijklema 1980, 249298; Kawashima et al. 1986, 249297; Nico and Zasoski 2000, 249299). This aspect is discussed further in section 4.5.
- Representation of an oxidation/reduction process by a single redox couple is an over-simplification. These processes generally involve multiple steps, in which each step is governed by reaction-specific kinetics and potentials (e.g., Fendorf 1995, 249296; Buerge and Hug 1999, 249295). As a result, a redox action that appears to be thermodynamically favored may not occur because a rate-limiting step is involved.
- Microbial effects on redox conditions are not addressed explicitly in this report. However, microbial communities exist by using redox disequilibria to obtain energy from their environment and almost certainly are present in the vicinity of the screened intervals. The presence of bacteria with the capability to either reduce or oxidize Cr could either enhance or inhibit redox changes to Cr in the system.

In summary, in the absence of detailed knowledge of the Fe- and Mn-bearing minerals in the aquifer, interpretation of redox-couple data is largely inferred. However, the extent of inconsistency among apparent Eh values calculated using the different redox couples generally reflects the extent of disequilibria of the groundwater with the materials with which it is in contact in the screened interval. Another caveat is the need to identify and focus on the redox indicators that are most relevant for the species of interest. For example, the most relevant abiotic redox couples for assessing the stability of Cr oxidation states are Cr(VI)/Cr(III), Fe(III)/Fe(II), and Mn(III/IV)/Mn(II). DO, N-containing, and S/SO_4 redox couples are not directly relevant to determining the oxidation state of Cr at R-61 S1.

4.5 Evaluation of Chromium Reactions with Reactive-Mineral Surfaces

This section evaluates potential reactions of dissolved Cr with the surfaces of minerals likely to be present in the aquifer media. In particular, this evaluation identifies mineral surfaces which act as Cr(VI) reductants or Cr(III) oxidants, both of which can affect the concentrations of Cr species in groundwater samples.

In the absence of solubility-controlling solids, such as amorphous or crystalline $Cr(OH)_3$, at well R-61, it would be expected that the primary controls on aqueous Cr(VI) concentrations under acidic to slightly alkaline conditions are adsorption/desorption processes on reactive mineral surfaces (Rai et al. 1989, 249300). The most relevant reactive mineral surfaces in well R-61 are amorphous Fe (oxy)hydroxides, MnO_2, and probably PO_4 minerals with an apatite or hydroxyapatite structure which can accommodate many substitutions.

Evaluation of Potential Cr(VI) Reductants

In natural waters, organic material, sulfides, and ferrous species appear to be the dominant reductants of Cr(VI) to Cr(III) (Rai et al. 1989, 249300; Richard and Bourg 1991, 107034). As mentioned in section 4.4, one may expect that Cr(VI) would directly transform to Cr(III) under reducing conditions. However, data from R-61 S1 show that significant Cr reduction is not occurring for samples collected after extended purging (section 4.6) because of the slow kinetics of this reaction. The 3-electron transfer required for Cr(VI) reduction to Cr(III) under environmental conditions requires that the equilibrium must be overstepped by a large amount. In other words, simply being slightly below the Cr(VI) stability field in Eh-pH space is not enough to cause the reduction in a reasonable period of time. Conditions must be substantially below the Cr(VI) field for reduction to occur.

In R-61 S1, Fe(II) would normally be the most suitable abiotic reductant for Cr(VI). However, Fe concentrations are only slightly above quantitation limits in recent samples from R-61 S1 and at these levels do not lead to lower Cr concentrations (Figure 4.5-1a). Fe(II) is probably not readily accessible to reduce Cr(VI) because residual PO_4 from redevelopment treatment chemicals is present and forms strong complexes with Fe(II) (e.g., Lijklema 1980, 249298). Furthermore, because of the low solubility of PO_4 minerals, the elevated PO_4 concentrations are not expected to decline to background levels representative of pre-drilling conditions within the next few years. Phosphate minerals also act as a pH buffer for groundwater passing through the screened interval, such that the pH in groundwater samples is expected to remain at its current slightly acidic value (pH 6.6 to pH 6.9, Table 4.3-1) in R-61 S1 for the foreseeable future.

Evaluation of Potential Cr(III) Oxidants

It is reasonable to postulate that $Cr(OH)_3$ may have precipitated in the vicinity of well R-61 before redevelopment via reduction of soluble Cr(VI) to insoluble Cr(III) by residual drilling-related organic products. In that case, one might expect that Cr concentrations in samples after redevelopment might be elevated relative to unimpacted groundwater as a result of reoxidation of this Cr(III) precipitate to soluble Cr(VI) during extended purges. Mn oxides are the only naturally occurring oxidant of Cr(III). Oxidation of Cr(III) to Cr(VI), although poor with DO, is very effective in the presence of solid MnO_2. However, there is no evidence that such oxidation, if occurring, has a significant influence on Cr concentrations (Figure 4.5-1b). A feasible explanation is that oxidation of Cr(III) by precipitation onto a MnO_2 surface can be restricted by competitive sorption (Fendorf 1995, 249296), which is likely to be the case for Mn sorbing or precipitating onto PO_4 mineral surfaces at well R-61. Mn(III) appears to be an important intermediate in the Cr(III) oxidation path, but PO_4 can limit the availability of Mn(III) and Mn(IV) to oxidize Cr(III) through complexation (Nico and Zasoski 2000, 249299). In addition, as in the case of Fe, Mn(III/IV) availability can be inhibited by incorporation of this species into minerals and by sorption onto PO_4 mineral surfaces (Kawashima et al. 1986, 249297).

4.6 Chromium Speciation and Stable Isotopes

This section presents time-series data for Cr concentrations collected during extended purges of R-61 S1. Concentrations in filtered (<0.45 µm), microfiltered (<0.02 µm), and unfiltered samples are compared with assess chromium speciation and identify trends in Cr concentrations during purging. Cr stable isotope data are used in conjunction with Cr(VI) concentrations to assess the oxidation state and stability of dissolved Cr during extended purges.

Chromium Speciation in Filtered Samples

Trends of increasing Cr concentrations during the most recent extended purge (Figure 4-6.1) suggest the possibility that samples may still contain a fraction of impacted groundwater, even at the end of the extended purge. If so, there could be a slight low bias in Cr concentrations in the samples obtained so far, relative to concentrations in groundwater outside the impacted zone around the well screen at R-61. Alternatively, the trends may reflect a contribution attributable to spatial variability in the plume, manifested during long purges by increased contributions from groundwater pulled into the screen from greater distances along faster paths.

No data are available for Cr(III) concentrations in groundwater. A simplistic approach is to estimate Cr(III) as the difference between the concentrations measured in unfiltered and filtered pairs of samples, assuming that the concentrations in the filtered samples represent Cr(VI). When this approach is used, Cr(III) appears to be minimal at R-61 S1 because total Cr concentrations in unfiltered and filtered samples are essentially the same for samples after redevelopment (Figures 4.6-1 and 4.6-2a). However, a more definitive result is obtained by comparing Cr concentrations in filtered and microfiltered samples. Microfiltration of the water sample removes colloids, which otherwise are small enough to pass through the standard filter size of 0.45 µm. Cr concentrations in microfiltered samples collected during the latter stages of extended purges are about 20% less than the total Cr in samples filtered using the standard 0.45 µm filtration (Figure 4.6-2b). The difference may be attributable to the presence of a colloidal fraction of Cr(III) or to adsorption of Cr(VI) on colloidal $Fe(OH)_3$, which has a large surface area and positive charge and is commonly present in groundwater. Either of these mechanisms still provides a bounding concentration of Cr in the Cr plume at the R-61 area. Alternatively, the difference may reflect variability across analytical laboratories or methods.

In R-61 S2, Cr is below detection in all filtered samples, in which case Cr-reducing conditions appear to extend beyond the immediate vicinity of the screen. This result is consistent with the hypothesis that Cr(VI) is the dominant oxidation state for Cr in solution at R-61 S1 but that Cr(VI) is absent from R-61 S2 samples because it is reduced completely to Cr(III) as soon as the groundwater enters the reducing zone next to the screen.

Isotopic Signature of Cr(VI)

Consistent trends observed in the Cr stable isotopic signature of groundwater samples collected during extended purges at R-61 S1 provide compelling evidence that samples collected after purging at least 6 CV provide usable Cr data at this location. The data trends also confirm that Cr(VI) is the dominant oxidation state of dissolved Cr in the groundwater.

In groundwater outside the zone impacted by residual organic chemicals or other materials in the screened interval, the δ^{53}Cr value of dissolved Cr at R-61 S1 is assumed to be similar to that at other regional aquifer wells along the periphery of the Cr plume beneath Mortandad Canyon ($\delta^{53}Cr = 1.12 \pm 0.12$‰; Table 4.6-1). Samples collected at 1 CV during extended purges at R-61 S1 show relatively heavy δ^{53}Cr values of +2.55‰ (July 15, 2013) and +3.40‰ (January 23, 2014) (Table 4.6-2). This heavy signature suggests that a significant fraction of the Cr(VI) in the immediate vicinity of the well had been reduced to Cr(III). During reduction of Cr(VI) to Cr(III), a kinetic isotope effect occurs in which the lighter isotope, ^{52}Cr, reacts preferentially, leaving the remaining dissolved Cr(VI) enriched in the heavier isotope, ^{53}Cr (Heikoop et al. 2014, 255424). The reduced Cr(III) product precipitates out of solution as insoluble $Cr(OH)_3$.

With increased purge volume, increasingly lighter δ^{53}Cr values indicate a decreasing proportion of Cr(VI) affected by reduction, either because of increased mixing with unaffected water farther from the well screen or from reoxidation and dissolution of $Cr(OH)_3$ that had precipitated in the impacted zone before redevelopment restored oxidizing conditions. In Figure 4.6-3 the trend established by the R-61 S1 data shows that, by the final sample (12 CV), δ^{53}Cr and Cr(VI) have attained relatively stable values very similar to those at other Cr plume-edge wells beneath Mortandad Canyon, such as R-11 and R-45 S1. This trend is consistent with the concept presented in section 3.0, according to which an extended purge allows R-61 S1 to sample groundwater beyond the influence of drilling fluids and redevelopment chemicals (Figure 3.0-1).

This simple conceptual mixing model can explain the Cr isotope data trends observed during the purge test. The observed data trend supports the conclusion that, with adequate purging, R-61 S1 yields representative regional aquifer plume-edge δ^{53}Cr values and Cr(VI) concentrations. Furthermore, the data trends for R-61 S1 in Figures 4.6-1 and 4.6-2 shown for the extended-purge event both provide evidence for a limited extent of impacts in R-61 S1, insofar as the concentration and isotopic values approach relatively stable levels after the 3-CV purge.

5.0 SUMMARY

The evaluation of data from R-61 S1 after redevelopment indicates some water-quality parameters are still affected by residual conditions in the aquifer around R-61. The cause is likely related to the presence of residual redevelopment chemicals and their byproducts, but the affected zone surrounding the well screen is limited. However, multiple lines of evidence indicate that concentrations of key monitored constituents (Cr, NO_3, and ClO_4) currently obtained from R-61 S1 are sufficiently representative of groundwater conditions that they can be used to support remediation and monitoring of the contaminant plumes. These lines of evidence include the following.

- Comparison of filtered and microfiltered Cr concentrations during extended purge events indicate that Cr(VI) is the dominant oxidation state of Cr in samples from R-61 S1. These data also suggest that up to 20% of total Cr in filtered samples may be attributed to a colloidal fraction of Cr(III) or to adsorption of Cr(VI) on colloidal $Fe(OH)_3$, either of which still provides a bounding concentration of Cr in the Cr plume at the R-61 area.
- After 6 CVs have been purged, total chromium and Cr(VI) concentrations attain relatively stable values. The Cr isotopic signature, a sensitive indicator of Cr reduction, falls within the range of values at other Cr plume-edge wells in Mortandad Canyon.
- Concentrations of cocontaminants (SO_4, Cl, ClO_4, and NO_3) relative to concentrations of Cr at R-61 S1 are within the range of those found in nearby regional monitoring wells in the plumes beneath Mortandad Canyon, indicating concentrations of Cr and these cocontaminants are not significantly impacted by conditions after redevelopment.
- Final field parameter values for DO and ORP during extended purge events show significant improvement relative to sampling events conducted before redevelopment and are consistent with values expected for the regional aquifer.
- Dissolved Mn and Fe concentrations are only slightly above quantitation limits in recent samples and have no apparent effect on Cr concentrations.
- The stability of NO_3 concentrations in samples after redevelopment indicates the absence of NO_3-reducing conditions and supports the concept that residual effects of drilling products on the redox state of groundwater in the screened interval is a near-field effect.

Because the affected zone around the well screen appears limited to a short radial distance from the well, usable data for key constituents can be obtained by pulling water from beyond this zone through extended purging before sampling. Although secondary, newly formed PO_4 minerals may be present in the formation surrounding the screen, they do not appear to adversely affect the usability of concentrations for the key constituents Cr, NO_3, and ClO_4 monitored at well R-61 S1.

Recommendations

The Laboratory recommends that the upper screen at well R-61 (R-61 S1) be retained for groundwater monitoring. Although some water-quality data remain affected by residual redevelopment chemicals and their byproducts, R-61 S1 is capable of providing data that are sufficiently representative of the plumes in that area. When used in conjunction with data collected for other wells in the Cr groundwater monitoring network, data from R-61 S1 provide useful information about distributions and temporal changes in contaminant concentrations in the Cr and ClO_4 contaminant plumes.

The Laboratory also proposes the following additional recommendations for well R-61:

- Convert well R-61 to a single-screen well, retaining R-61 S1 and sealing off R-61 S2. Data from the lower screen (R-61 S2) are not required for monitoring and remedial decisions at the current phase of the project.
- Explore the possibility of using a larger-capacity pump (e.g. 5 gpm) to increase purging efficiency in R-61 S1, taking advantage of the improved yield following redevelopment.
- Conduct extended purging for future samples at the well and use a variety of field measurements monitored during purging to assess stability and representativeness of groundwater samples.
- Maintain R-61 on a watch list, similar to other wells, and establish trigger levels of specific indicators that would initiate an action if necessary. Key indicators may include increases in concentrations of dissolved Fe and Mn, examination of differences between filtered and nonfiltered results for trace metals, Cr isotope data, increased drawdown during purging, and field parameters that are indicators of reducing conditions.

6.0 REFERENCES

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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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TerranearPMC, July 2013. “Field Summary Report, Mortandad and Sandia (Chromium Investigation and General Surveillance Monitoring Groups) and Pajarito (TA-54 Monitoring Group) Watershed Quarterly Sampling Event 4, 2013 Interim Facility-Wide Groundwater Monitoring Plan, and Other Field Activities from June 24-July 29, 2013,” report prepared for Los Alamos National Laboratory, Los Alamos, New Mexico. (TerranearPMC 2013, 249229)

TerranearPMC, November 2013. “Field Summary Report, Mortandad and Sandia Watershed (Chromium Investigation, MDA C, and General Surveillance Monitoring Groups) Quarterly Sampling Event 1, 2014 Interim Facility-Wide Groundwater Monitoring Plan, and Other Field Activities from September 24-November 25, 2013,” report prepared for Los Alamos National Laboratory, Los Alamos, New Mexico. (TerranearPMC 2013, 252853)

TerranearPMC, January 2014. “Field Summary Report, Mortandad and Sandia (Chromium Investigation and General Surveillance Monitoring Groups) and Pajarito (TA-54 Monitoring Group) Watershed Quarterly Sampling Event 2, 2014 Interim Facility-Wide Groundwater Monitoring Plan, and Other Field Activities from January 7-January 29, 2014,” report prepared for Los Alamos National Laboratory, Los Alamos, New Mexico. (TerranearPMC 2014, 254704)

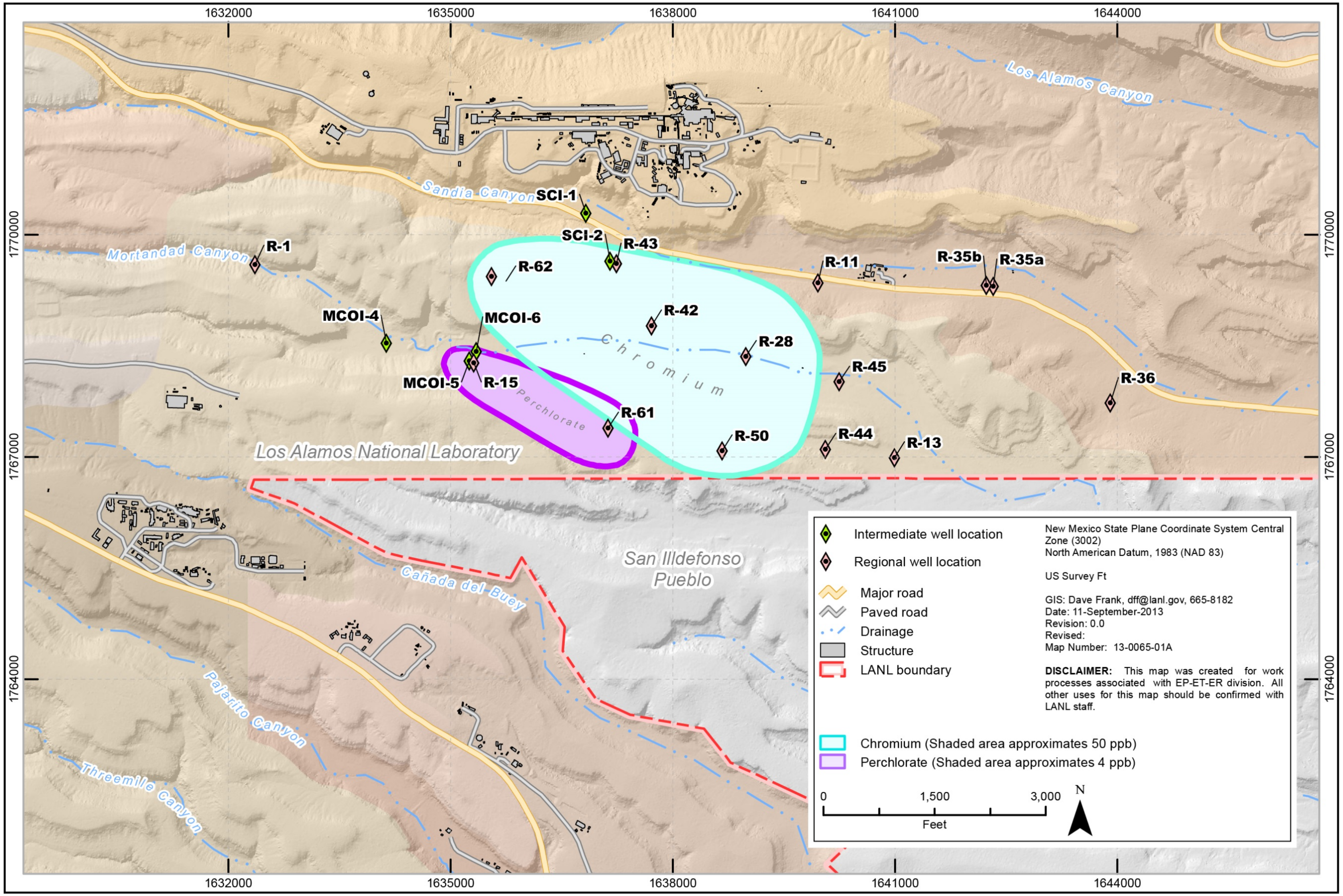
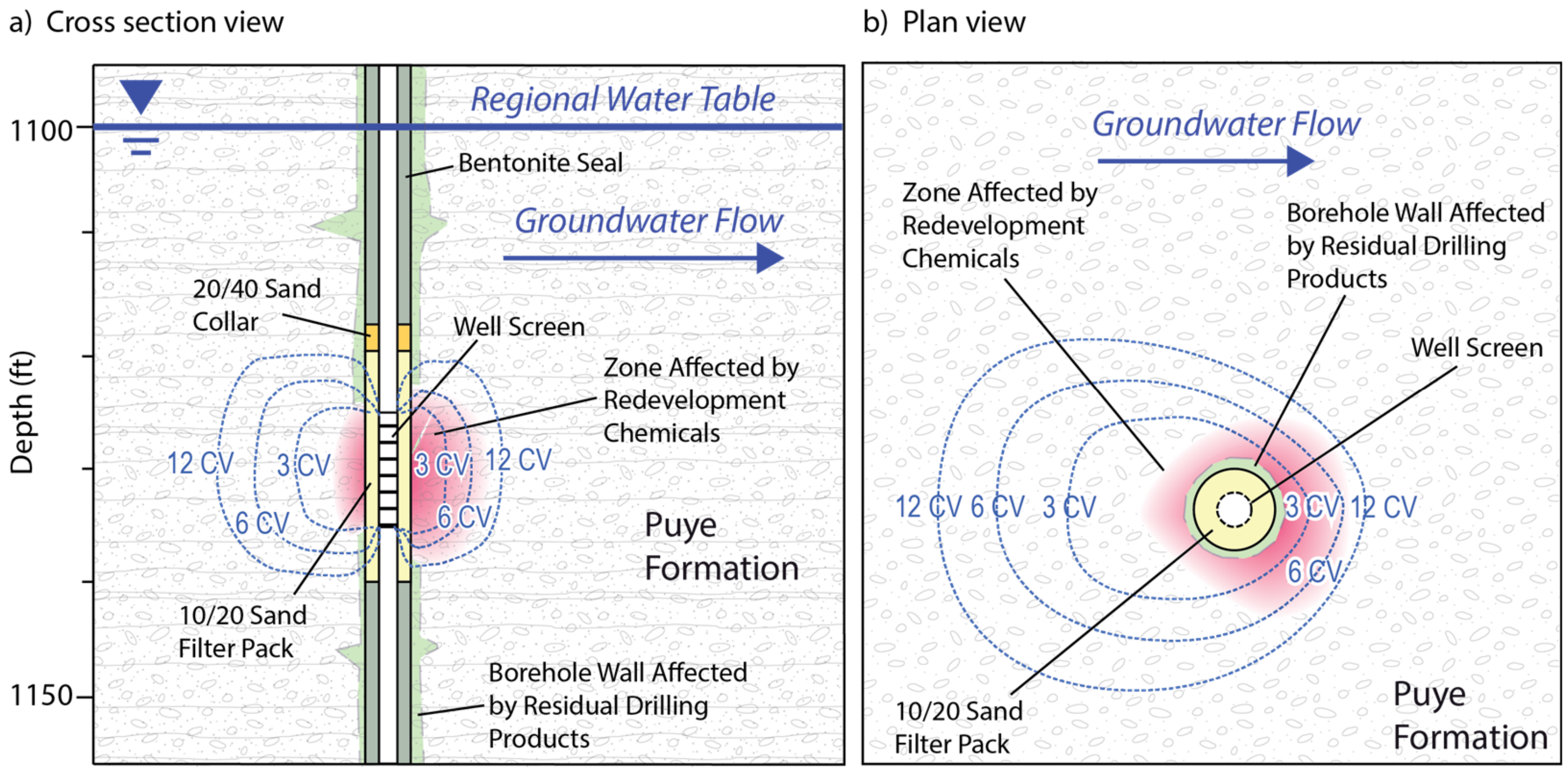


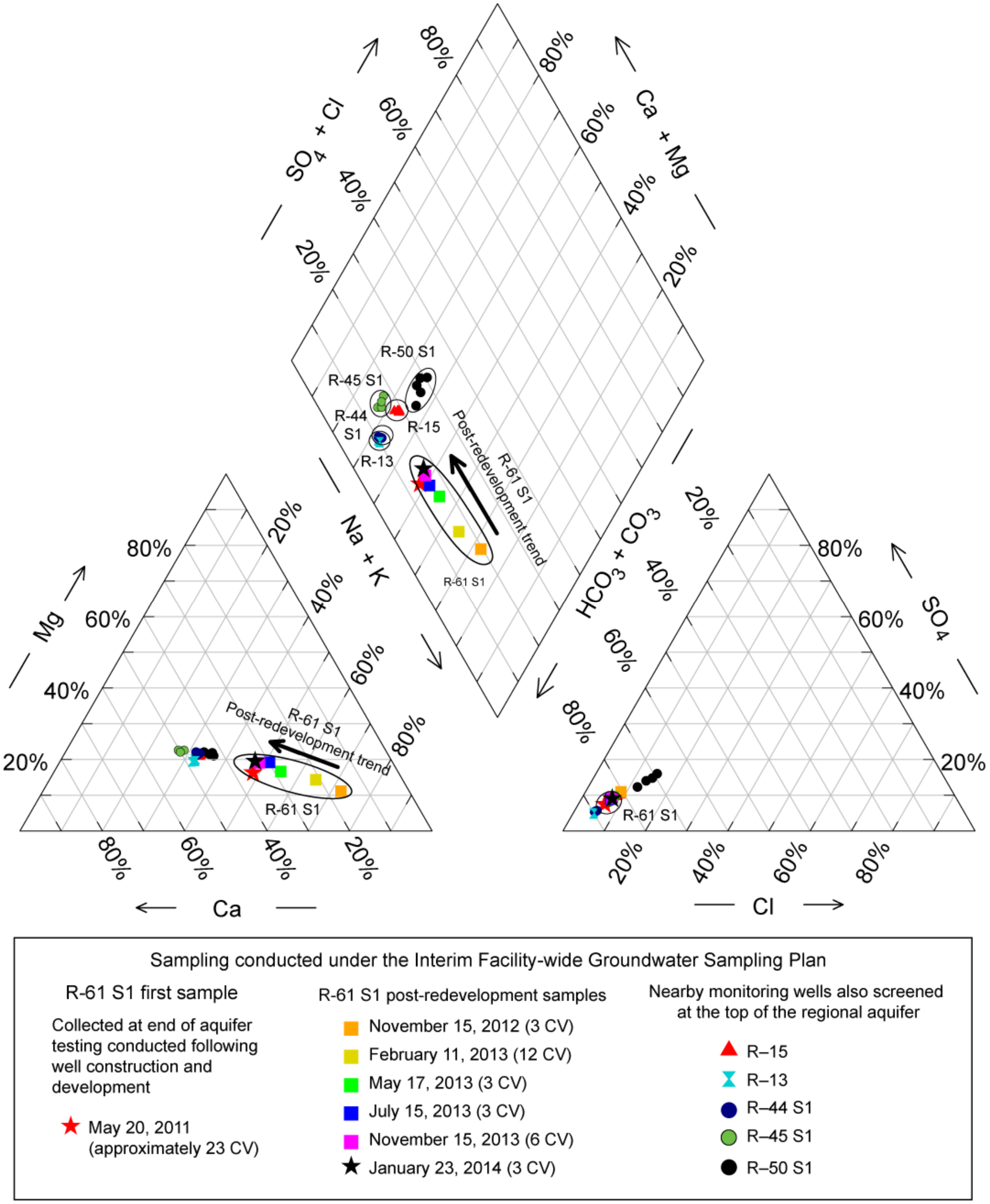
Figure 1.0-1 Location of well R-61


a) Cross section view

b) Plan view

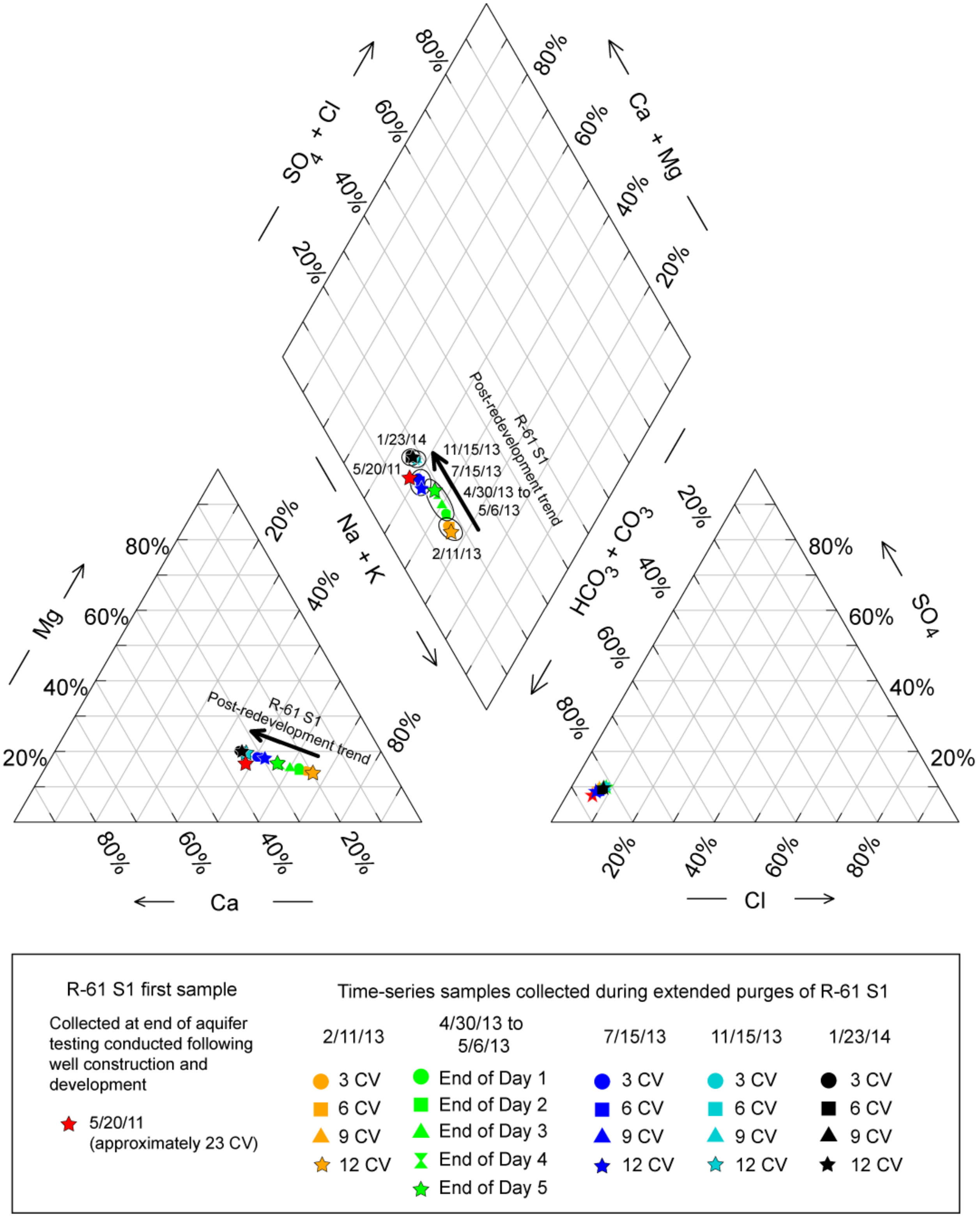
Notes: The light green shaded area adjacent to the installed well represents the borehole wall that is affected by fluids introduced during drilling and is the zone responsible for reducing conditions in initial water samples collected from the well. The width of the light green shaded area is exaggerated for illustration purposes. The light red shaded area represents the zone affected by redevelopment chemicals used to treat the drilling fluids causing reducing conditions. The blue dashed contour lines schematically show the portions of the aquifer contributing to water samples taken after 3, 6, and 12 CV are purged from the well. At R-61 S1, 1 CV corresponds to about 60 gal. Recent groundwater data show that purging between 6 and 12 CV before sampling yields groundwater samples that are representative of key contaminants in groundwater. For scale, the diameter of the well borehole is 1 ft.

Figure 3.0-1 Conceptual cross-section of R-61 screen 1 showing how parts of the aquifer next to the well are affected by drilling fluids and redevelopment efforts



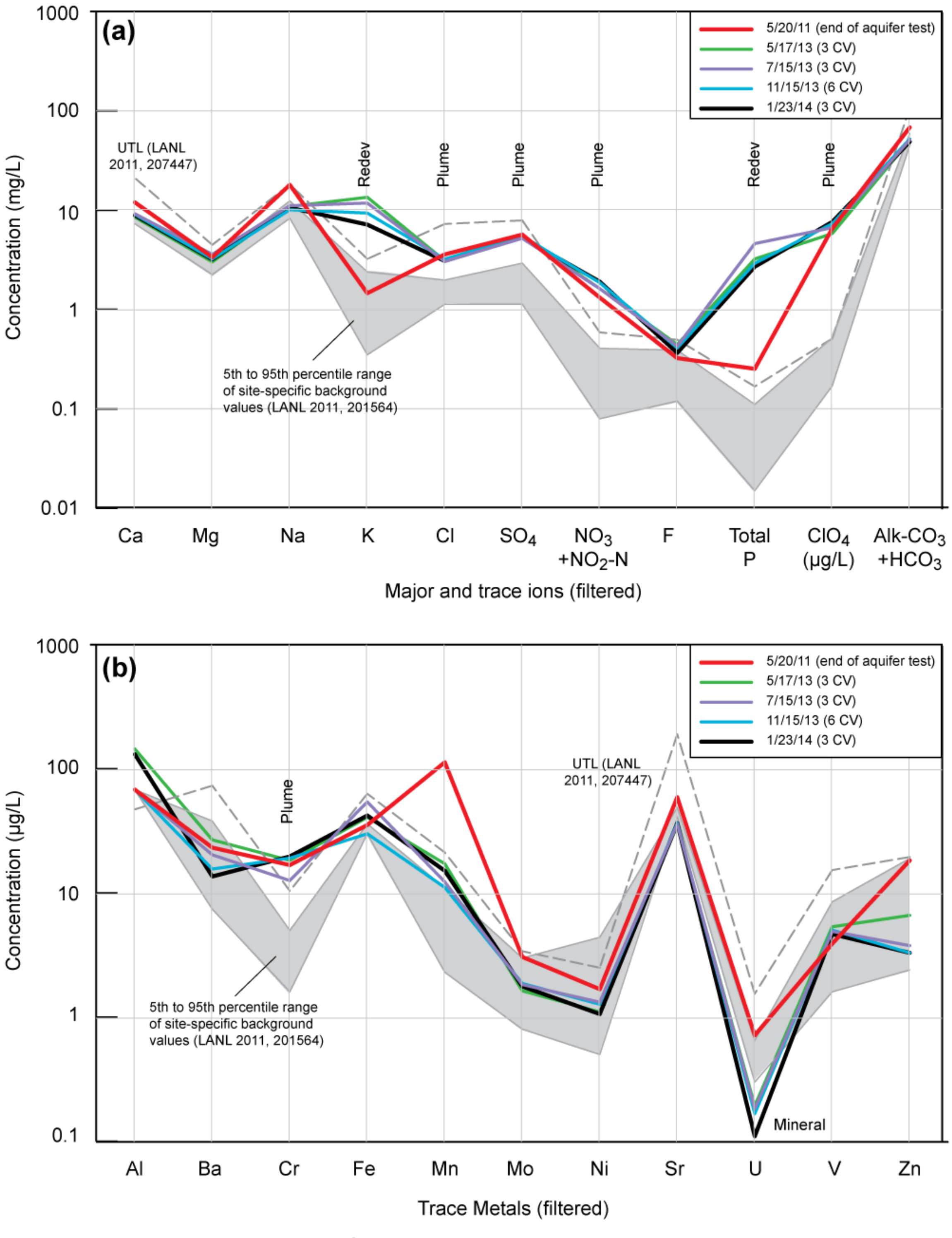
Data source: Table 4.2-1.

Figure 4.2-1 Trilinear plot showing major-ion chemistry of groundwater from R-61 S1 relative to nearby monitoring wells and reequilibration trends for R-61 S1 following redevelopment



Data source: Appendix B.

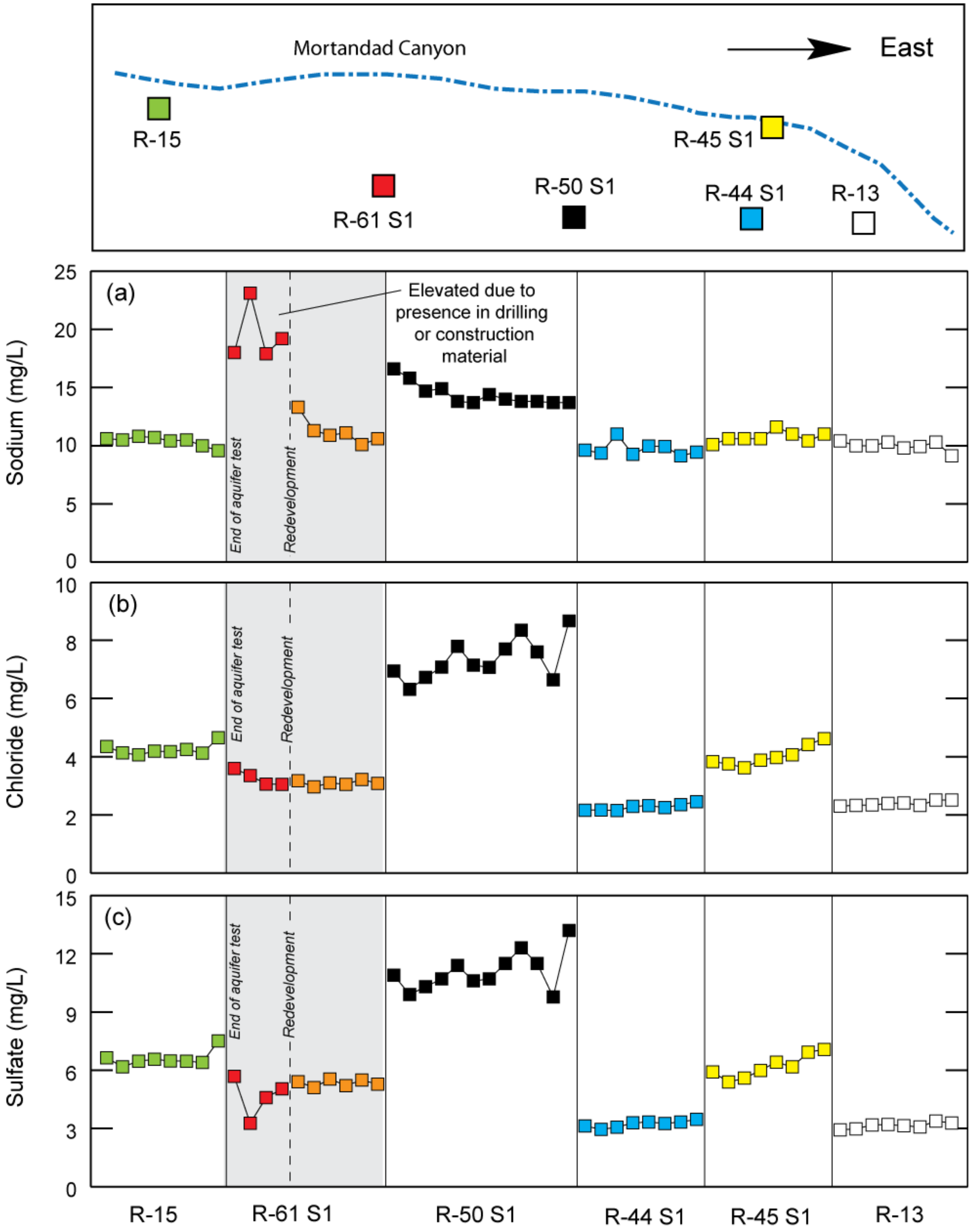
Figure 4.2-2 **Trilinear plot showing reequilibration of major-ion chemistry of groundwater for R-61 S1 during extended purge events conducted following redevelopment**



Note: Plume = Elevated concentrations of this constituent are due to its presence in a local contaminant plume.
Redev = Elevated concentrations of this constituent are due to its presence in a chemical used during redevelopment.
Mineral = Concentrations of uranium are low due to its interactions with phosphate minerals precipitated in the screened interval.

Data source: Table 4.2-1, Table 4.2-3, and Appendix B.

Figure 4.2-3 Schoeller plots of geochemical data collected during sampling of R-61 S1: (a) major ions and perchlorate and (b) trace metals



Data source: Table 4.2-1 and Appendix B. Includes data available for samples collected under the IFGMP between May 19, 2011, and May 7, 2014.

Figure 4.2-4 Concentrations of major ions for well R-61 S1 and other wells in the Chromium Investigation monitoring group: (a) sodium, (b) chloride, (c) sulfate, (d) potassium, (e) total phosphate, and (f) calcium

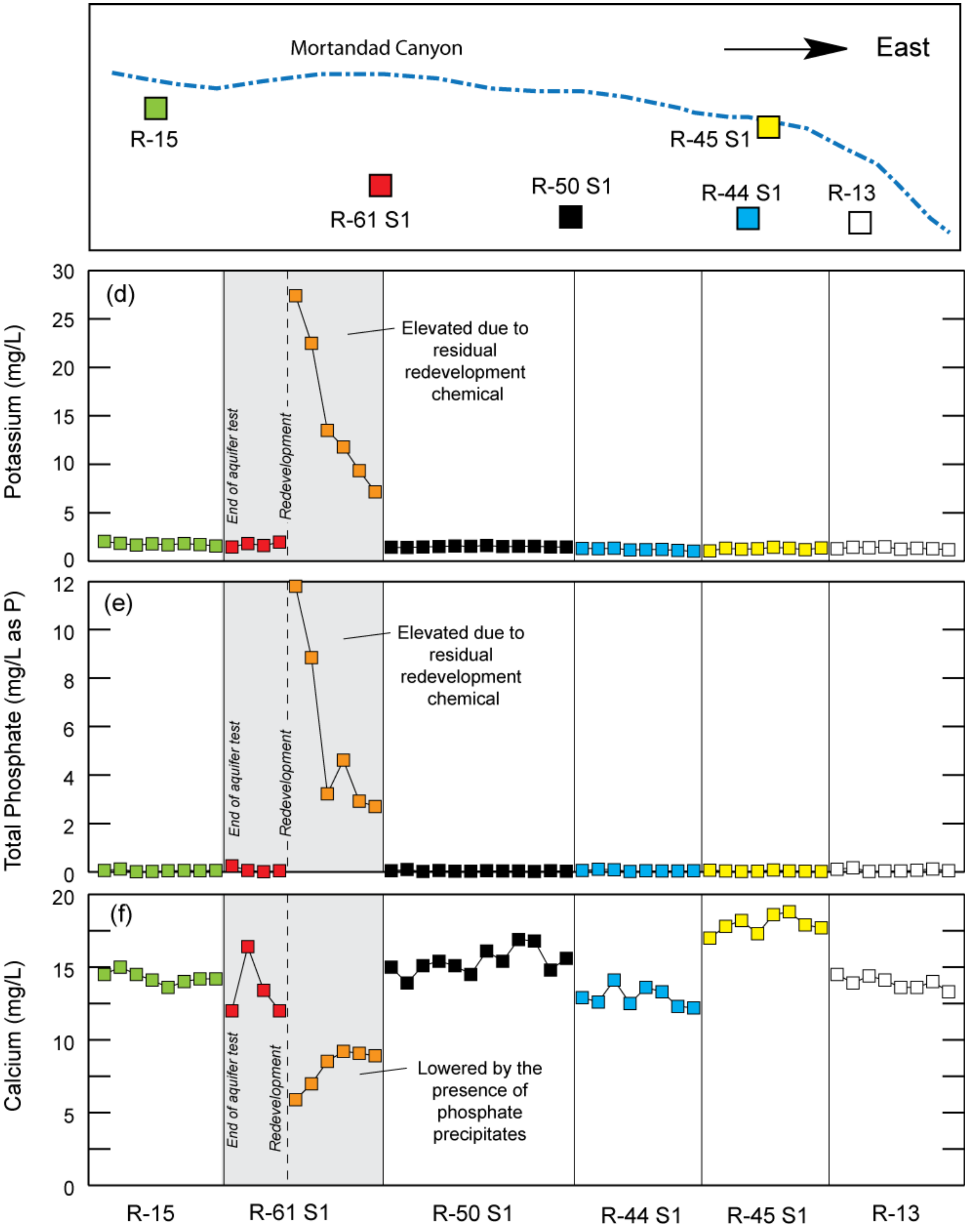
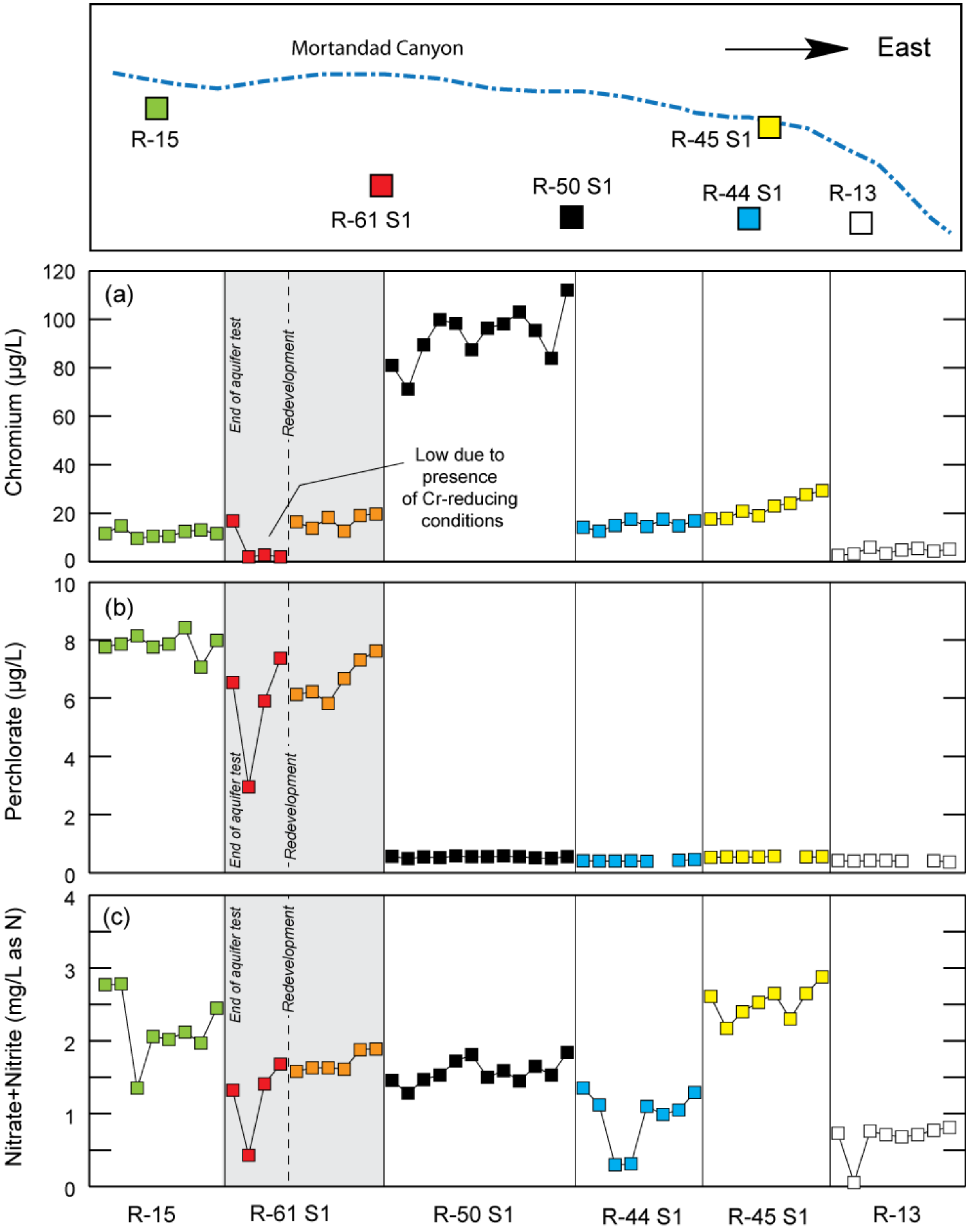
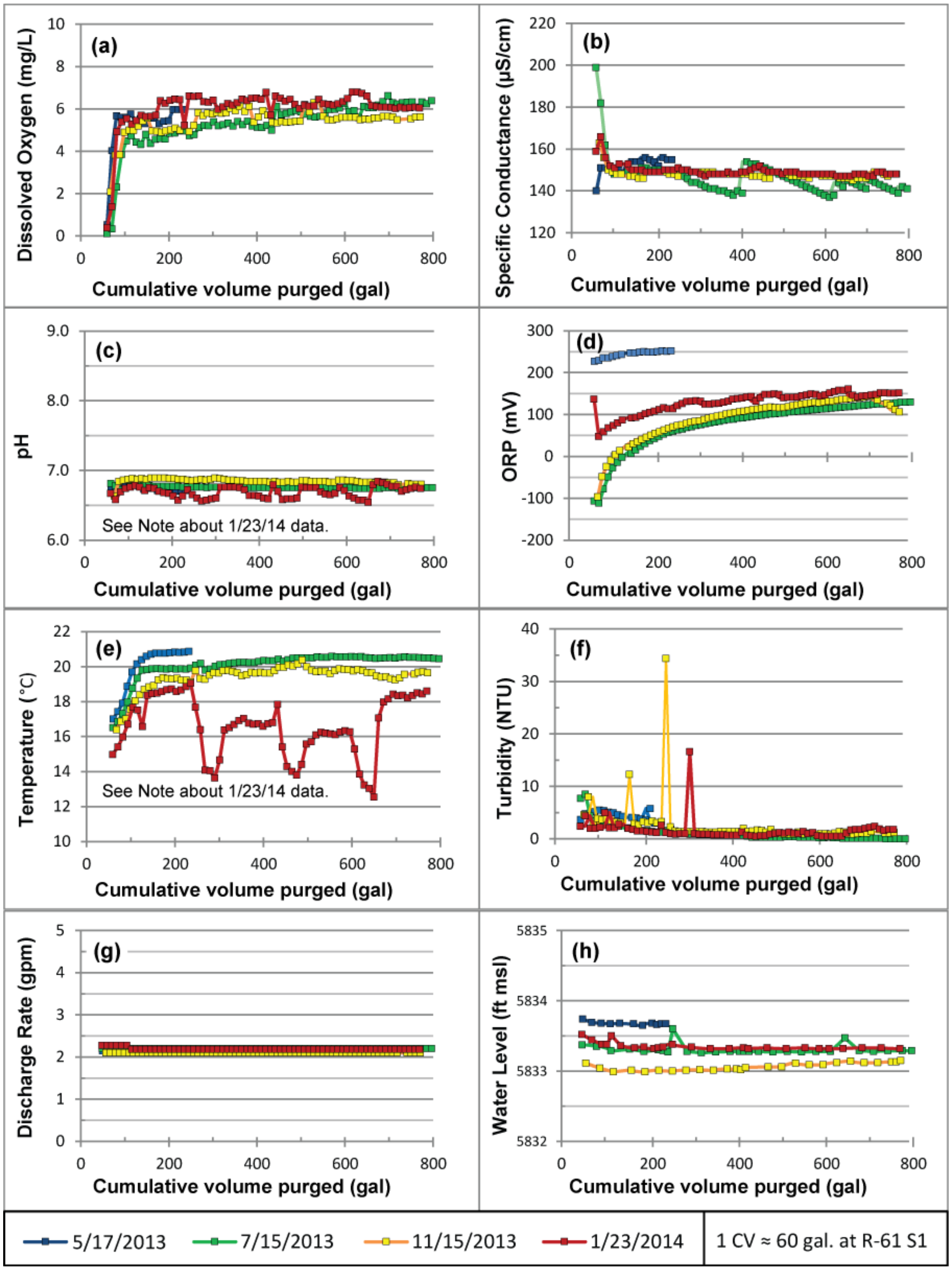


Figure 4.2-4 (continued) Concentrations of major ions for well R-61 S1 and other wells in the Chromium Investigation monitoring group: (a) sodium, (b) chloride, (c) sulfate, (d) potassium, (e) total phosphate, and (f) calcium



Data source: Table 4.2-1, Table 4.2-3, and Appendix B. Includes data available for samples collected under the IFGMP between May 19, 2011, and May 7, 2014.

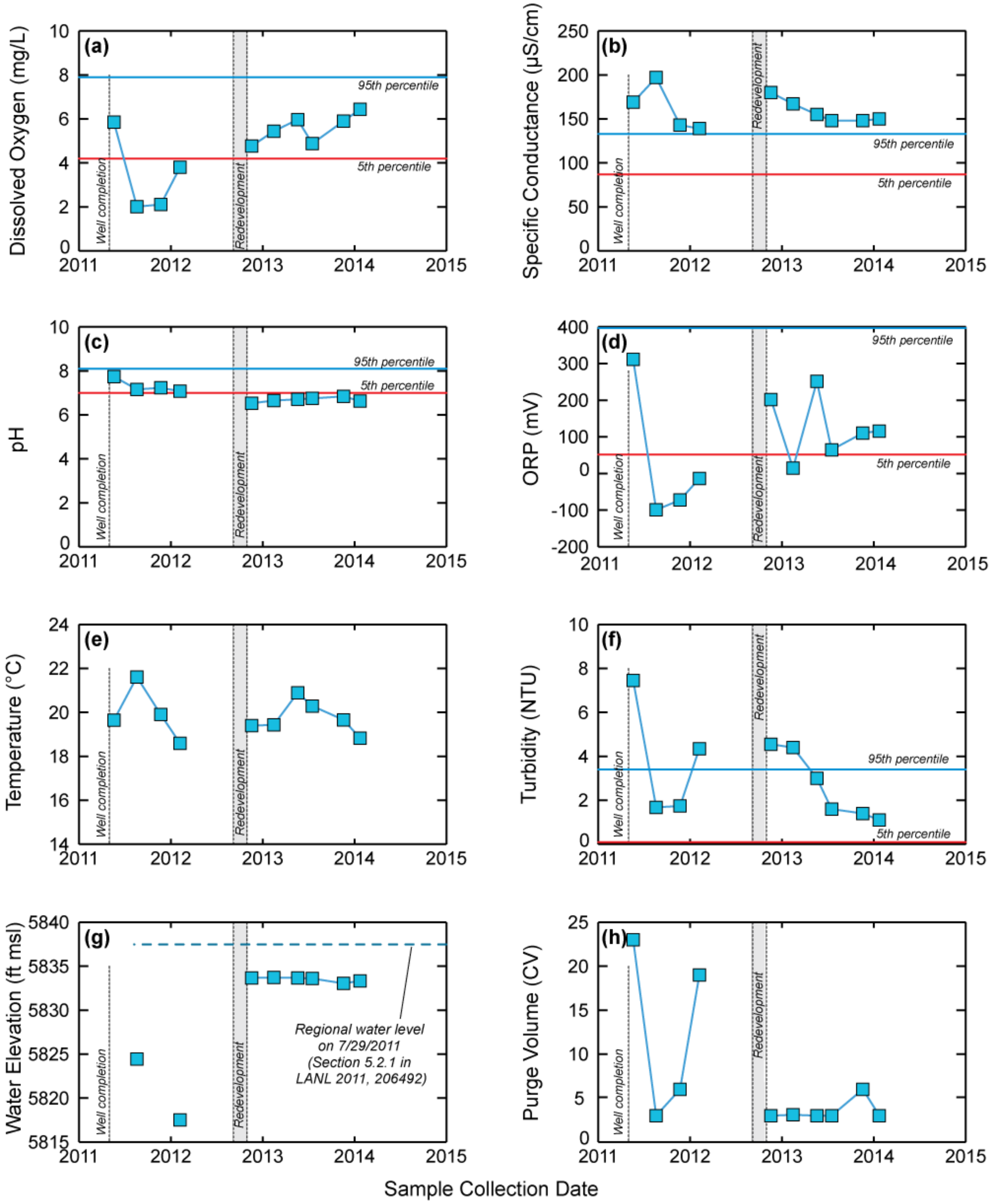
Figure 4.2-5 Concentrations of chromium, perchlorate, and nitrate for well R-61 S1 and other wells in the Chromium Investigation monitoring group



Note: Temperature fluctuated during the January 23, 2014, purge due to cold atmospheric temperatures and variable cloud cover affecting the temperature of the water in the flow through cell (Table 4.1-1 in TerranearPMC 2014, 254704). The variable pH values measured during purging on January 23, 2014, may be from temperature fluctuations.

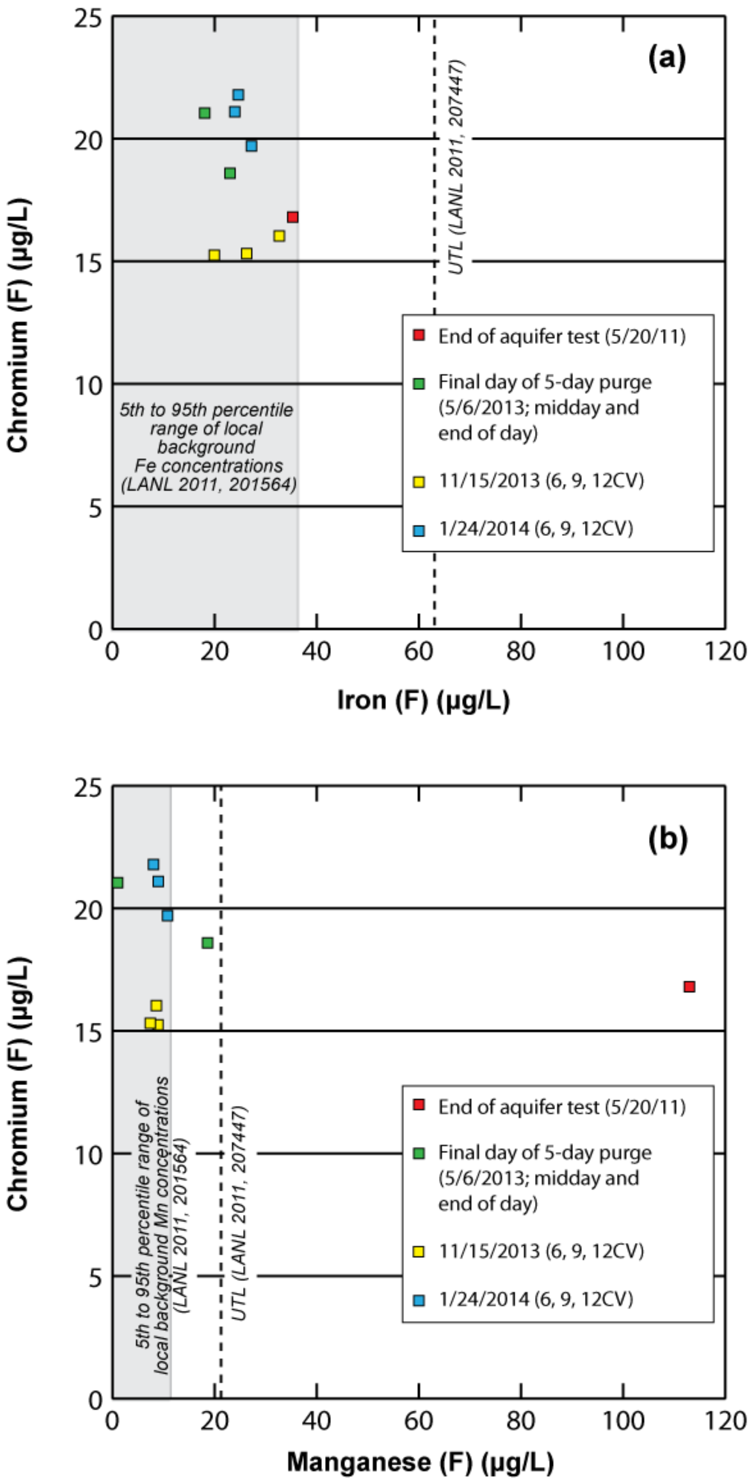
Data source: Appendix C in field summary reports (TerranearPMC 2013, 245624; TerranearPMC 2013, 249229; TerranearPMC 2013, 252853; TerranearPMC 2014, 254704).

Figure 4.3-1 Field parameters monitored during purging of R-61 S1: (a) dissolved oxygen, (b) specific conductance, (c) pH, (d) ORP, (e) temperature, (f) turbidity, (g) discharge rate, and (h) water level



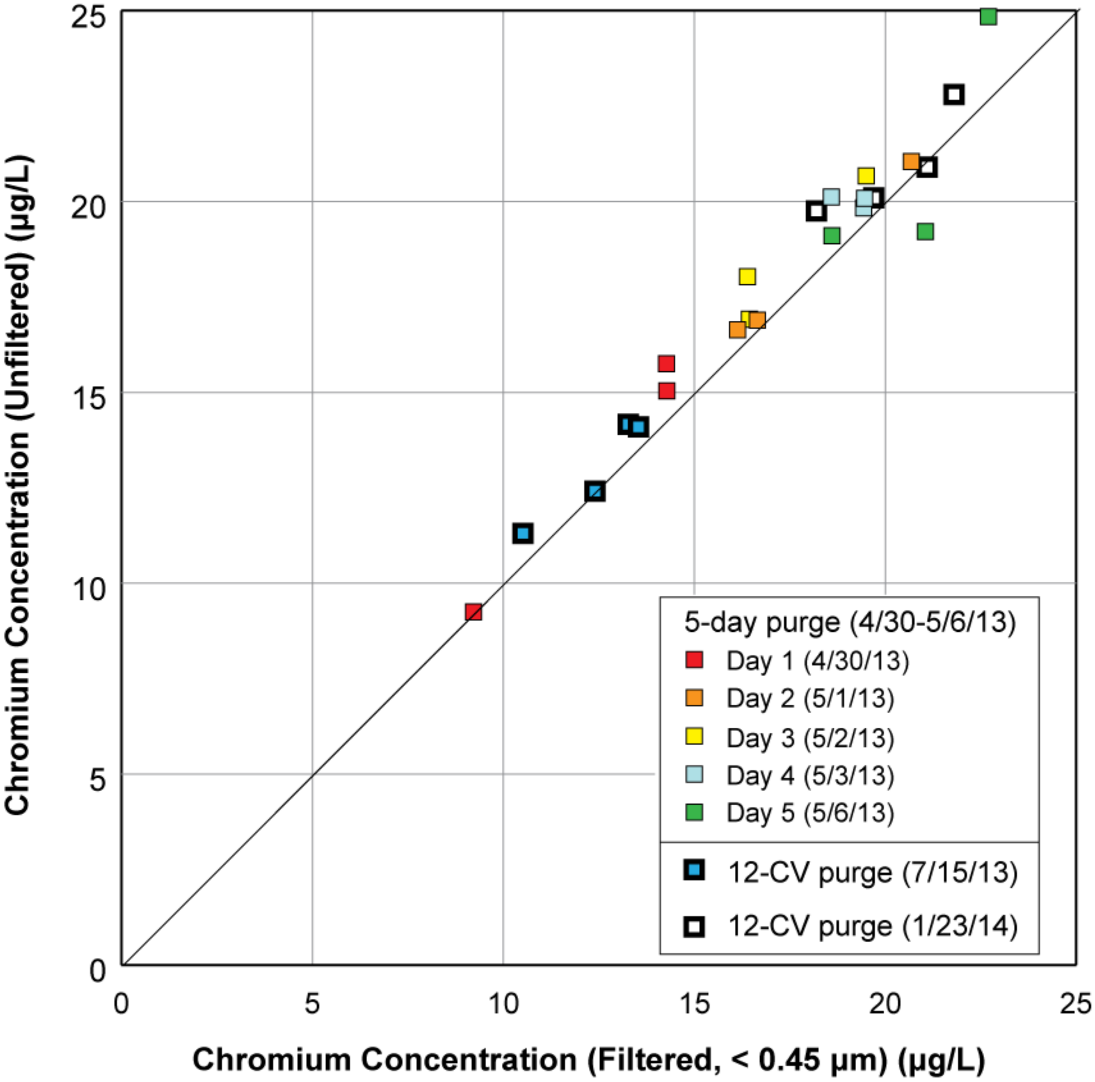
Note: On the above plots, horizontal lines indicate 5th (lower red line) and 95th (upper blue line) percentiles of background values for field parameters in hydrogeologic settings similar to that at R-61 S1. The development and use of these background values were derived from data for other deep wells screened in the Puye Formation or the Cerro Toledo interval (Table A-3.0-4 in LANL 2011, 201564).

Figure 4.3-2 Final field parameters for samples collected at R-61 S1 under the IFGMP



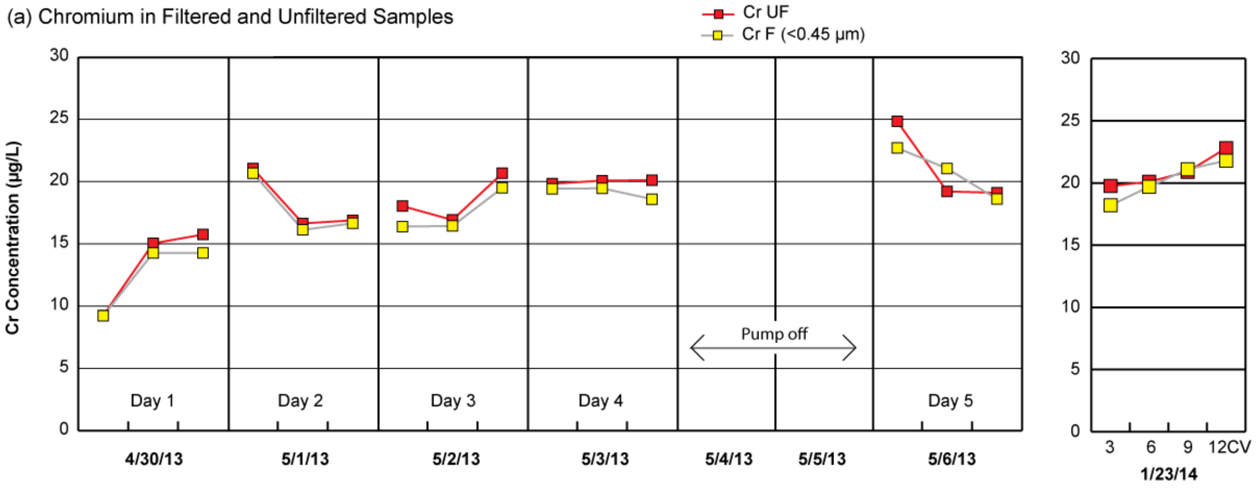
Data source: Table 4.2-3 and Appendix B.

Figure 4.5-1 Absence of correlation between filtered concentrations of chromium at R-61 S1 with low concentrations of (a) iron and (b) manganese

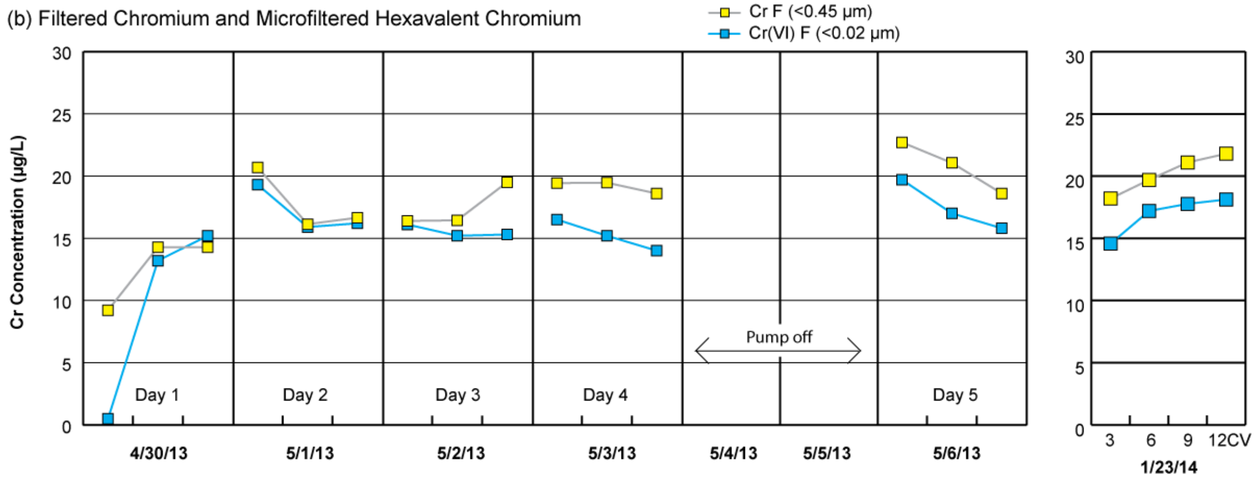


Data source:Table 4.2-3 and Appendix B.

Figure 4.6-1 **Correlation between concentrations of chromium in filtered and unfiltered samples collected during extended purges of R-61 S1**



(a) Chromium in Filtered and Unfiltered Samples

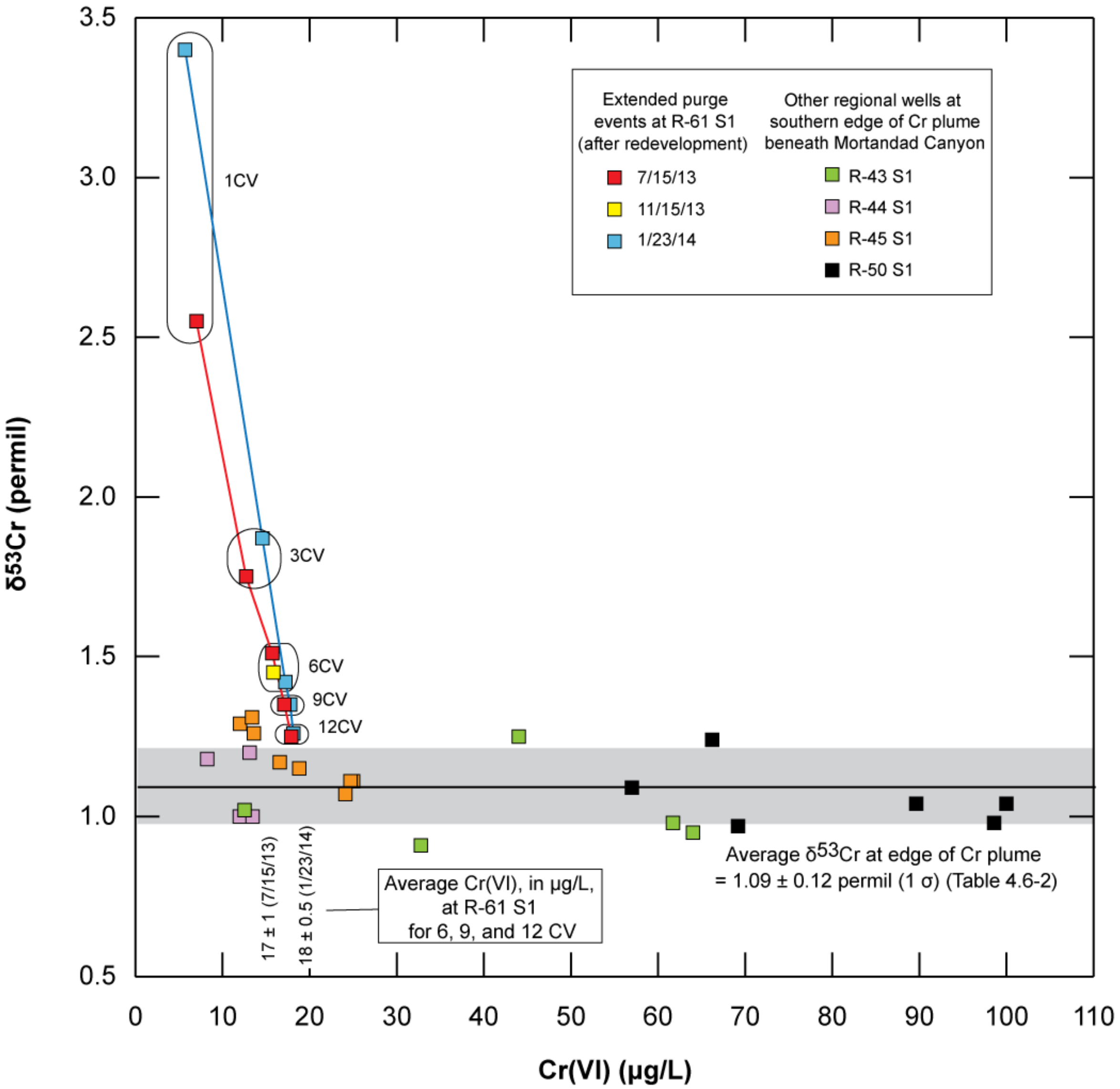


(b) Filtered Chromium and Microfiltered Hexavalent Chromium

Data source: Table 4.4-3, Table 4.6-1, and Appendix B.

Notes: The pump was turned off at the end of each day during the 5-d extended purge (April 30,2013, to May 6, 2013). Samples were collected at the beginning, midpoint, and end of each day.

Figure 4.6-2 Temporal trends of chromium concentrations in samples from R-61 S1 during extended purges



Data source: Tables 4.6-1 and 4.6-2.

Figure 4.6-3 **Stable chromium isotopes and hexavalent chromium concentrations in time-series samples collected from R-61 S1 during extended purge events**

Table 4.1-1
Sampling Events Included in the Evaluation of R-61 S1

Date	Time	Volume Purged Gal.	CV*	Comments
Full-Suite Sampling Events before Redevelopment Activities				
5/20/2011	6:30	1400	23	Full-suite sampling event at end of initial aquifer test
8/18/2011	14:51	229	3	Full-suite sampling event
11/21/2011	14:38	378	6	Full-suite sampling event
2/7/2012	17:34	1778	28	Full-suite sampling event at end of extended purge
Sampling Events after Redevelopment Activities				
11/15/2012	11:51	185	3	First full-suite sampling event after redevelopment activities
2/11/2013	11:51	238	3	Extended 12-CV purge; full-suite sample collected at 3 CV
	16:21	732	12	
5/6/2013	15:15	660	10	Day 5 of 5-d extended purge; cumulative volume purged = 64 CV
5/17/2013	12:52	185	3	Full-suite sampling event after 5-d purge ending 5/6/2013
7/15/2013	10:12	115	1	Extended 12-CV purge; full-suite sample collected at 3 CV
	11:07	180	3	
	11:12	190	3	
	12:33	360	6	
	13:59	540	9	
	15:23	725	12	
11/15/2013	9:00	105	1	Extended 12-CV purge; full-suite sample collected at 6 CV
	9:57	180	3	
	11:23	359	6	
	12:49	539	9	
	14:15	718	12	
1/23/2014	8:48	105	1	Extended 12-CV purge; full-suite sample collected at 3 CV
	9:43	180	3	
	11:06	361	6	
	12:29	541	9	
	13:52	721	12	

*CV = Casing volumes (of water purged). At R-61 S1, 1 CV corresponds to about 60 gal.

Table 4.1-2
Sampling Events at R-61 S2

Date	Time	Volume Purged		Comments
		Gal.	CV*	
Full-Suite Sampling Events before Redevelopment Activities				
5/24/2011	6:38	25100	291	Sample collected at end of initial aquifer test
8/19/2011	12:26	264	3	Full-suite sampling event
11/18/2011	14:18	520	5	Full-suite sampling event
2/8/2012	17:16	1214	14	Full-suite sampling event at end of extended purge
Sampling Events after Redevelopment Activities				
11/15/2012	14:59	259	3	First full-suite sampling event after redevelopment activities
2/12/2013	11:29	513	3	Extended 12-CV purge; full-suite sample collected at 3 CV
	17:50	1015	12	
5/14/2013	15:45	Not reported	Not calculated	Day 5 of 5-d extended purge
5/22/2013	13:01	259	3	Full-suite sampling event after 5-d purge ending 5/14/2013
7/16/2013	9:17	134	1	Extended 12-CV purge; full-suite sample collected at 3 CV
	10:37	259	3	
	12:37	518	6	
	14:37	777	9	
	16:47	1036	12	
11/14/2013	8:42	134	1	Extended 12-CV purge; full-suite sample collected at 6 CV
	10:06	259	3	
	12:11	518	6	
	14:16	777	9	
	16:21	1036	12	
1/22/2014	8:53	134	1	Extended 12-CV purge; full-suite sample collected at 3 CV
	10:15	259	3	
	12:18	518	6	
	14:21	777	9	
	16:24	1036	12	

*At R-61 S2, 1 CV corresponds to about 86 gal.

Table 4.2-1
Laboratory pH, Major-Ion, and Silica Concentrations in Groundwater Samples from R-61 S1

				Major Cations (mg/L)				Major Anions (mg/L except as otherwise noted)								
Sampling Date	**CV**	**Lab[a]**	**Lab pH**	**Na**	**K**	**Ca**	**Mg**	**HCO_3[b]**	**Alk-HCO_3+ CO_3 as $CaCO_3$[c]**	**Cl**	**SO_4**	**NO_3+ NO_2-N**	**F**	**Total P**	**PO_4 as P**	**SiO_2 (mg/L)**
5/20/2011	23	GELC	7.6	18	1.5	12	3.4	—[d]	68	3.6	5.7	1.3	0.32	0.25	—	68
Sampling Events after Redevelopment Activities																
11/15/2012	3	GELC	6.8	13	27	6.4	2.4	—	42	3.2	5.4	1.6	0.59	12	—	102
2/11/2013	3	GELC	6.9	11	23	7.0	2.9	—	48	3.0	5.1	1.6	0.60	8.8	—	95
	12	GELC	7.0	11	23	6.4	2.7	—	48	2.9	5.2	2.0	0.57	7.5	—	89
5/6/2013	10	GGRL	6.8	10	13	7.3	2.7	61	—	3.7	5.8	2.3	0.48	—	0.9	76
5/17/2013	3	GELC	6.9	11	14	8.5	3.0	—	50	3.1	5.6	1.6	0.44	3.2	—	84
7/15/2013	3	GGRL	6.5	11	12	9.7	3.5	66	—	3.5	5.2	1.7	0.54	—	3.9	95
	3	GELC	7.0	11	12	9.2	3.6	—	51	3.1	5.2	1.6	0.43	4.6	—	82
	6	GGRL	6.7	11	12	9.4	3.4	65	—	3.5	5.2	1.8	0.54	—	3.9	93
	9	GGRL	6.7	12	13	9.9	3.6	64	—	3.3	5.0	1.8	0.54	—	3.4	96
	12	GGRL	6.8	11	13	9.0	3.3	64	—	2.9	5.1	1.8	0.55	—	4.8	91
11/15/2013	3	GGRL	7.1	10	9.1	9.9	3.4	67	—	3.8	6.1	1.8	0.69	—	4.7	80
	6	GGRL	7.0	9.9	9.2	9.5	3.3	64	—	3.8	6.1	1.8	0.75	—	4.4	76
	6	GELC	7.5	10	9.4	9.1	3.2	—	52	3.2	5.5	1.9	0.41	2.9	—	74
	9	GGRL	7.0	9.9	9.3	9.4	3.3	64	—	3.8	6.1	1.8	0.97	—	4.5	76
	12	GGRL	7.0	9.7	9.6	9.4	3.3	63	—	3.7	6.0	1.8	0.69	—	3.9	76
1/23/2014	3	GGRL	7.2	10	7.9	10.1	3.6	67	—	3.8	5.9	1.9	0.52	—	3.1	78
	3	GELC	7.1	11	7.2	8.9	3.2	—	49	3.1	5.3	1.9	0.37	2.7	—	69
	6	GGRL	7.0	10	7.9	9.6	3.4	66	—	3.6	5.6	2.0	0.44	—	3.0	75
	9	GGRL	7.1	10	8.1	9.7	3.4	66	—	3.7	5.9	2.0	0.59	—	3.0	75
	12	GGRL	7.0	10	8.1	9.4	3.4	66	—	3.7	6.0	2.2	0.56	—	2.9	74

Data source: Appendix B.

Note: Data are for filtered samples, except for pH measured by Geochemistry and Geomaterials Research Laboratories (GGRL) in the Laboratory's Earth Systems Observations Group (EES-14).

[a] Regulatory analyses that support Laboratory's characterization, cleanup, and monitoring programs are provided by external contract analytical laboratories such as General Engineering Laboratories, Inc. (GELC). However, in some specific situations, samples are most appropriately submitted for on-site analysis by GGRL.

[b] Reported in water-quality database as the parameter, Alkalinity-CO_3+HCO_3. However, GGRL reports measured alkalinity as mg/L of carbonate species, which is a different reporting method than used by the outside analytical laboratory, GELC (see note c).

[c] Reported in units of mg/L as $CaCO_3$.

[d] — = Not measured.

Table 4.2-2
Laboratory pH, Major-Ion, and Silica Concentrations in Groundwater Samples from R-61 S2

				Major Cations (mg/L)				Major Anions (mg/L except as otherwise noted)								
Sampling Date	CV	Lab	Lab pH	Na	K	Ca	Mg	HCO_3[a]	Alk-HCO_3+CO_3 as $CaCO_3$[b]	Cl	SO_4	NO_3+NO_2-N	F	Total P	PO_4 as P	SiO_2 (mg/L)
5/24/2011	291	GELC	7.8	11	1.6	10	3.3	—[c]	69	2.2	2.6	0.4	0.34	<0.05	—	69
Sampling Events after Redevelopment Activities																
11/15/2012	3	GELC	6.7	21	22	8.0	3.4	—	52	2.6	2.2	0.3	0.74	19	—	120
2/12/2013	3	GELC	6.7	20	24	9.2	3.8	—	68	2.3	1.9	0.3	0.85	20	—	115
	12	GELC	6.9	16	17	7.0	3.0	—	62	2.1	2.2	0.3	0.74	9.6	—	95
5/14/2013	10	GGRL	6.9	12	9.8	6.3	2.6	72	—	2.3	3.5	0.5	0.60	—	2.0	76
5/22/2013	3	GELC	7.0	14	12	7.7	3.2	—	60	2.0	2.2	0.2	0.52	4.7	—	91
7/16/2013	3	GGRL	6.8	13	12	7.2	2.9	111	—	2.2	1.5	0.2	0.62	—	10	79
	3	GELC	6.8	16	14	8.3	3.4	—	66	1.9	1.9	0.2	0.50	7.5	—	94
	6	GGRL	6.7	13	11	6.8	2.8	86	—	2.1	1.7	0.3	0.63	—	8.5	76
	9	GGRL	6.8	12	10	6.5	2.7	81	—	2.1	1.9	0.3	0.63	—	7.2	73
	12	GGRL	6.9	11	9.8	6.1	2.5	78	—	2.1	2.0	0.4	0.59	—	6.1	70
11/14/2013	3	GGRL	6.7	18	15	10	4.0	106	—	2.5	2.0	0.2	0.90	—	11	97
	6	GGRL	6.8	16	13	9.0	3.5	97	—	2.5	2.1	0.3	0.87	—	9.2	86
	6	GELC	7.2	17	14	8.7	3.4	—	76	2.0	2.1	0.2	0.51	6.6	—	84
	9	GGRL	6.8	15	12	8.5	3.3	90	—	2.5	2.3	0.3	0.88	—	8.3	82
	12	GGRL	6.9	14	12	8.0	3.2	87	—	2.4	2.3	0.3	0.80	—	7.0	80
1/22/2014	3	GGRL	6.8	17	13	9.5	3.9	104	—	2.5	2.0	0.2	0.6	—	8.4	92
	3	GELC	7.1	18	14	9.4	3.8	—	77	1.9	1.8	0.2	0.49	7.4	—	90
	6	GGRL	6.7	17	13	8.9	3.6	96	—	2.5	2.1	0.3	0.7	—	8.1	88
	9	GGRL	7.4	16	12	8.4	3.5	92	—	2.5	2.2	0.3	0.6	—	8.6	84
	12	GGRL	6.9	15	11	8.0	3.2	96	—	2.4	2.2	0.3	0.5	—	6.1	80

Data source: Appendix B.

Note: Data are for filtered samples, except for pH measured by GGRL.

[a] Reported in water-quality database as the parameter, Alkalinity-CO_3+HCO_3. However, GGRL reports measured alkalinity as mg/L of carbonate species, which is a different reporting method than used by the outside analytical laboratory GELC (see note b).

[b] Reported in units of mg/L as $CaCO_3$.

[c] — = Not measured.

Table 4.2-3
Total Organic Carbon, Perchlorate, and Trace-Metal Concentrations in Groundwater Samples from R-61 S1

Sampling Date	CV	TOC[a] mg/L	ClO_4 µg/L	Trace Metals (µg/L)													
				Al	Al (UF[b])	Ba	Cr	Cr (UF)	Fe	Fe (UF)	Mn	Mo	Ni	Sr	U	V	Zn
5/20/2011	23	0.8	6.5	<200	<200	23	17	18	35	217	113	3	2	59	0.7	4	18
Sampling Events after Redevelopment Activities																	
11/15/2012	3	1.6	6.1	107	—[c]	31	16	—	72	—	34	2	3	26	0.3	4	5
2/11/2013	3	1.2	6.2	117	—	26	14	—	88	—	17	2	3	29	0.2	4	5
	12	1.1	—	77	—	16	16	—	39	—	18	2	2	26	0.1	4	5
5/6/2013	10	0.2	—	11	38	11	19	19	23	54	19	1	2	30	<0.2	4	2
5/17/2013	3	1.3	5.8	143	—	27	18	—	41	—	17	2	1	35	0.2	5	7
7/15/2013	3	0.5	—	74	227	19	11	11	73	115	10	2	1	34	<0.2	4	2
	3	0.8	6.7	<200	—	20	13	—	54	—	12	2	1	36	0.2	5	4
	6	0.4	—	81	173	17	12	12	71	116	7	2	1	34	<0.2	4	2
	9	0.5	7.9	96	116	16	13	14	82	87	7	2	1	34	<0.2	4	2
	12	0.4	8.0	28	93	14	14	14	29	71	7	1	1	33	<0.2	4	4
11/15/2013	3	0.3	—	57	—	16	15	—	45	—	16	2	2	37	<0.2	4	<1
	6	<0.2	—	21	—	13	15	—	20	—	9	1	1	34	<0.2	4	<1
	6	0.8	7.3	<200	—	16	19	—	<100	—	11	2	1	36	0.2	5	<10
	9	<0.2	—	31	—	14	16	—	33	—	9	1	1	36	<0.2	4	<1
	12	<0.2	—	25	—	12	15	—	26	—	7	1	1	34	<0.2	4	<1
1/23/2014	3	0.3	—	28	92	13	18	20	39	96	17	1	1	46	<0.2	5	2
	3	<1	7.6	131	—	14	20	—	42	—	15	2	1	36	0.1	5	<10
	6	0.2	—	24	79	13	20	20	27	41	11	1	1	47	<0.2	5	1
	9	0.2	—	43	66	13	21	21	24	35	9	1	1	50	<0.2	5	1
	12	0.2	—	23	92	13	22	23	25	35	8	<1	1	50	<0.2	5	1

Data source: Appendix B.

Note: For trace metals, filtered samples unless otherwise noted.

[a] TOC = Total organic carbon.

[b] UF = Unfiltered.

[c] — = Not measured.

Table 4.2-4
Total Organic Carbon, Perchlorate, and Trace-Metal Concentrations in Groundwater Samples from R-61 S2

				Trace Metals (µg/L)													
Sampling Date	**CV**	**TOC[a] mg/L**	**ClO_4 µg/L**	**Al**	**Al (UF[b])**	**Ba**	**Cr**	**Cr (UF)**	**Fe**	**Fe (UF)**	**Mn**	**Mo**	**Ni**	**Sr**	**U**	**V**	**Zn**
5/24/2011	291	0.6	0.3	<200	76	20	2.2	2.6	<100	57	22	2	<2	44	0.8	4	<10
Sampling Events after Redevelopment Activities																	
11/15/2012	3	3.6	0.3	197	—[c]	33	2.2	—	331	—	92	7	2	34	0.2	5	10
2/12/2013	3	5.5	0.2	134	—	24	<2	—	1760	—	174	7	3	41	<0.2	2	5
	12	2.1	—	149	—	17	<2	—	464	—	100	4	2	29	0.07	5	3
5/14/2013	10	0.3	—	<1	178	10	1	2	80	180	47	2	2	25	<0.2	7	7
5/22/2013	3	1.5	0.2	<200	—	19	<10	—	167	—	71	3	1	32	0.09	8	3
7/16/2013	3	2.9	—	78	336	25	<1	2.4	665	820	106	5	2	39	<0.2	3	<1
	3	1.4	0.2	124	—	24	<10	—	599	—	111	3	1	36	0.15	6	5
	6	2.4	—	64	118	19	<1	1.2	418	489	88	4	1	35	<0.2	5	<1
	9	2.0	0.2	38	177	16	<1	1.4	319	359	76	3	1	31	<0.2	5	<1
	12	1.2	0.2	28	87	13	<1	1.8	246	268	68	3	1	29	<0.2	6	<1
11/14/2013	3	1.1	—	91	—	24	<1	—	1534	—	168	4	2	41	<0.2	3	2
	6	1.4	—	91	—	18	1.5	—	910	—	135	3	2	36	<0.2	4	<1
	6	1.5	—	<200	—	19	<10	—	863	—	127	4	2	37	0.1	5	<10
	9	1.1	—	63	—	13	3.0	—	637	—	117	3	1	30	<0.2	5	<1
	12	1.2	—	55	—	12	3.2	—	486	—	103	3	1	30	<0.2	5	<1
1/22/2014	3	1.3	—	69	223	20	1	2	1138	1226	120	1	2	54	<0.2	4	2
	3	1.1	0.2	95	—	21	<10	—	1130	—	143	4	1	41	0.1	4	5
	6	1.0	—	78	139	17	<1	2	844	859	109	<1	1	48	<0.2	5	2
	9	0.8	—	41	106	13	<1	1	614	641	98	<1	1	44	<0.2	6	<1
	12	0.7	—	28	82	12	<1	1	479	517	87	<1	1	44	<0.2	6	2

Data source: Appendix B.

Note: For trace metals, filtered samples unless otherwise noted.

[a] TOC = Total organic carbon.

[b] UF = Unfiltered.

[c] — = Not measured.

Table 4.3-1
Field Parameters Measured at R-61 S1

Sampling Date	Time	CV	Temp (°C)	Field pH	DO (mg/L)	ORP (mV[a])	Eh (mV[b])	Sp Cond[c] (µS/cm)
Full-Suite Sampling Events before Redevelopment Activities								
5/20/2011	6:30	23	19	7.47	5.9	311	515	169
8/18/2011	2:51	3	22	7.16	2.0	-99	100	197
11/21/2011	2:38	6	20	7.23	2.1	-72	127	143
2/7/2012	5:34	28	19	7.08	3.8	-14	185	139
Sampling Events after Redevelopment Activities								
11/15/2012	11:51	3	19	6.53	4.8	202	406	180
2/11/2013	11:51	3	19	6.65	5.4	14	218	167
	16:21	12	18	6.67	6.2	29	233	163
5/6/2013	15:15	10	na[d]	6.88	7.2	243	447	154
5/17/2013	12:52	3	21	6.71	6.0	251	455	155
7/15/2013	10:12	1	19	6.78	4.7	-13	191	148
	11:07	3	20	6.75	4.9	65	269	148
	11:12	3	20	6.75	4.9	65	269	148
	12:33	6	20	6.75	5.6	96	300	153
	13:59	9	21	6.75	6.4	115	319	137
	15:25	12	20	6.75	6.5	131	335	141
11/15/2013	9:00	1	19	6.89	5.6	21	225	147
	9:57	3	20	6.85	5.0	74	278	147
	11:23	6	20	6.84	5.9	110	314	148
	12:49	9	20	6.86	5.6	128	332	147
	14:15	12	20	6.80	5.6	105	309	148
1/23/2014	8:48	1	18	6.75	5.6	75	279	151
	9:43	3	19	6.63	6.4	116	320	150
	11:06	6	17	6.46	6.5	147	351	149
	12:29	9	16	6.75	6.2	145	349	148
	13:52	12	19	6.71	6.0	152	356	148

Data source: Appendix B.

[a] mV = Millivolt.

[b] To apply corrections to obtain Eh from the direct field measurement, the known half-cell potential of the reference electrode is added to the recorded field ORP value (http://www.epa.gov/region4/sesd/fbqstp/Field-Measurement-of-ORP.pdf, p. 20):

$$Eh_{sample} = ORP_{sample} + \text{half-cell potential of reference electrode}$$

Half-cell potentials of a silver/silver chloride reference electrode with a saturated (4-molar) potassium chloride (KCl) filling solution, such as the YSI sonde, which is used in the Laboratory groundwater monitoring program, is 209, 204, and 199 mV at temperatures of 15°C, 20°C, and 25°C, respectively. An average temperature of 20°C is used for Eh calculations shown in the table above.

[c] Sp Cond = Specific conductance.

[d] na = Not available.

Table 4.3-2
Field Parameters Measured at R-61 S2

Sampling Date	Time	CV	Temp (°C)	Field pH	DO (mg/L)	ORP (mV[a])	Eh (mV[b])	Sp Cond[c] (µS/cm)
Full-Suite Sampling Events before Redevelopment Activities								
5/24/2011	6:38	291	18	7.67	7.7	178	382	149
8/19/2011	12:26	3	21	7.0	0.8	-109	90	224
11/18/2011	14:18	5	20	7.0	1.8	-80	119	141
2/8/2012	17:16	14	21	7.2	2.1	-62	137	158
Sampling Events after Redevelopment Activities								
11/15/2012	14:59	3	19	6.46	3.3	49	253	199
2/12/2013	11:29	3	20	7.12	1.0	-78	126	180
	17:50	12	18	6.66	3.4	-37	167	165
5/14/2013	15:45	10	21	6.99	4.8	299	503	142
5/22/2013	13:01	3	21	6.56	3.0	94	298	152
7/16/2013	9:17	1	20	6.52	0.5	-53	151	185
	10:37	3	21	6.50	1.5	-48	156	183
	12:37	6	21	6.46	2.2	-38	166	163
	14:37	9	21	6.50	3.4	-28	176	154
	16:47	12	21	6.59	3.5	225	429	147
11/14/2013	8:42	1	18	6.50	0.3	-60	144	202
	10:06	3	19	6.49	1.1	-40	164	201
	12:11	6	20	6.57	1.8	-20	184	183
	14:16	9	20	6.62	2.4	-7	197	165
	16:21	12	20	6.67	2.7	11	215	152
1/22/2014	8:53	1	19	6.60	0.8	-112	92	195
	10:15	3	19	6.54	1.7	-71	133	192
	12:18	6	18	6.57	2.7	-54	150	181
	14:21	9	20	6.67	2.8	-54	150	171
	16:24	12	20	6.69	3.5	-41	163	164

Data source: Appendix B.

[a] mV = Millivolt.

[b] To apply corrections to obtain Eh from the direct field measurement, the known half-cell potential of the reference electrode is added to the recorded field ORP value (http://www.epa.gov/region4/sesd/fbqstp/Field-Measurement-of-ORP.pdf, p. 20):

$Eh_{sample} = ORP_{sample}$ + half-cell potential of reference electrode

Half-cell potentials of a silver/silver chloride reference electrode with a saturated (4-molar) potassium chloride (KCl) filling solution, such as the YSI sonde, which is used in the Laboratory groundwater monitoring program, is 209, 204, and 199 mV at temperatures of 15°C, 20°C, and 25°C, respectively. An average temperature of 20°C is used for Eh calculations shown in the table above.

[c] Sp Cond = Specific conductance.

Table 4.4-1
Concentrations of Redox Couples in Groundwater Samples from R-61 S1

Date	Time	Purge Vol (CV)	Analytical Laboratory	General Inorganics (mg/L)				Trace Metals (µg/L)				
				SO_4	NO_3-N	NO_2-N	NH_3-N	Fe (UF)	Fe (F)	Mn (F)	Cr (UF)	Cr (F)
Full-Suite Sampling Events before Redevelopment Activities												
5/20/11	6:30	23	GELC	5.7	1.3[a]	—[b]	0.03	217	35	113	18.2	16.8
8/18/11	14:51	3	GELC	3.3	0.4[a]	—	<0.02[c]	3070	2550	1100	2.6	<2
11/21/11	14:38	6	GELC	4.6	1.4[a]	—	0.02	1040	909	902	5.3	2.8
2/7/12	17:34	28	GGRL	5.0	1.7	<0.003	0.02[d]	265	151	708	4.1	1.3
Extended Purge Events after Redevelopment Activities												
7/15/13	11:07	3	GGRL	5.2	1.71	0.022	—	115	73	10	11.3	10.5
	11:12	3	GELC	5.2	1.61[a]	—	0.089	—	54	12	—	12.6
	12:33	6	GGRL	5.2	1.80	0.026	—	116	71	7	12.4	12.4
	13:59	9	GGRL	5.0	1.75	0.034	—	87	82	7	14.2	13.3
	15:25	12	GGRL	5.1	1.80	0.048	—	71	29	7	14.1	13.5
11/15/13	9:57	3	GGRL	6.1	1.76	<0.003	—	—	45	16	—	14.6
	11:23	6	GELC	5.5	1.88[a]	—	0.186	—	<100	11	—	19.1
	11:23	6	GGRL	6.1	1.81	<0.003	—	—	20	9	—	15.2
	12:49	9	GGRL	6.1	1.84	<0.003	—	—	33	9	—	16.0
	14:15	12	GGRL	6.0	1.82	<0.003	—	—	26	7	—	15.3
1/23/14	9:43	3	GELC	5.3	1.89[b]	—	0.098	—	42	15	—	19.7
	9:43	3	GGRL	5.9	1.93	<0.003	—	96	39	17	19.8	18.2
	11:06	6	GGRL	5.6	2.01	<0.003	—	41	27	11	20.1	19.7
	12:29	9	GGRL	5.9	2.04	<0.003	—	35	24	9	20.9	21.1
	13:52	12	GGRL	6.0	2.22	<0.003	—	35	25	8	22.8	21.8

Data source: Appendix B.

Notes: F = Filtered, UF = unfiltered.

[a] Reported as NO_3+NO_2-N. For Eh calculations, this concentration is assumed to be approximately the same as NO_3-N.

[b] — = Not measured.

[c] < = Not detected above the indicated method detection limit (MDL).

[d] Data from outside analytical laboratory (GELC).

Table 4.4-2
Concentrations of Redox Couples in Groundwater Samples from R-61 S2

Date	Time	Purge Vol (CV)	Analytical Laboratory	General Inorganics (mg/L)				Trace Metals (µg/L)				
				SO_4	NO_3-N	NO_2-N	NH_3-N	Fe (UF)	Fe (F)	Mn (F)	Cr (UF)	Cr (F)
Full-Suite Sampling Events before Redevelopment Activities												
5/24/11	6:38	291	GELC	2.6	0.44[a]	—[b]	0.02	57	<30[c]	22	2.59	2.17
8/19/11	12:26	3	GELC	1.8	0.36[a]	—	0.05	5680	5590	908	<2	<2
11/18/11	14:18	6	GELC	2.1	0.31[a]	—	<0.02	2160	1750	566	<2	<2
2/8/12	17:16	28	GGRL	2.0	0.80	<0.003	<0.02[d]	1121	1009	502	1.17	<1
Extended Purge Events after Redevelopment Activities												
7/16/13	10:37	3	GGRL	1.5	0.20	0.025	—	820	665	106	2.4	<1
	10:37	3	GELC	1.9	0.25[a]	—	<0.049	—	599	111	—	<2
	12:37	6	GGRL	1.7	0.29	0.025	—	489	418	88	1.2	<1
	14:37	9	GGRL	1.9	0.32	0.031	—	359	319	76	1.4	<1
	16:37	12	GGRL	2.0	0.36	0.028	—	268	246	68	1.8	<1
11/14/13	10:06	3	GGRL	2.0	0.23	<0.003	—	—	1534	168	—	<1
	12:11	6	GELC	2.1	0.24[a]	—	0.145	—	863	127	—	<2
	12:11	6	GGRL	2.1	0.29	<0.003	—	—	910	135	—	1.5
	14:16	9	GGRL	2.3	0.31	<0.003	—	—	637	117	—	3.0
	16:21	12	GGRL	2.3	0.31	<0.003	—	—	486	103	—	3.2
1/22/14	10:15	3	GGRL	2.0	0.24	<0.003	—	1226	1138	120	2.0	1.5
	10:17	3	GELC	1.8	0.25[a]	—	0.050	—	1130	143	—	<2
	12:18	6	GGRL	2.1	0.31	<0.003	—	859	844	109	2.1	<1
	14:21	9	GGRL	2.2	0.25	<0.003	—	641	614	98	1.3	<1
	16:24	12	GGRL	2.2	0.34	<0.003	—	527	479	87	1.5	<1

Data source: Appendix B.

Notes: F= Filtered, UF = unfiltered.

[a] Reported as NO_3+NO_2-N. For Eh calculations, this concentration is assumed to be approximately the same as NO_3-N.

[b] — = Not measured.

[c] < = Not detected above the indicated method detection limit (MDL).

[d] Data from outside analytical laboratory (GELC).

Table 4.4-3
Standard Electrode Potentials for Pertinent Reduction Half-Reactions at 25°C

Redox Couple	Redox Couple	Half-Reaction	Standard Potential, E^0 (V)	dE^0/dT (mV/K)[a]	Ref.[b]
Oxygen redox couple					
1	$O_2(aq)/H_2O$	$O_2(aq) + 4H^+ + 4e^- > 2H_2O$	1.272	-0.0601	[1]
Nitrogen redox couples					
2	NO_3^-/NO_2^-	$NO_3^- + 2H^+ + 2e^- > NO_2^- + H_2O$	0.837	-0.282	[1]
3	NO_3^-/NH_4^+	$NO_3^- + 10H^+ + 8e^- > NH_4^+ + 3H_2O$	0.881	-0.448	[1]
4	NO_2^-/NH_4^+	$NO_2^- + 8H^+ + 6e^- > NH_4^+ + 2H_2O$	0.895	-0.503	[1]
Manganese redox couples					
5	$MnO_2(pt)/Mn^{2+}$	$MnO_2(pt) + 4H^+ + 2e^- > Mn^{2+} + 2H_2O$	1.32	0.62	[1]
6	$MnO_2(\gamma,\beta)/Mn^{2+}$	$MnO_2(c,\beta) + 4H^+ + 2e^- > Mn^{2+} + 2H_2O$	1.230	-0.609	[1]
7	$MnO_2(s)/Mn^{2+}$	$MnO_2(s) + 4H^+ + 2e^- > Mn^{2+} + 2H_2O$	1.224	—[c]	[1]
Chromium redox couples					
8	$Cr_2O_7^{2-}/Cr^{3+}$	$Cr_2O_7^{2-} + 14H^+ + 6e^- > 2Cr^{3+} + 7H_2O$	1.36	-1.32	[1]
9	$HCrO_4^-/CrOH^{2+}$	$HCrO_4^- + 6H^+ + 3e^- > CrOH^{2+} + 3H_2O$	1.277	—	[2]
10	$HCrO_4^-/Cr(OH)_2^+$	$HCrO_4^- + 5H^+ + 3e^- > Cr(OH)_2^+ + 2H_2O$	1.153	—	[2]
11	$HCrO_4^-/Cr(OH)_3$	$HCrO_4^- + 4H^+ + 3e^- > Cr(OH)_3 + H_2O$	1.029	—	[2]
12	$CrO_4^{2-}/Cr(OH)_3$	$CrO_4^{2-} + 4H^+ + 3e^- > Cr(OH)_3 + H_2O$	1.159	—	[2]
Iron redox couples					
13	$Fe(OH)_3(s)/Fe^{2+}$	$Fe(OH)_3(s) + 3H^+ + e^- > Fe^{2+} + 3H_2O$	1.06	—	[1]
14	$FeOOH(c)/Fe^{2+}$	$FeOOH(s) + 3H^+ + e^- > Fe^{2+} + 2H_2O$	0.74	1.05	[1]
15	α-FeOOH (goethite)/Fe^{2+}	$FeOOH(s) + 3H^+ + e^- > Fe^{2+} + 2H_2O$	-0.274	—	[3]
16	γ-FeOOH (lepidocrocite)/Fe^{2+}	$FeOOH(s) + 3H^+ + e^- > Fe^{2+} + 2H_2O$	-0.088	—	[3]
17	α-Fe_2O_3 (hematite)/Fe^{2+}	$Fe_2O_3(s) + 6H^+ + 2e^- > 2Fe^{2+} + 3H_2O$	-0.287	—	[3]
18	Fe^{3+}/Fe^{2+}	$Fe^{3+} + e^- > Fe^{2+}$	0.771	1.175	[1]
Sulfur redox couples					
19	SO_4^{2-}/HS^-	$SO_4^{2-} + 9H^+ + 8e^- > HS^- + 4H_2O$	0.251	—	[4]
20	$SO_4^{2-}/H_2S(aq)$	$SO_4^{2-} + 10H^+ + 8e^- > H_2S(aq) + 4H_2O$	0.310	—	[1]

Notes: α = alpha phase, β = beta phase, γ = gamma phase, aq = aqueous, c = crystalline phase, pt = precipitate, s = solid, V = volts.

[a] Values from Bratsch (1989, 249358). The effect of temperature T on standard potential E^0 can be calculated using dE^0/dT by the formula (Bratsch 1989, 249358):

$$E^0_T = E^0_{298K} + (T - 298.15K)\,(dE^0/dT)_{298K}$$

For example, the potential for the half-reaction involving $Cr_2O_7^{-}/Cr^{3+}$ increases from 1.36 mV at 25˚C to 1.37 mV at 20˚C:

$$E^0_{20C} = 1.36\text{ V} + (293K - 298K)\,(-1.32\text{ mV/K} \times 10^{-3}\text{ V/mV}) = 1.37\text{ V}$$

The adjustment is sufficiently small given the narrow range of local groundwater temperatures that it has not been taken into account for calculations in this report.

[b] References for E^0: [1] Bratsch (1989, 249358); [2] Richard and Bourg (1991, 107034); [3] Straub et al. (2001, 249357); [4] Stumm and Morgan (1981, 249359).

[c] — = Not reported.

Table 4.6-1
Hexavalent Chromium Concentrations and Chromium Isotopes in Groundwater at Other Regional Wells Near the Periphery of the Chromium Plume

Location	Collection Date	Collection Time	δ^{53}Cr (‰)[a]	Cr(VI) (µg/L)[a]	Cr (F) (µg/L)[b]
R-43 S1	16-Nov-10	13:28	1.02	12.5	14.3
	15-Nov-11	16:05	0.91	33	32.4
	22-May-12	13:03	0.97	—[c]	34.5
	07-Nov-12	14:44	1.25	44	49.6
	19-Nov-13	13:06	0.95	64.0	69.9
	21-Jan-14	12:20	0.98	61.7	72.7
R-44 S1	13-Nov-09	13:15	1.20	13.1	11.2
	18-Nov-10	12:20	1.00	12.0	13.7
	17-Nov-11	10:34	1.00	13.5	14.9
R-45 S1	19-Aug-09	14:36	1.29	12	14.5
	16-Nov-09	14:22	1.31	13.4	17.4
	27-Jan-10	14:17	1.26	13.6	21.4
	19-Nov-10	12:26	1.17	17.0	17.5
	16-Nov-11	12:40	1.15	18.8	20.9
	06-Nov-12	12:40	1.11	25	23.0
	6-Nov-13	13:15	1.11	24.7	27.7
	14-Jan-14	12:17	1.07	24.1	
R-50 S1	27-May-10	11:03	1.09	57	53.8
	16-Nov-10	15:54	1.24	66.2	67.0
	18-Nov-11	12:02	1.04	89.6	89.4
	09-Nov-12	12:17	1.04	100	96.3
	12-Nov-13	16:02	0.97	69.2	83.9
	15-Jan-14	14:35	0.98	98.6	112
Average (± 1 standard deviation)			1.09 ± 0.12	Not calculated	Not calculated

Data source: Appendix B.

[a] Data from University of Illinois at Urbana-Champaign. Typical uncertainty is ± 1.0‰.

[b] Data from outside analytical laboratory (GELC).

[c] — = Not reported.

Table 4.6-2
Hexavalent Chromium Concentrations and Chromium Isotopes in Groundwater at R-61 S1

Collection Date	Collection Time	Purge Volume (CVs)	δ^{53}Cr (‰)[a]	Cr(VI) (µg/L)[a]	Cr (F) (µg/L)[b]	Cr (F) (µg/L)[c]
15-Jul-13	10:07	1	2.55	7.0	—[d]	—
	11:07	3	1.75	12.7	10.5	12.6
	12:33	6	1.51	15.7	12.4	—
	13:59	9	1.35	17.1	13.3	—
	15:25	12	1.25	17.9	13.5	—
15-Nov-13	11:23	6	1.45	15.8	15.2	19.1
	11:23	6[e]	1.46	16.1	—	19.1
23-Jan-14	8:48	1	3.40	5.7	—	—
	9:43	3	1.87	14.6	18.2	19.7
	11:06	6	1.42	17.2	19.7	—
	12:29	9	1.35	17.8	21.1	—
	13:52	12	1.26	18.1	21.8	—

Data source: Appendix B; Johnson (2014, 255423).

[a] Data from University of Illinois at Urbana-Champaign (Johnson 2014, 255423).

[b] Data from GGRL (EES-14).

[c] Data from outside analytical laboratory (GELC).

[d] — = Not measured.

[e] Field duplicate.

Appendix A

Physical and Hydrologic Attributes of Well R-61

INTRODUCTION

This appendix describes the physical and hydrologic attributes of regional monitoring well R-61, located at Technical Area 05 at Los Alamos National Laboratory (LANL or the Laboratory).

The following abbreviations and acronyms are used throughout Appendix A.

bgs	below ground surface
gpm	gallons per minute
I.D.	inside diameter
LANL or the Laboratory	Los Alamos National Laboratory
O.D.	outside diameter
PVC	polyvinyl chloride
TD	total depth

Table A-1
Summary of Well Screen Information for R-61

Screen	Depth Interval (ft)	Screen Length (ft)	Geologic Unit	Primary Sand-Pack Gradation and Depth Interval (ft)	Hydrogeologic Target of Screen	Comments
1	1125.0–1135.0	10	Puye Formation	10/20 sand 1119.4–1140.4	Uppermost part of the regional zone of saturation	Top of screen is submerged 24 ft below the water table
2	1220.4–1241.0	20.6	Miocene Pumiceous Sedimentary Deposits	10/20 sand 1215.5–1246.2	Deeper within the upper regional zone of saturation	Top of screen is submerged 119.4 ft below the water table

Table A-2
R-61 Drilling and Well Construction

Attribute	Description	Evaluation
Drilling Method	R-61 was drilled using open-hole fluid-assisted air-rotary drilling methods with casing advance. Drilling fluids consisted of municipal water and municipal water mixed with foam. The drilling fluid was added to the compressed-air circulating medium to help remove cuttings and stabilize the hole.	Well R-61 was drilled by methods commonly used to install groundwater wells at the Laboratory and approved by the New Mexico Environment Department (NMED) in the drilling work plan (LANL 2010, 110998; NMED 2012, 520923). Geologic conditions encountered during drilling are similar to those predicted in the work plan (Figure A-1). Drilling operations, hydrogeologic conditions, and well installation at well R-61 are summarized in the well completion report (LANL 2011, 206492). The R-61 borehole was drilled using a Foremost DR-24HD dual-rotary drilling rig with casing rotator. Dual-rotary drilling has the advantage of simultaneously advancing and casing the borehole. The Foremost DR-24HD drill rig was equipped with conventional drilling rods, tricone bits, downhole hammer bits, a deck-mounted air compressor, and general drilling equipment. Auxiliary equipment included two Ingersoll Rand trailer-mounted air compressors. Three sizes of A53 grade B flush-welded mild carbon-steel casing (18-in., 16-in., and 12-in. inside diameter [I.D.]) were used for the R-61 project. The dual-rotary and standard rotary (open hole) techniques used filtered, compressed air and fluid-assisted air to evacuate cuttings from the borehole. Drilling from the surface to a depth of 145 ft below ground surface (bgs) employed dual-rotary methods with 18-in. drill casing and a 17-in. tricone bit. An open borehole was advanced from 145 to 612 ft bgs using a 14.75-in. tricone bit. The open borehole was then reamed to a diameter of 20 in. from approximately 150 to 610 ft bgs. A 16-in. casing string was installed in the open borehole to a depth of 612 ft at the top of the Cerros del Rio volcanic series. A 15-in. hammer bit was used to advance an open borehole to 896 ft bgs where drilling was halted because cuttings did not circulate out of the borehole in the interval from 865 to 896 ft bgs. A 12-in. casing string was installed in the borehole to seal off the lost-circulation zone. A 12-in. underreaming hammer bit was then used to advance the borehole and 12-in. casing string through the remaining portion of the Cerros del Rio volcanic series, the Puye Formation, and Miocene pumiceous sediments. Casing advance drilling proceeded to total depth (TD) at 1265 ft bgs.

Table A-2 (continued)

Attribute	Description	Evaluation
Drilling Method (cont.)		The use of foam as a drilling additive was discontinued at 992 ft bgs, approximately 109 ft above the regional water table that was encountered at 1101 ft bgs. No additives other than potable water were used as drilling fluids below 992 ft bgs.
General Well Characteristics	R-61 is a dual-screen well constructed of 5.0-in.-I.D./5.56-in.outside diameter (O.D.) passivated type A304 stainless-steel well casing.	The well design is shown in Figure A-2. The stainless-steel materials used at R-61 are chemically inert.
Well Screen Construction	Well R-61 was constructed with stainless-steel rod-based wire-wrapped screens with 0.020-in. slots.	Wire-wrapped screen with 0.020-in. slots is considered the optimum design for promoting the free flow of water during well development and sampling.
Screen Length and Placement	Screen 1 extends from 1125.0–1135.0 ft bgs (length 10 ft) and targets regional groundwater. Screen 2 extends from 1220.4–1241.0 ft bgs (length 20.6 ft) and targets regional groundwater.	The screen lengths and placements achieve the following goals identified in the drilling work plan and well design justification document: • Primary Goal–Define the southern extent of chromium contamination in the regional aquifer, specifically to identify potential pathways for chromium migration from R-42 and R-28 that may be more southerly than those sampled at wells R-44, R-45, and R-50. • Secondary Goal–Monitor water levels to investigate the direction of groundwater flow and hydraulic gradients within the regional aquifer • Secondary Goal–provide information about potential perched groundwater, if present. The placement and hydrogeologic setting of screen 1 is representative of aquifer conditions and meets all characterization and monitoring goals. It is placed in the upper part of the regional groundwater system to monitor groundwater down gradient of potential chromium infiltration sites. The main goal for this screen is to determine if Laboratory contamination occurs at this site and to provide constraints on the size, shape, and flow directions for the contaminant plume encountered at wells R-42 and R-28. The well screen is within the lower part of the Pliocene Puye Formation. Based on R-61 cuttings and geophysical data from nearby wells, the Puye Formation is a sedimentary deposit made up of stacked beds of boulders, cobbles, and sandy gravels derived from dacitic lavas of the Tschicoma Formation. At 24 ft below the piezometric surface, the top of well screen 1 is located within the uppermost permeable horizon that could be clearly delineated in the regional groundwater system. Ordinarily, well screens targeting the uppermost part of the regional aquifer are placed 20 to 30 ft below the piezometric surface, particularly when, like well R-61, they are located proximal to expected infiltration zones. Shallow well screens are better suited to detect contaminants entering the regional aquifer before significant dilution takes place.

Table A-2 (continued)

Attribute	Description	Evaluation
Screen Length and Placement (cont.)		Consideration was given to placing R-61 screen 1 slightly higher in the aquifer, but this approach was rejected because there was risk that this interval might dewater during pumping development and sampling. The R-61 well screen 1 is at an elevation of 5810 to 5820 ft, comparable to screen 1 at R-50 (5817- to 5827-ft elevation) and to the screen at R-42 (5806- to -5827-ft elevation). Water-level data collected from screen 1 is used to construct a regional water table map and to monitor groundwater responses to pumping at municipal supply wells. The placement and hydrogeologic setting of screen 2 is representative of aquifer conditions and meets all characterization and monitoring goals. The top of the well screen is 119.4 ft below the water table and 85.4 ft below the bottom of screen 1. Well screen 2 is placed deeper in the regional groundwater system to determine the vertical extent of the chromium plume at this location, to provide information about vertical hydraulic gradients, and to monitor groundwater responses to pumping at municipal supply wells. An important goal for this screen is to determine if Laboratory contamination occurs at depth in the regional aquifer and to provide constraints on the size, shape, and flow directions for the contaminant plume encountered at wells R-42 and R-28. Screen 2 is within the central part of Miocene pumiceous sedimentary deposits that consist of well-bedded silts, sands, and gravels made up of pumice-rich rhyolitic detritus and subordinate dacitic detritus. Screen 2 is within strata identified by the driller and site geologist as having an increased rate of water produced from ~10 gallons per minute (gpm) to 20 to 30 gpm. The location of this deeper screen is at an elevation of 5705 to 5725 ft, comparable to screen 2 at R-50 (5698- to 5719-ft elevation).
Filter Pack Materials and Placement	The filter packs and their placements are discussed for the two well screens in the column to the right.	The lengths and placements of the filter packs for both well screens meet the design goals for this well. Screen 1 primary filter pack is made up of 10/20 sand from 1119.4 to 1140.4 ft bgs. The primary filter pack extends 5.5 ft above and 5.4 ft below the well screen and is optimum for the well design. A secondary filter pack of 20/40 sand is located above the primary filter pack from 1116.9 to 1119.4 ft bgs. Screen 2 primary filter pack is made up of 10/20 sand from 1215.5 to 1246.2 ft bgs. The primary filter pack extends 4.9 ft above and 5.2 ft below the well screen and is optimum for the well design. A secondary filter pack of 20/40 sand is located above the primary filter pack from 1213.6 to 1215.5 ft bgs.
Sampling System	Submersible pump	The sampling system meets the design goals for this well. Well R-61 uses a sampling system manufactured by Baski, Inc., that utilizes a single 3-hp, 4-in.-O.D. environmentally retrofitted Grundfos submersible pump capable of purging each screened interval discretely via pneumatically actuated access port valves. The system includes a Viton-wrapped isolation packer between the screened intervals. The pump column consists of threaded and coupled passivated 1-in.-I.D. stainless steel. Water levels are measured by In-Situ, Inc. Level Troll 500 30-psig transducers in two 1-in.-I.D. schedule 80 polyvinyl chloride (PVC) tubes banded to the pump riser.

Table A-2 (continued)

Attribute	Description	Evaluation
Sampling System (cont.)		The upper PVC transducer tube is equipped with a 0.010-in. slotted screen with a threaded end cap at the bottom of the tube. The lower PVC transducer tube is equipped with a flexible nylon tube that extends from a threaded end cap at the bottom of the PVC tube through the isolation packer and measures water levels in screen 2. The Baski sampling system allows groundwater to be collected from two depths within the aquifer from a single well. Packers isolate the two well screens and samples collected represent two independent depth intervals. Use of the submersible pump for both screens allows groundwater to be purged from the well casing, well-filter pack, and to some degree, near-well formation materials.
Other Issues That Could Affect Well Performance	Use of hammer oil while drilling in the regional aquifer	It appears likely that aquifer materials in the vicinity of both well screens are contaminated by hammer oil used during drilling operations. Because of lost-circulation problems in the interval from 865 to 896 ft bgs, a 12-in. underreaming hammer bit was used to advance the borehole and 12-in. casing string from 896 to 1265 ft bgs (TD). This drilling method was used to advance the borehole through the lower part of the unsaturated zone and throughout the zone of regional saturation below 1101 ft bgs. Oil was used to lubricate the underreaming hammer bit throughout the interval from 896 to 1265 ft bgs. Based on aquifer test conducted after the well was installed, it appears that high-pressure compressed air used in the drilling process invaded the aquifer zones during drilling, collecting in formation pore spaces and/or dissolving into the groundwater (LANL 2011, 206492). When water is pumped from the aquifer, trapped air in the formation pores can move with the pumped water as well as expand and contract in response to pressure changes. Also, pressure reduction associated with pumping can allow dissolved gas or air to come out of solution. The air present in the formations in other wells tested has had several effects, including (1) interfering with pump operating efficiency, (2) causing transient changes in aquifer permeability, (3) inducing pressure transients as the gas or air expands and contracts, and (4) causing storage-like effects associated with changes in air volume in the formation voids, filter pack, and/or well casing.
Downhole Products Used during Drilling		Air Municipal water Baroid AQF-2 QUIK-FOAM Hammer oil (BioBlend BioLube RDP)
Annular Fill Other Than Filter and Transition Sands		3/8-in. chips of bentonite were hydrated to create annular seals. A Portland cement surface seal was placed from 3 to 59.9 ft.

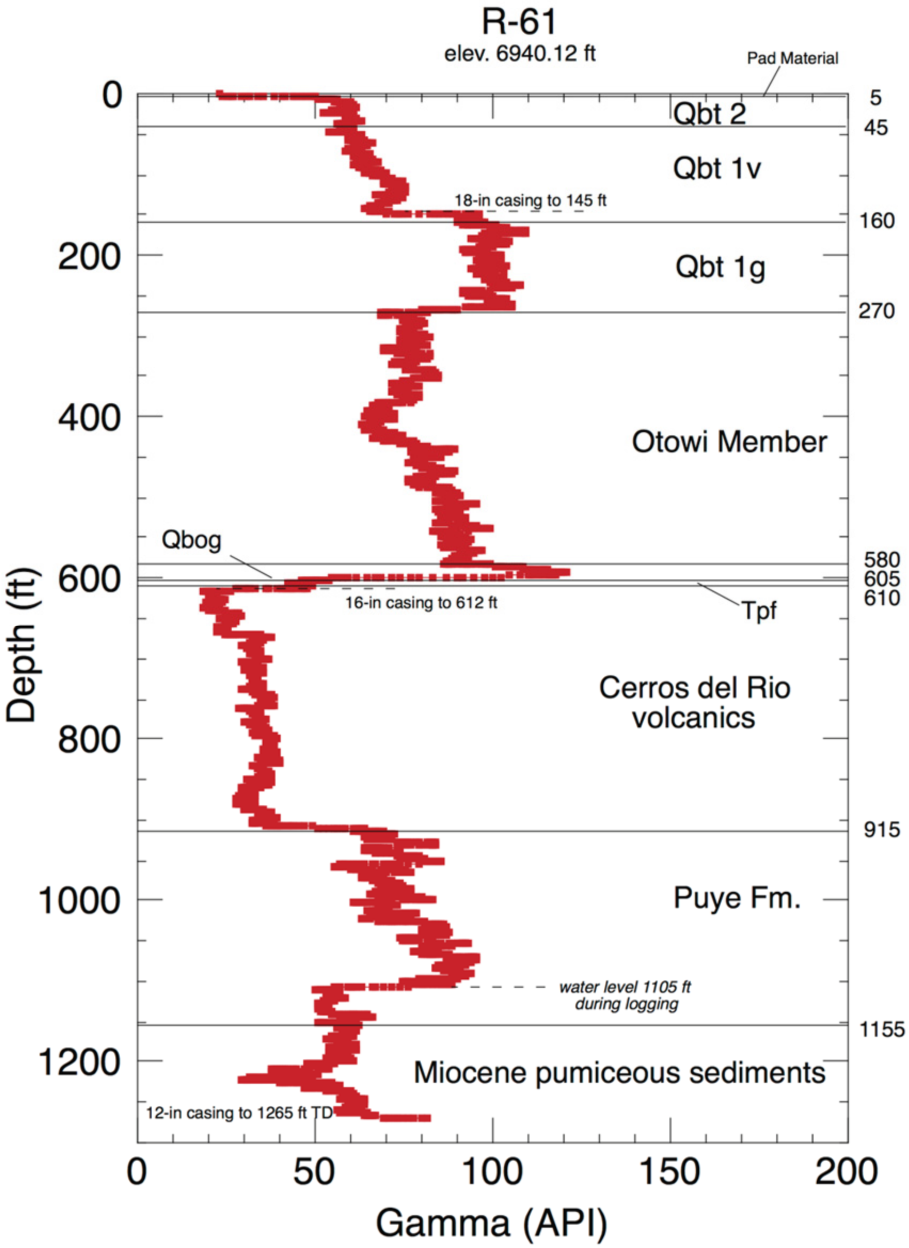


Figure A-1 Well R-61 geology and borehole gamma log

TOTAL LENGTH
OF CASING AND SCREEN (FT) 1254.4

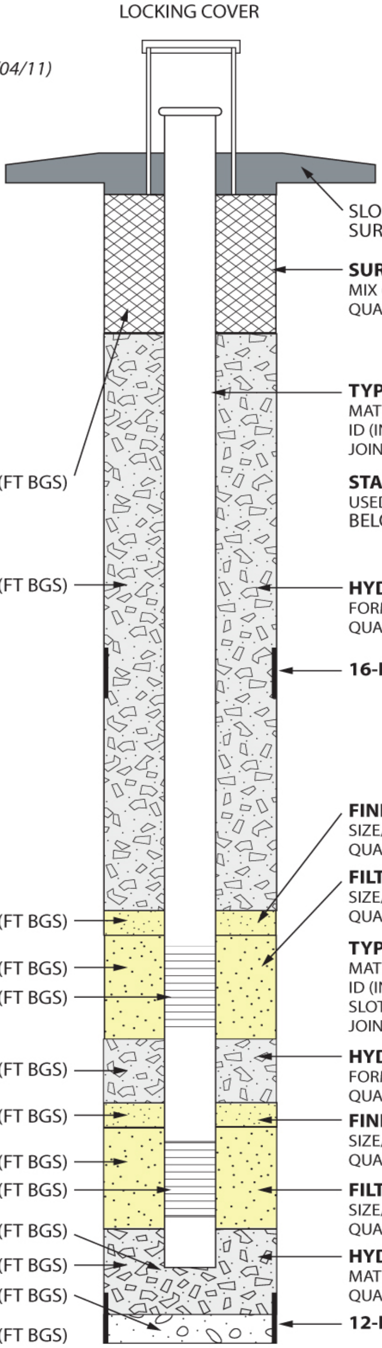
DEPTH TO WATER
FOLLOWING INSTALLATION (FT BGS) 1101.3 *(05/04/11)*

DIAMETER OF BOREHOLE
18.75 (IN) FROM 0 TO 145.0 (FT BGS)
20.00 (IN) FROM 145.0 TO 612.2 (FT BGS)
15.88 (IN) FROM 612.2 TO 896.0 (FT BGS)
13.50 (IN) FROM 896.0 TO 1266.4 (FT BGS)

SURFACE COMPLETION *(proposed)*
PROTECTIVE CASING
TYPE STEEL SIZE (IN) 16
PROTECTIVE POSTS INSTALLED YES
SURFACE SEAL AND PAD
CHECK FOR SETTLEMENT YES
PAD MATERIAL CONCRETE
REINFORCED WIRE MESH
PAD DIMENSIONS (FT) 10 (L) 10 (W) 0.5 (H)

ELEVATIONS (FT AMSL)
WELL CASING 6942.93
PROTECTIVE CASING 6943.81
GROUND SURFACE 6940.00
BRASS CAP (MARKER) 6940.12

WELL COMPLETION BEGAN
DATE 04/09/11 TIME 1330h
WELL COMPLETION FINISHED
DATE 05/03/11 TIME 1300h



SURFACE SEAL	3.0	TO	59.9	(FT BGS)
BENTONITE SEAL	59.9	TO	1116.9	(FT BGS)
FINE SAND COLLAR	1116.9	TO	1119.4	(FT BGS)
FILTER PACK	1119.4	TO	1140.4	(FT BGS)
SCREENED INTERVAL	1125.0	TO	1135.0	(FT BGS)
BENTONITE SEAL	1140.4	TO	1213.6	(FT BGS)
FINE SAND COLLAR	1213.6	TO	1215.5	(FT BGS)
FILTER PACK	1215.5	TO	1246.2	(FT BGS)
SCREENED INTERVAL	1220.4	TO	1241.0	(FT BGS)
BOTTOM OF CASING	1251.6			(FT BGS)
BACKFILL	1246.2	TO	1263.6	(FT BGS)
SLOUGH	1263.6	TO	1266.4	(FT BGS)
BOTTOM OF BORING	1265.0			(FT BGS)

SURFACE SEAL
MIX (WT%) PORTLAND CEMENT 100 BENTONITE 0
QUANTITY USED 132.0 FT^3 CALC 91.2 FT^3

TYPE OF CASING
MATERIAL PASSIVATED A304 STAINLESS STEEL
ID (IN) 5.00 OD (IN) 5.56 ($5\frac{9}{16}$)
JOINT TYPE THREADED/COUPLED

STAINLESS-STEEL CENTRALIZERS
USED YES AT 2.0 ft ABOVE AND
BELOW WELL SCREENS

HYDRATED BENTONITE SEAL
FORM ⅜-IN BENTONITE CHIP
QUANTITY USED 1472.7 FT^3 CALC 1557.2 FT^3

16-IN CSG/SHOE 600.0 TO 612.2 (FT BGS)

FINE SAND COLLAR
SIZE/TYPE 20/40 SILICA
QUANTITY USED 2.0 FT^3 CALC 2.2 FT^3

FILTER PACK SAND
SIZE/TYPE 10/20 SILICA
QUANTITY USED 24.0 FT^3 CALC 18.6 FT^3

TYPE OF SCREEN(S)
MATERIAL A304 STAINLESS STEEL
ID (IN) 5.00 OD (IN) 5.88 ($5\frac{7}{8}$)
SLOT SIZE (IN) 0.020
JOINT TYPE THREADED/COUPLED

HYDRATED BENTONITE SEAL
FORM ⅜-IN BENTONITE CHIP
QUANTITY USED 60.3 FT^3 CALC 65.2 FT^3

FINE SAND COLLAR
SIZE/TYPE 20/40 SILICA
QUANTITY USED 3.0 FT^3 CALC 1.7 FT^3

FILTER PACK SAND
SIZE/TYPE 10/20 SILICA
QUANTITY USED 37.0 FT^3 CALC 27.3 FT^3

HYDRATED BENTONITE BACKFILL
MATERIAL ⅜-IN BENTONITE CHIP
QUANTITY USED 6.7 FT^3 CALC 17.6 FT^3

12-IN CSG/SHOE 1258.8 TO 1266.4 (FT BGS)

WELL DEVELOPMENT INFORMATION:

WELL DEVELOPMENT
DATE 05/04/11 TIME 1335h
TO
DATE 05/15/11 TIME 1800h

DEVELOPMENT METHOD
☑SWABBING ☑BAILING ☑PUMPING
DEVEOPMENT PURGE VOLUME (GAL) 12,305
TOTAL PURGE VOLUME (GAL) 44,175

FINAL PARAMETERS *(Upper/Lower Screen)*
pH 7.94/8.28
TEMPERATURE (°C) 22.41/21.22
SPECIFIC CONDUCTANCE (µS/cm) 101/101
TURBIDITY (NTU) 17.4/3.2

TerranearPMC
Drafted By: TPMC
Project Number: 88200
Date: July 12, 2011
File Name: R61_AsBuiltWellConstruction_Fig7-2-1

R-61 AS-BUILT WELL CONSTRUCTION DIAGRAM
Technical Area 5 (TA-05)
Los Alamos National Laboratory
Los Alamos, New Mexico

Fig.
7.2-1
NOT TO SCALE

Figure A-2 R-61 well design

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), October 2010. "Drilling Work Plan for Regional Aquifer Well R-61," Los Alamos National Laboratory document LA-UR-10-6970, Los Alamos, New Mexico. (LANL 2010, 110998)

LANL (Los Alamos National Laboratory), September 2011. "Completion Report for Regional Well R-61," Los Alamos National Laboratory document LA-UR-11-5091, Los Alamos, New Mexico. (LANL 2011, 206492)

NMED (New Mexico Environment Department), July 10, 2012. "Approval, Work Plan for Redevelopment of Monitoring Well R-61," New Mexico Environment Department letter to P. Maggiore (DOE-LASO) and M.J. Graham (LANL) from J.E. Kieling (NMED-HWB), Santa Fe, New Mexico. (NMED 2012, 520923)

Appendix B

Water-Quality Data
(on CD included with this document)