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Date: APR 26 2018
Refer To: ADEM-18-0046
LAUR: 18-23418

John Kieling, Bureau Chief
Hazardous Waste Bureau
New Mexico Environment Department
2905 Rodeo Park Drive East, Building 1
Santa Fe, NM 87505-6303

Subject: Second Quarterly Report on Pilot-Scale Amendments Testing for Chromium in Groundwater Beneath Mortandad Canyon

Dear Mr. Kieling:

Enclosed please find two hard copies with electronic files of the second Quarterly Report on Pilot-Scale Amendments Testing for Chromium in Groundwater Beneath Mortandad Canyon.

If you have any questions, please contact Danny Katzman at (505) 667-6333 (katzman@lanl.gov) or Cheryl Rodriguez at (505) 665-5330 (cheryl.rodriguez@em.doe.gov).

Sincerely,

Enrique Torres, Program Director
Environmental Remediation Program
Los Alamos National Laboratory

Sincerely,

David S. Rhodes, Director
Office of Quality and Regulatory Compliance
Environmental Management
Los Alamos Field Office

ET/DR/DK

Enclosures: Second Quarterly Report on Pilot-Scale Amendments Testing for Chromium in Groundwater beneath Mortandad Canyon (EP2018-0062)

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LA-UR-18-23418
April 2018
EP2018-0062

Second Quarterly Report on Pilot-Scale Amendments Testing for Chromium in Groundwater Beneath Mortandad Canyon

Los Alamos
NATIONAL LABORATORY
EST. 1943

Prepared by the Associate Directorate for Environmental Management

EP2018-0062

Second Quarterly Report on Pilot-Scale Amendments Testing for Chromium in Groundwater Beneath Mortandad Canyon

April 2018

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David S. Rhodes		Office Director	Quality and Regulatory Compliance	4-26-2018

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Figures

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Attachment

1.0 INTRODUCTION

This report is the second quarterly report presenting results of two pilot-scale amendment tests being conducted to evaluate feasibility for in situ reduction of hexavalent chromium in the regional aquifer. The study is being conducted in accordance with the “Pilot-Scale Amendments Testing Work Plan for Chromium in Groundwater beneath Mortandad Canyon” (LANL 2017, 602505) as approved by the New Mexico Environment Department (NMED 2017, 602546). The deployments occurred at regional groundwater monitoring wells R-42 and R-28. Sodium dithionite was injected into R-42 in late August 2017, and molasses was injected into R-28 in early September 2017 (Figure 1.0-1). The objectives of the tests are to evaluate (1) the ability of the amendments to reduce and immobilize hexavalent chromium [Cr(VI)] in the regional aquifer, (2) the longevity of the treatments in keeping Cr(VI) concentrations low (i.e., reduction capacity), (3) any adverse geochemical effects and their persistence, and (4) any adverse hydrological impacts of the treatments on hydraulic properties of the aquifer. The first quarterly report, issued at the end of January 2018 (LANL 2018, 602862), provided details of how the amendments were deployed and of the pumping and sampling strategies in each of the test wells, as well as the geochemistry data from the tests, through the end of calendar year 2017; these details will not be repeated in this quarterly report. This quarterly report discusses additional sampling of R-42 and R-28 that occurred during January through March of 2018, and it presents all the new geochemistry data associated with these samples in Attachment 1 (on CD included with this document, plotted and discussed along with previously reported data). Attachment 1 also presents the results of (1) a borehole dilution tracer test that was conducted in R-42 in January 2018 to estimate the post-amendment ambient groundwater flow velocity through the R-42 screened interval, and (2) an analysis of pre- and post-amendment drawdown data from both R-42 and R-28 so that the effects of the amendments on near-well hydraulic conductivity can be evaluated.

2.0 UPDATE OF AMENDMENT TEST GEOCHEMISTRY RESULTS

2.1 Sodium Dithionite at R-42

Figure 2.1-1 shows an updated plot of the concentration trends of selected cations and metals, including chromium, measured in samples collected from R-42 as a function of time. Results are also shown in Figure 2.1-1 for the injection batches, which are plotted to the left of the vertical dashed line that indicates when pumping of the well was initiated. On January 16, 2018, a dilution tracer test was conducted in R-42 (see section 3) that temporarily perturbed the geochemical data from the well because potable water was used for the tracer injection. After this test was conducted, each sample that was collected from R-42 was preceded by purging of approximately 50 gal. of water from the well (approximately one casing volume in the current configuration). Vertical dashed lines are shown in Figure 2.1-1 for when continuous pumping of R-42 stopped in September 2017, when net withdrawal of water from the well stopped in October 2017, and when the 50-gal. biweekly purges were initiated after the dilution tracer test in January 2018. Figure 2.1-2 shows concentration trends for some of the other elements of interest, including arsenic and selenium, and Figure 2.1-3 shows concentration trends for selected anions measured in samples collected from R-42. Plots of the concentration trends of Figures 2.1-1 to 2.1-3 as a function of volume pumped from R-42 were provided in the previous quarterly report, and they are not updated here because only very small additional volumes were pumped with each 50-gal. purge. Concentrations of other elements or ions not shown in Figures 2.1-1 to 2.1-3 can be found in Attachment 1 (on CD included with this document).

Several points can be made regarding Figures 2.1-1 to 2.1-3. First, it is apparent that Cr(VI) concentrations in R-42 have remained very low, even after initiating the 50-gal. biweekly purges in

January 2018. Second, it is apparent that the perturbation introduced by the borehole dilution tracer test was relatively short-lived. Third, after the initiation of the 50-gal. purges, ferrous iron (Fe^{2+}) and arsenic concentrations have increased considerably, almost reaching the concentrations they were at before stopping continuous pumping from R-42 in October 2017. Additionally, concentrations of nitrate (NO_3^-) have dropped to their lowest levels since the test began. Finally, whereas Cl^- concentrations have remained very close to their pre-test levels since the withdrawal of the dithionite injection solution in September 2017, sulfate ($SO_4^=$) concentrations have remained persistently elevated by a factor of 3 to 4 higher than their pre-test concentrations.

These observations are consistent with the persistence of reducing conditions in the immediate vicinity of R-42 as a result of the dithionite injection in August 2017. The increases in Fe^{2+} and arsenic concentrations and the decrease in NO_3^- concentrations since the initiation of the 50-gal. purges, which are being conducted approximately twice per week, suggest that when the well was being passively sampled without any purging (from October 14, 2017, to the start of the dilution tracer test on January 16, 2018), the water in the wellbore became oxygenated and the measured concentrations of these redox-sensitive constituents did not reflect their true concentrations just outside the well. Thus, the 50-gal. biweekly purges appear to be providing more representative samples that better reflect geochemical conditions in the aquifer near R-42. The persistence of elevated concentrations of $SO_4^=$ suggest that there is a steady production of $SO_4^=$ as a result of slow oxidation of reduced sulfur species that were formed during and immediately after the dithionite was injected. This result is not surprising given that sulfur recovery during the pumping period in August through mid-October of 2017 was only about 70% of the total sulfur injected (LANL 2018, 602862, Figure 7). The implication is that both reduced sulfur species, as well as Fe^{2+}, are likely contributing to the persistence of reducing conditions in the vicinity of R-42. Cr(VI) concentrations in R-42 have not risen as of March 30, 2018, despite the fact that Cl^- (naturally occurring anion) and Br^- (conservative tracer injected with dithionite) concentration trends have indicated that the water present in the well has been predominantly (non-injected) aquifer water since early September 2017. Furthermore, approximately 8 times as much water was pumped from R-42 from late August through mid-October 2017 as the amount of dithionite solution and chase water that was injected. Thus, the dithionite treatment has apparently been very effective at reducing Cr(VI) that has entered the reaction zone surrounding R-42 after the dithionite deployment, both under forced-gradient and natural-gradient flow conditions.

2.2 Molasses at R-28

With the exception of a 1000-gal. purge on November 20, 2017, R-28 was passively sampled until early February 2018. Starting on February 6, 2018, approximately 50 gal. of water was purged from R-28 before each biweekly sampling event (similar to R-42), although the first sampling event involved a purge of about 200 gal. Figure 2.2-1 shows the trends of selected cations and metals, including chromium, during the molasses test so far. Figure 2.2-2 shows concentration trends for some of the other elements of interest, including arsenic and selenium, and Figure 2.2-3 shows trends for anions during the test. Figure 2.2-4 shows the bromide (Br^-) and total organic carbon (TOC) concentrations during the test. TOC is being used as a surrogate for molasses, as background concentrations of organic carbon in the aquifer are negligible compared with the levels of molasses introduced. However, TOC data also include ethanol (used in chase water) and molasses breakdown products as well. The decrease in concentrations of many constituents on November 20, 2017, is associated with the 1000-gal. purge that was conducted that day. Figure 2.2-5 shows an updated plot of the selected metals concentrations during the purge, and Figure 2.2-6 shows the anions and TOC concentrations during the purge.

As was discussed in the previous quarterly report, an unexpected result of the test was the observation of higher concentrations of chromium after introducing molasses than had ever previously been observed in

R-28 (by a factor of 3 or more) up until the 1000-gal. purge on November 20, 2018. During the purge, concentrations of chromium dropped abruptly (Figure 2.2-5), but they have remained persistently above or near 50-μg/L ever since. These results have been surprising given that laboratory testing had shown that molasses is capable of rapidly and abiotically reducing Cr(VI) to trivalent chromium [Cr(III)]; measurable concentrations of Cr(VI) were not expected until all molasses had drifted downgradient or had been consumed (which is still not the case). Ultraviolet-visible spectroscopic measurements were made from samples and indicate that all the measured chromium is Cr(III) [or at least it is not Cr(VI)]. These chromium concentrations have been attributed to leaching/corrosion of the stainless-steel casing in R-28, as concentrations of nickel are also elevated well above background concentrations. Chromium and nickel are the two main additives (to iron) in stainless steel. The post-injection pH in the well water has been consistently in the range of 4.6 to 4.8, which was expected because of organic acids generated as a result of molasses breakdown and was also observed in laboratory experiments. While this is a relatively low pH, it is not thought to be low enough to cause such elevated concentrations of chromium and nickel from stainless steel. It is suspected that very local-scale microbial corrosion/leaching processes could be the cause of these observations, and it is also possible that something in the molasses is complexing Cr(III) and possibly Ni(II) to increase their effective solubility.

The concentration trends of anions, cations, metals, and TOC in R-28 have not changed dramatically since the 50-gal. biweekly purges were initiated on February 6, 2018 (Figures 2.2-1 to 2.2-4). It appears that there was a delayed drop of perhaps a factor of 2 in the Br^- tracer concentration within the first 2 wk of purging/sampling, followed by a gradual recovery in the Br^- concentrations. However, these trends were not mimicked by the TOC concentrations (Br^- was co-injected with the molasses), which remained relatively steady before and after the initiation of purging. Most other species also appear to have remained essentially unaffected by the initiation of purging on February 6, 2018, which is contrary to the observations that were made during the early portion of the November 20, 2017, purge of R-28 (Figures 2.2-5 and 2.2-6). Concentrations of Cr(III) have actually increased somewhat since purging began.

The persistence of Br^- and TOC, as well as several other species associated with the molasses, at elevated and relatively steady concentrations indicates that the molasses injection pulse is lingering in the vicinity of R-28. Furthermore, the lack of any notable change in trends with the initiation of the 50-gal. purges suggests that this is not strictly a very near-well phenomenon, but rather it appears to be representative of the aquifer some distance outside the well (though still not far from the well). The total amount of water purged from R-28 since February 6, 2018, was about 1000 gal. as of the end of March 2018.

The molasses injection pulse is lingering far longer than was expected based on the concentration histories of two tracers that were injected into R-28 in 2016 and allowed to drift away under natural gradient conditions. Figure 14 of the previous quarterly report showed the concentration history of one of those tracers, as well as the concentration history of the Br^- tracer that was injected with the molasses in 2017. This plot shows that if the molasses behaved like the 2016 tracer, it should have drifted entirely away from R-28 within 3 mo of injection, but it is clearly still lingering and not notably decreasing in concentration some 7 mo after injection. This suggests that there has been some reduction of permeability in the vicinity of R-28, likely due to the growth of biomass stimulated by the molasses. As long as molasses persists at measureable concentrations in R-28, no Cr(VI) is expected to be detected because of the abiotic reaction of molasses with Cr(VI) to reduce the chromium to Cr(III). Thus, there is really no ability to interrogate the Cr(VI) reduction capacity imparted to the surrounding aquifer by the molasses treatment until the molasses is gone, and this test may remain inconclusive until that occurs.

3.0 BOREHOLE DILUTION TRACER TEST IN R-42 IN JANUARY 2018

A borehole dilution tracer test was conducted in R-42 from January 16 to January 18, 2018, with the intent of estimating the ambient groundwater flow velocity through R-42 so that appropriate constraints could be placed on how much Cr(VI)-bearing groundwater should have flowed through the dithionite reaction zone surrounding the well since active pumping of R-42 was stopped in October 2017. The test was conducted by injecting potable water containing a fluorescent tracer (sodium 1,5-naphthalene disulfonate) while simultaneously pumping the well at an equal rate until the tracer returned to the surface. Equalizing the rates of injection and withdrawal ensured that the tracer remained in the well casing between the point of injection and the pump intake, which was below the bottom of the well screen. After the tracer returned to the surface, the water being pumped from the well was routed directly into the injection line to form a closed loop, and the pump was kept running to circulate the water within the well, bringing it to the surface and returning it. This circulation loop was periodically sampled to allow observation of the decline in tracer concentration, which would provide an estimate of the groundwater flow velocity that was flushing tracer out of the well. The result could be compared with the results of a borehole dilution tracer test conducted in R-42 in 2014 to allow an evaluation of any differences in groundwater flow velocity in 2014, before dithionite injection, and in 2018, after dithionite injection.

Figure 3.0-1 shows the results of the 2018 R-42 borehole dilution tracer test plotted along with the results of the 2014 R-42 dilution tracer test. The much steeper slope of the decline in log tracer concentrations in 2018 suggests a much higher groundwater velocity in 2018 than in 2014, which was initially quite surprising given that R-42 seemed to undergo a drastic permeability reduction just before the dithionite injection (see previous quarterly report). However, further investigation revealed that the injection tube in 2018 was discharging significantly *below* the top of the well screen, whereas in 2014 it was discharging above the top of the well screen. This meant that the 2018 test effectively interrogated the groundwater flow through only the lower portion of the well screen (estimated to be only the bottom 40% or so of the well screen). Furthermore, the location of the discharge point within the well screen greatly increased the potential for the discharge to flow out of the casing and into the formation rather than simply moving vertically down the well screen as it would if the discharge point were located in the unscreened casing above the well screen. Even accounting for the decreased volume of interrogation in 2018, the flow rate through the well screen is estimated to be over 10 times greater in 2018 than in 2014, which does not seem to be a credible result given that all other evidence suggested that the permeability around the well decreased between 2014 and 2018. Rather, it seems likely that some of the water injected into the well screen flowed directly into the formation, and because the flow-in and flow-out of the well were always equal, this meant that some of the water pumped to the surface must have come into the well screen from the formation. This situation is depicted schematically in Figure 3.0-2.

Further evidence that water injected from the surface made its way into the surrounding formation rather than remaining completely within the well during the test (as assumed for an ideal borehole dilution test) is apparent in Figure 3.0-3, which shows the concentration history of the dilution tracer over the few weeks following the dilution tracer test. It is clear that some of the tracer must have been pushed out of the well in the *upgradient* direction during the test because the tracer concentrations first increased and then decreased again long after the circulation flow had stopped. This would not be possible if the ideal assumed conditions for a valid borehole dilution test were satisfied. Note that each sampling event after January 19 was after a 50-gal. purge of the well.

Thus, the 2018 borehole dilution tracer test was not considered to have provided a valid estimate of the ambient groundwater flow velocity through the R-42 well screen after the dithionite injection. However, it is apparent that the rate of decline in log tracer concentrations after the tracer moved back through the well screen (i.e., after the concentration peaked) was not much different from the rate of decline in 2014

(Figure 3.0-3), so in the absence of a better estimate, the flow velocity deduced from the 2014 test was assumed to apply in 2018 to estimate how much groundwater would have flowed through the dithionite reaction zone after active pumping of R-42 had ended in mid-October 2017. This flow velocity was estimated to be about 0.14 m/d (assuming a flow porosity of 0.2).

Assuming ideal radial flow in a homogeneous isotropic medium over the entire length of the R-42 well screen during the dithionite injection, and an aquifer flow porosity of 0.2, the 10,000-gal. dithionite injection (including chase water) would have reached approximately 3 m into the aquifer around R-42. If a small allowance for permeability reduction is made such that the groundwater flow velocity after the dithionite injection is assumed to be about 0.1 m/d, then it would take roughly 1 mo for groundwater to move from the upgradient outer edge of the 3-m-radius reaction zone into the well. Given that 6 mo have passed since the end of active pumping, one could assume that 6 pore volumes of aquifer water have passed from the leading edge of the zone to the well during the time since active pumping stopped. Given that approximately 8 pore volumes were pumped out of R-42 before the end of active pumping (almost 80,000 gal. vs a 10,000-gal. injection pulse), this means that the dithionite injection can be estimated to have effectively reduced the Cr(VI) in approximately 14 reaction zone pore volumes of water since it was deployed (although 1 pore volume was the dithionite solution itself, so it is really 13 pore volumes of R-42 water). The moles of Cr(VI) predicted to have been reduced so far per mole of dithionite deployed is about 0.0045 moles/mole (assuming the 300 kg of sodium dithionite deployed was 90% pure, as indicated by the manufacturer). This is in the presence of much higher molar concentrations of both dissolved oxygen and NO_3^-, which are also presumably being reduced by the dithionite reaction products present in the zone surrounding the well. Based on laboratory test results, it would take up to an estimated 18 pore volumes to exhaust the reduction capacity imparted by the dithionite treatment and see Cr(VI) concentrations start to increase in R-42. Thus, Cr(VI) concentrations might begin to increase in approximately another 4 to 5 mo under current natural flow conditions. Of course, this prediction has a great deal of uncertainty associated with it because of all the unverifiable assumptions outlined above. If Cr(VI) concentrations have not begun to increase after another 6 mo of observation under natural flow conditions, resuming pumping of R-42 would be warranted until Cr (VI) concentrations begin to increase.

4.0 ANALYSIS OF IMPACTS OF AMENDMENTS ON PERMEABILITIES NEAR R-42 AND R-28

In lieu of sophisticated aquifer test analyses, the effects of the amendment deployments on aquifer permeabilities in the vicinity of R-42 and R-28 were evaluated by simply comparing the specific capacity of the wells before and after deployment of the amendments. The specific capacity is the steady-state flow rate divided by the steady-state drawdown, with units of length squared per unit of time, which are the same units as transmissivity. This method is consistent with the Cooper-Jacob method (Cooper and Jacob 1946, 098236) and with a relatively new single-well steady-state method for estimating transmissivities (Aragon-Jose and Robbins 2011, 603002). This method does not yield absolute estimates of transmissivity or permeability, but rather relative changes before and after amendment deployments. Normally one would consider the specific capacity to be a poor measure of true aquifer permeability because wellbore artifacts such as skin effects or other completion artifacts might account for a significant fraction of the drawdown at a given flow rate, but here the specific capacity is considered to be reasonable indicator of amendment effects because even increased skin effects (due to biofouling, for example) are of interest in an evaluation of amendments.

4.1 Dithionite at R-42

As was discussed in the previous quarterly report, the permeability in the vicinity of R-42 underwent a large apparent decrease just before introducing dithionite, which was believed to be the result of injection of air into the well during a shakedown test that was conducted with a packer inflated directly above the well screen (thus trapping the air). Although pressure transducer readings were not automatically recorded during the shakedown test nor during dithionite injection, Figure 4.1-1 shows the drawdown history immediately before and after the dithionite deployment with annotations indicating the pumping rates at various times. It is apparent that the initial drawdown immediately after the dithionite injection was quite large, but then it steadily decreased during continuous pumping at 1.95 gallons per minute (gpm). In fact, the initial pumping rate of about 3.1 gpm had to be lowered to 1.95 gpm to avoid having the water level drop below the transducer.

The specific capacity of R-42 at various times before and after the dithionite test is listed in Table 4.1-1. From this table, it is apparent that the specific capacity by the time of the 50-gal. purges in January 2018 had recovered to within 60%–70% of the values observed in several tests conducted before the dithionite deployment. This suggests that the dithionite deployment had little permanent adverse impacts on aquifer permeability (or wellbore efficiency) near R-42. In fact, it is unlikely that the dithionite had any short-term impacts, as the rate at which dithionite could be injected for a given water-level rise in R-42 steadily increased throughout the approximately 18-h injection period. The observed permeability reduction after the dithionite injection was almost certainly due to the air that was injected during the shakedown test and had nothing to do with the dithionite because it occurred before any dithionite was introduced and then gradually recovered.

4.2 Molasses at R-28

The specific capacity of R-28 has always been large compared with most other regional aquifer wells in Mortandad Canyon. Table 4.2-1 lists the specific capacity of R-28 at various times before and after the molasses deployment. It is apparent that during the 50-gal. biweekly purges that began in February 2018 (preceded by a 200-gal. purge on February 6), the specific capacity was consistently about a factor of 3 less than it was before the molasses injection. This result is consistent with the lingering of molasses and other species in the vicinity of R-28 long after they would have been expected to drift away based on the results of the 2016 tracer test in R-28 (discussed above). This suggests that molasses injection has had a slight adverse impact on the permeability of the aquifer in the vicinity of R-28, likely due to some biofouling, although it cannot be determined from the data whether the impact is very near the well or extends to some distance into the aquifer. The drawdown each time a 50-gal. purge is conducted has been very consistent since purging was initiated, so it appears that the permeability near the well has not decreased with time as water has been drawn out (since early February). Formal analysis of the drawdown data from R-28 would be complicated by the fact that there appears to be a leaky check valve that allows the discharge pipe to drain every time the pump is shut off, so the initial drawdown is larger than the steady-state drawdown because the pump can initially pump more quickly into the empty pipe than it can against a full pipe (Figure 4.2-1).

5.0 REFERENCES AND MAP DATA SOURCES

5.1 References

The following reference list includes documents cited in this report. Parenthetical information following each reference provides the author(s), publication date, and ERID or ESHID. This information is also included in text citations. ERIDs were assigned by the Associate Directorate for Environmental Management's (ADEM's) Records Processing Facility (IDs through 599999), and ESHIDs are assigned by the Environment, Safety, and Health Directorate (IDs 600000 and above). IDs are used to locate documents in the Laboratory's Electronic Document Management System and in the Master Reference

Set. The NMED Hazardous Waste Bureau and ADEM maintain copies of the Master Reference Set. The set ensures that NMED has the references to review documents. The set is updated when new references are cited in documents.

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Kleinfelder, February 9, 2005. "Revision 1, Well R-28 Completion Report," report prepared for Los Alamos National Laboratory, Project No. 37151/16.12, Albuquerque, New Mexico. (Kleinfelder 2005, 094042)

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LANL (Los Alamos National Laboratory), January 2018. "Quarterly Report on Pilot-Scale Amendments Testing for Chromium in Groundwater beneath Mortandad Canyon," Los Alamos National Laboratory document LA-UR-18-20467, Los Alamos, New Mexico. (LANL 2018, 602862)

NMED (New Mexico Environment Department), July 31, 2017. "Approval, Pilot-Scale Amendments Testing Work Plan for Chromium in Groundwater beneath Mortandad Canyon," New Mexico Environment Department letter to D. Hintze (DOE-EM) and B. Robinson (LANL) from J.E. Kieling (NMED-HWB), Santa Fe, New Mexico. (NMED 2017, 602546)

5.2 Map Data Sources

Hillshade; Los Alamos National Laboratory, ER-ES, As published; \\slip\gis\Data\HYP\LiDAR\2014\Bare_Earth\BareEarth_DEM_Mosaic.gdb; 2014.

Unpaved roads; Los Alamos National Laboratory, ER-ES, As published, GIS projects folder; \\slip\gis\GIS\Projects\14-Projects\14-0062\project_data.gdb\digitized_site_features\digitized_roads; 2017.

Drainage channel; Los Alamos National Laboratory, ER-ES, As published, GIS projects folder; \\slip\gis\GIS\Projects\15-Projects\15-0080\project_data.gdb\correct_drainage; 2017.

Structures; Los Alamos National Laboratory, KSL Site Support Services, Planning, Locating and Mapping Section; 06 January 2004; as published 29 November 2010.

Paved Road Arcs; Los Alamos National Laboratory, FWO Site Support Services, Planning, Locating and Mapping Section; 06 January 2004; as published 29 November 2010.

Chromium plume > 50 ppb; Los Alamos National Laboratory, ER-ES, As published; \\slip\gis\GIS\Projects\13-Projects\13-0065\shp\chromium_plume_2.shp; 2018.

Regional groundwater contour May 2017, 4-ft interval; Los Alamos National Laboratory, ER-ES, As published; \\slip\gis\GIS\Projects\16-Projects\16-0027\project_data.gdb\line\contour_wl2017may_2ft; 2017.

Regional groundwater contour November 2017, 2-ft interval; Los Alamos National Laboratory, ER-ES, As published; \\slip\gis\GIS\Projects\16-Projects\16-0027\project_data.gdb\line\contour_wl2017nov_2ft; 2017.

Point features; As published; EIM data pull; 2017.

Technical Area Boundaries; Los Alamos National Laboratory, Site Planning & Project Initiation Group, Infrastructure Planning Office; September 2007; as published 13 August 2010.

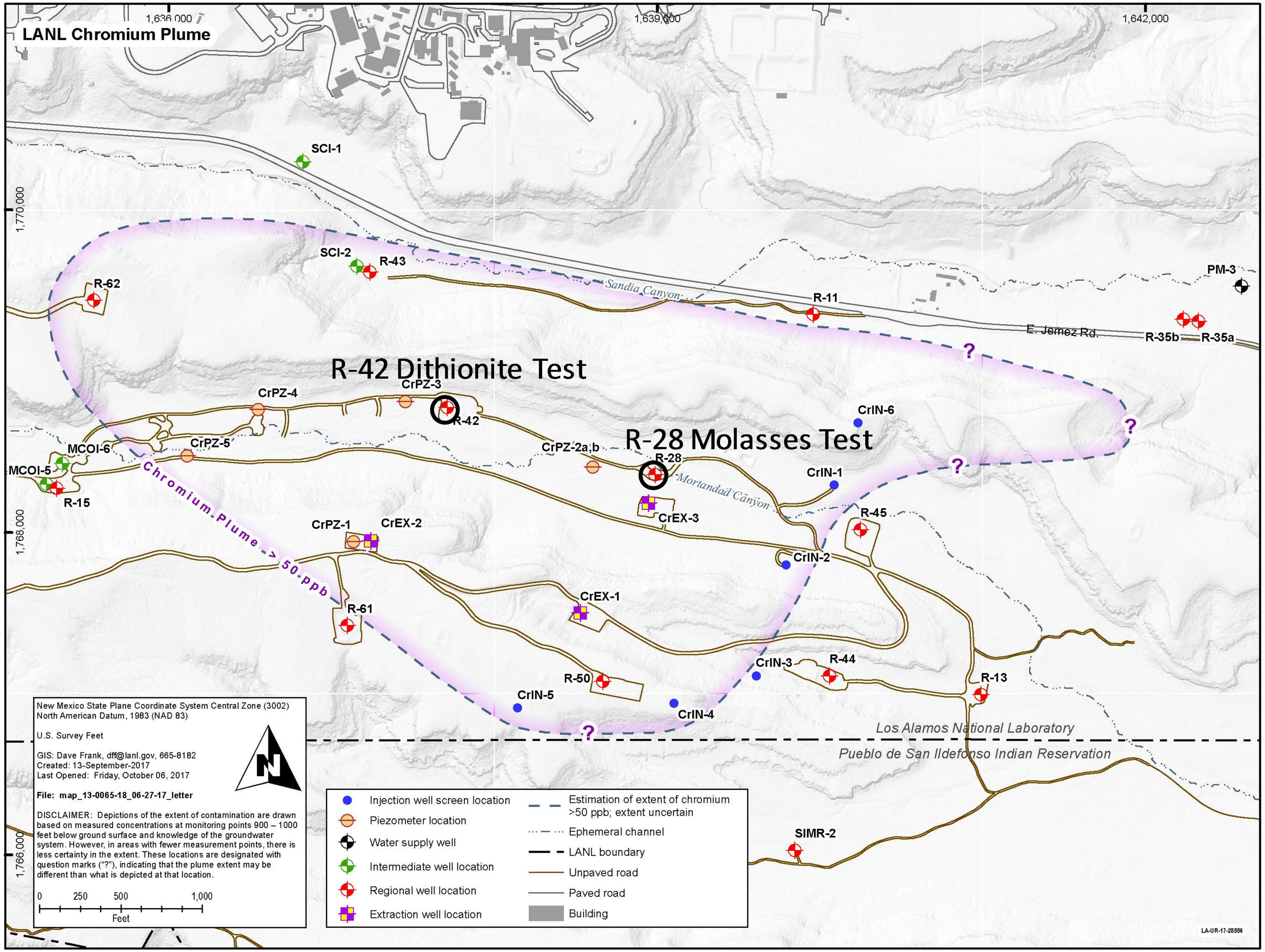


Figure 1.0-1 Map of the Cr(VI) plume showing locations of R-42 dithionite test and R-28 molasses test

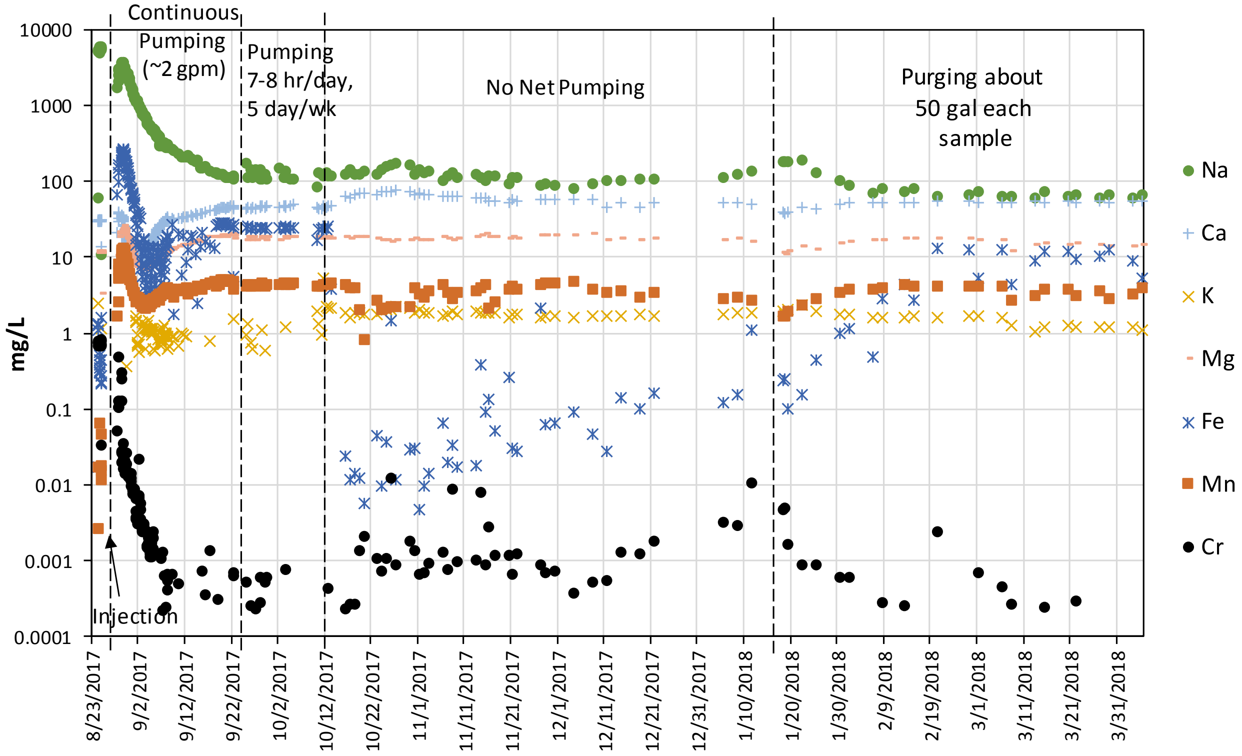


Figure 2.1-1 **Concentrations of selected cations and metals in R-42 dithionite test as a function of time**

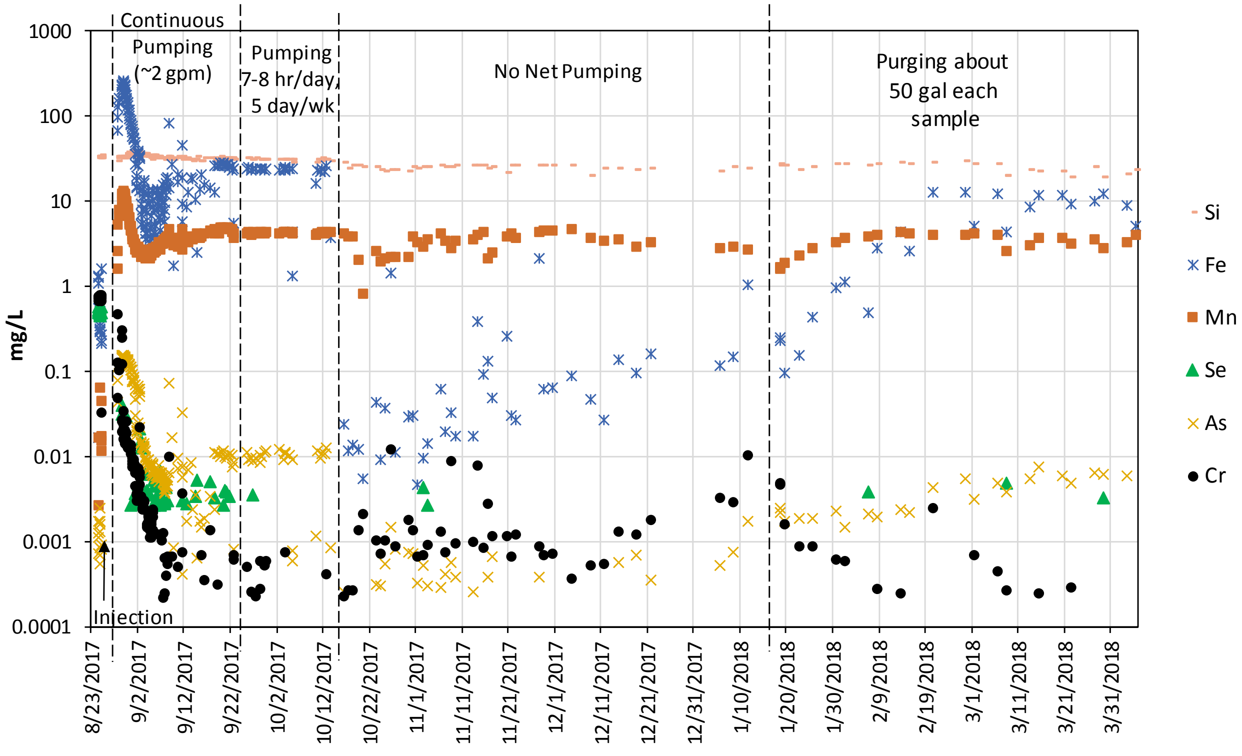


Figure 2.1-2 **Concentrations of selected constituents during R-42 dithionite test as a function of time**

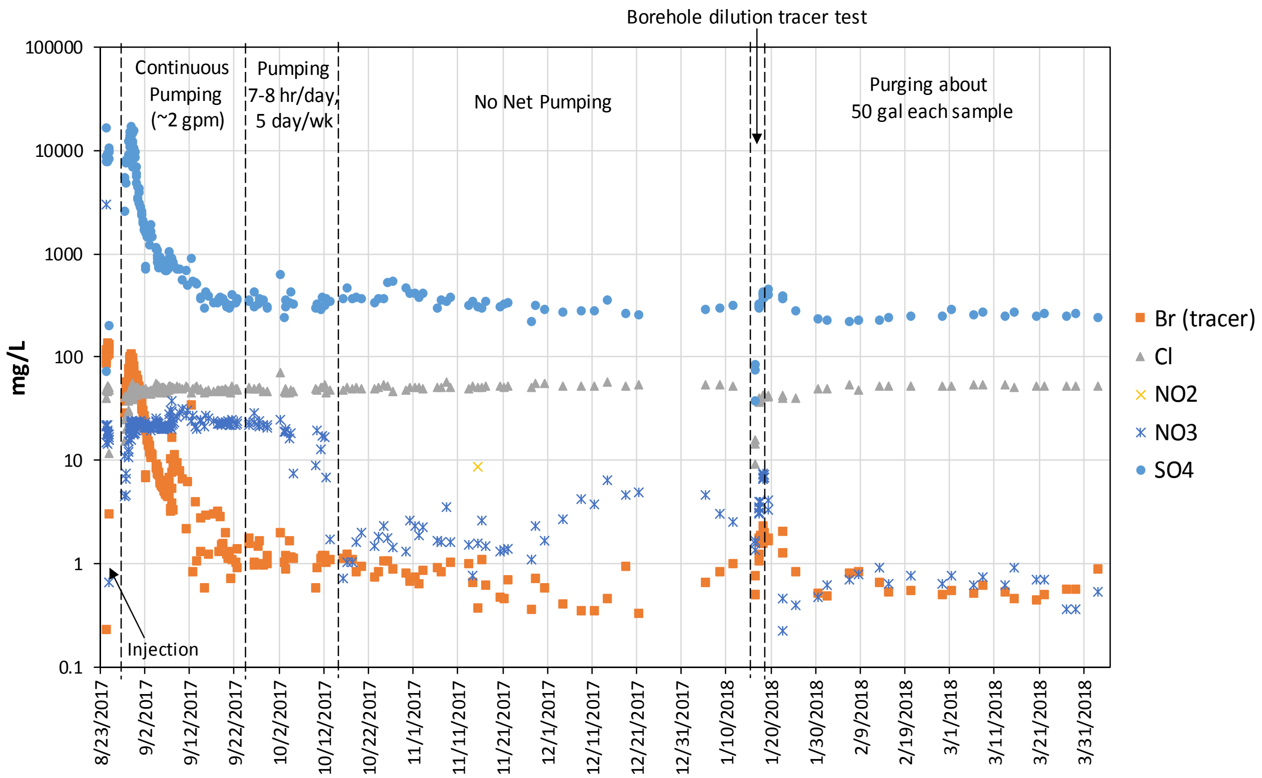


Figure 2.1-3 **Concentrations of anions in R-42 dithionite test as a function of time**

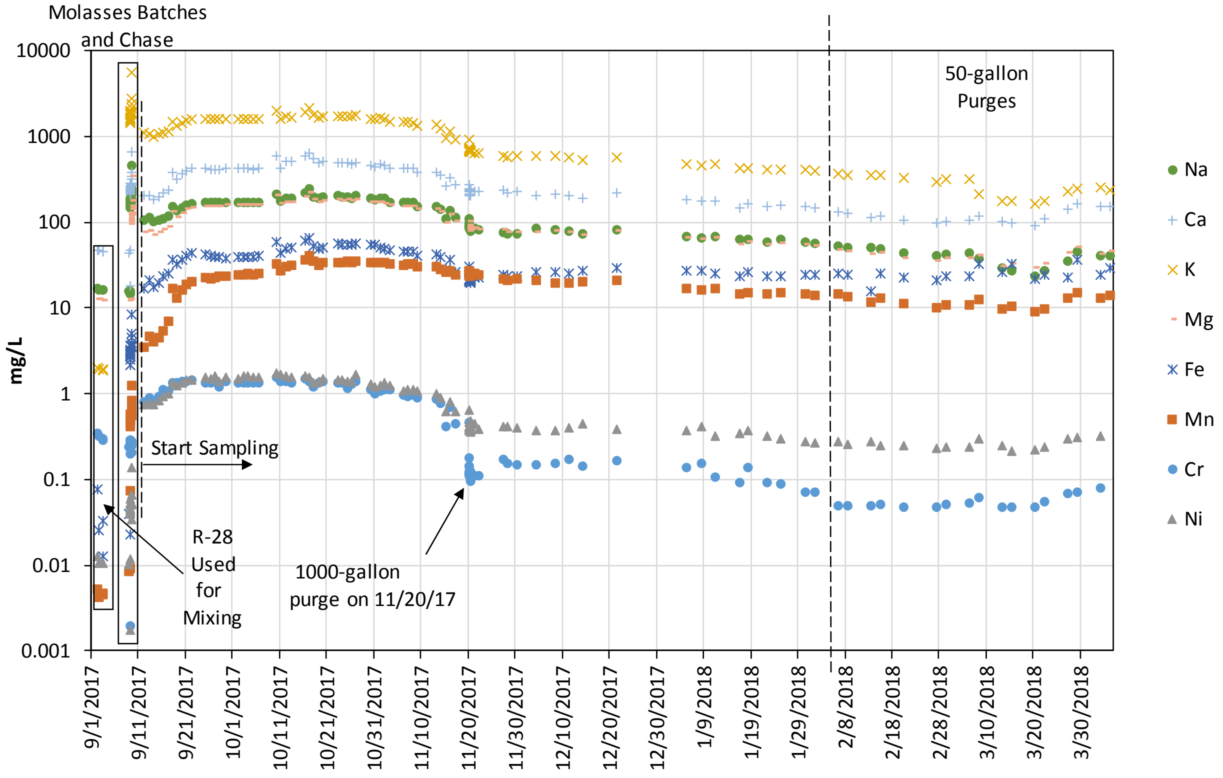


Figure 2.2-1 **Concentrations of selected cations and metals in R-28 molasses test as a function of time**

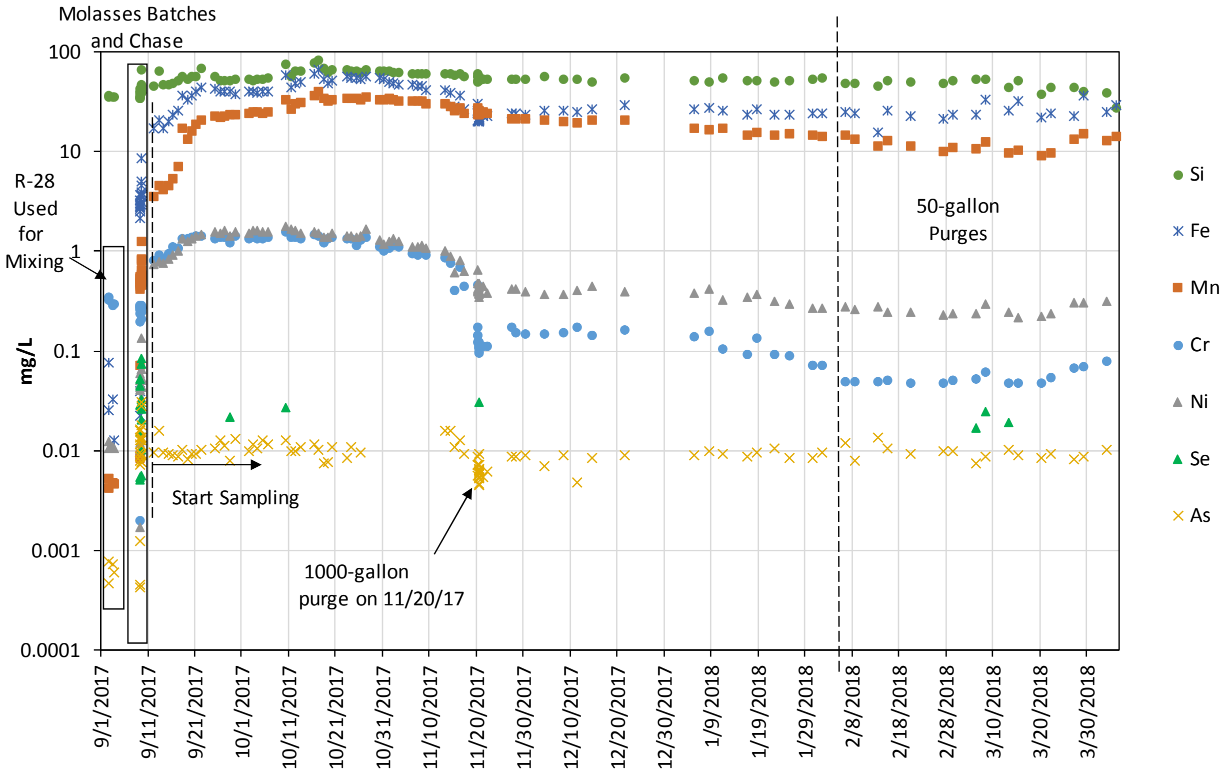


Figure 2.2-2 Concentrations of selected constituents during R-28 molasses test as a function of time

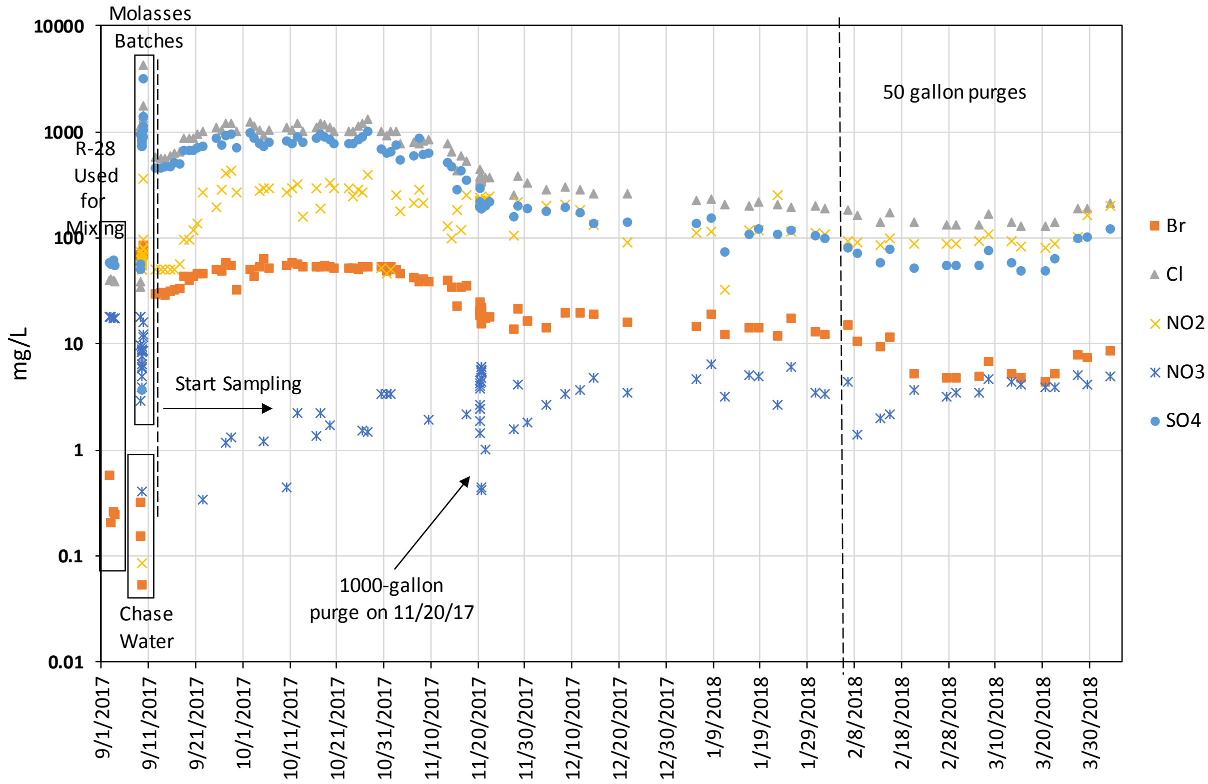
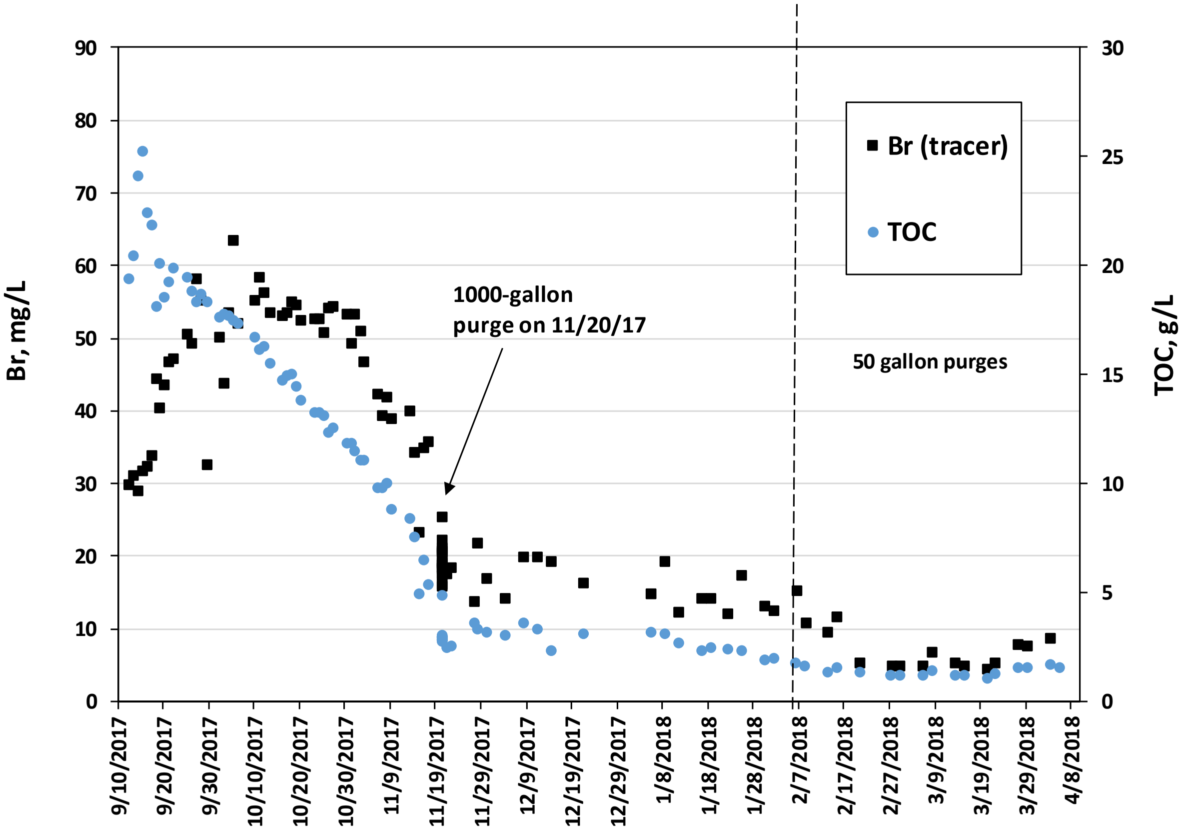


Figure 2.2-3 Concentrations of anions in R-28 molasses test as a function of time



Note: Unlike other plots, concentrations scales are not logarithmic.

Figure 2.2-4 Concentrations of bromide and TOC in R-28 molasses test

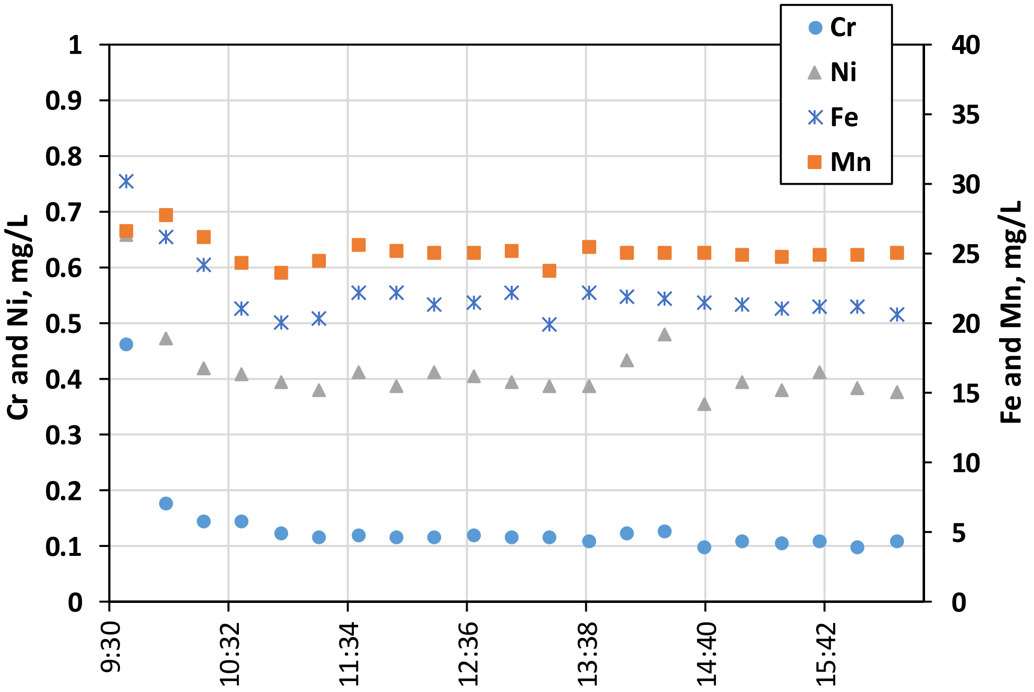


Figure 2.2-5 Concentrations of selected metals during the R-28 purge on November 20, 2017

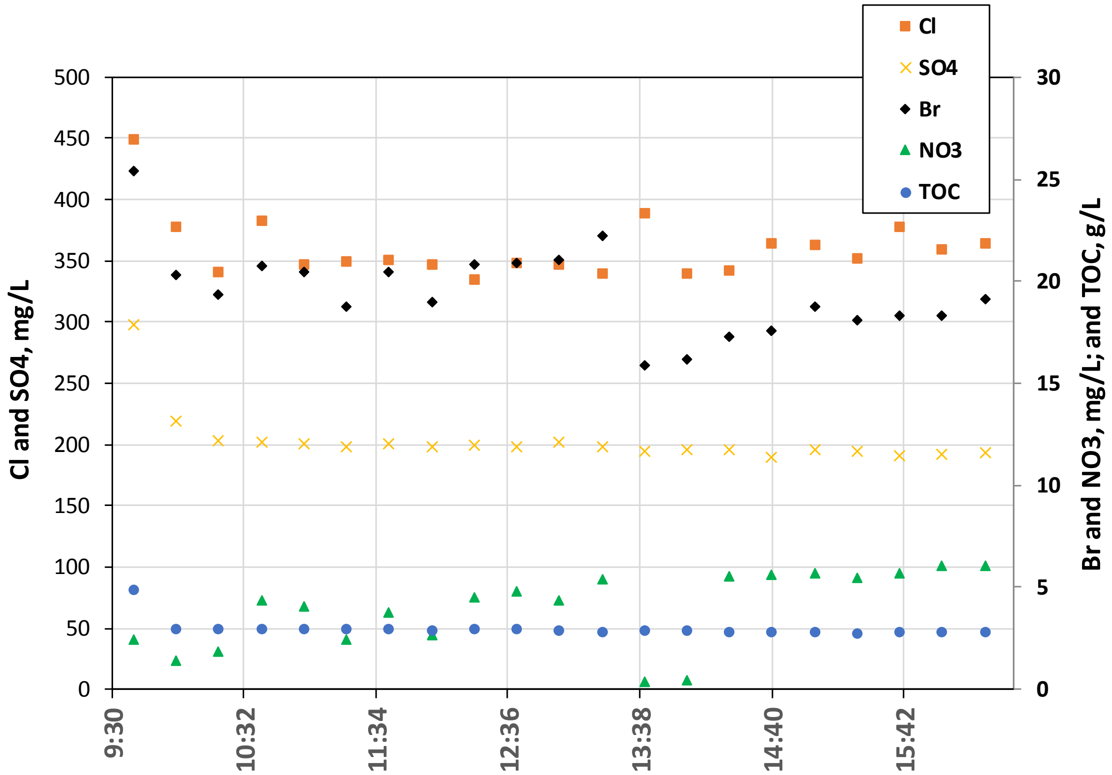
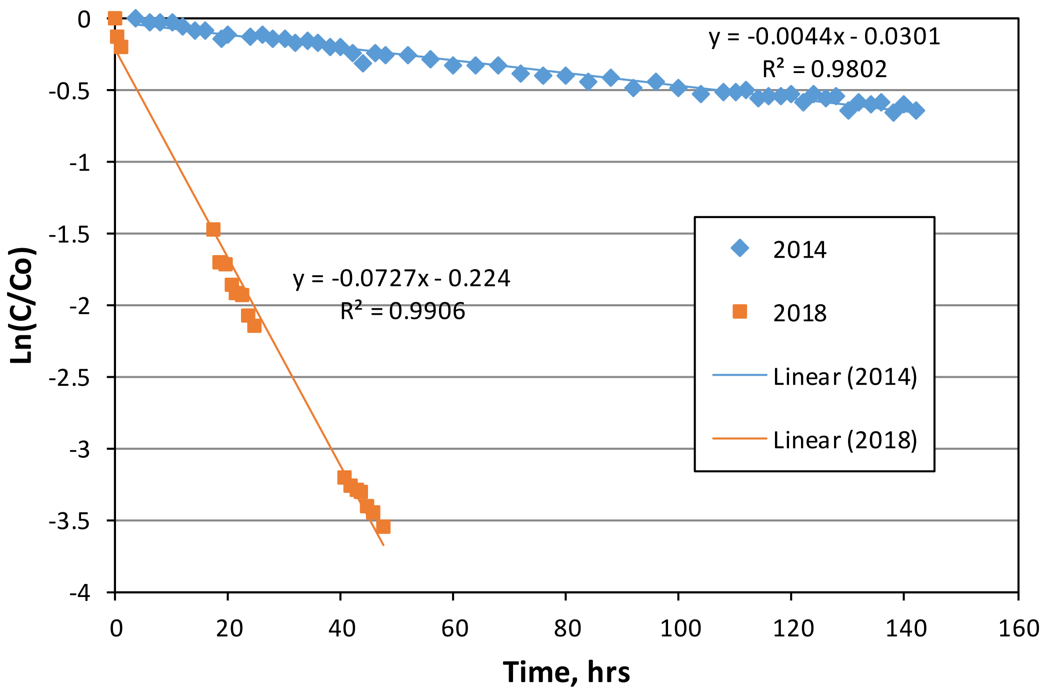
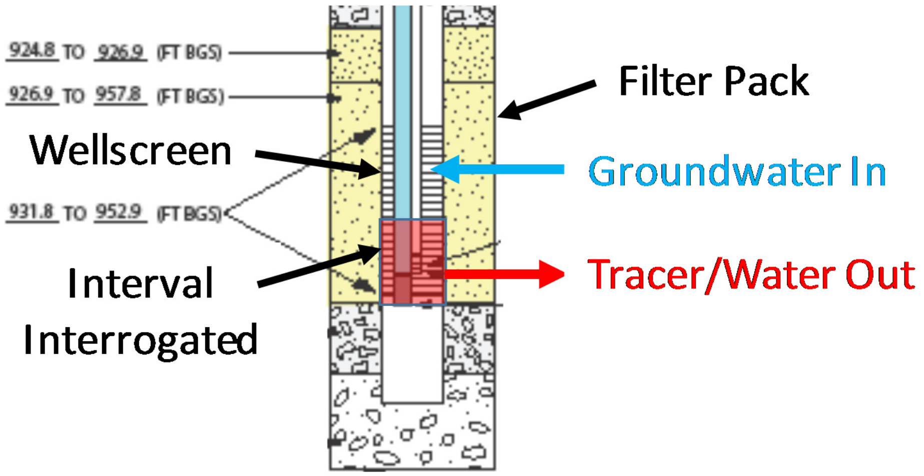


Figure 2.2-6 **Concentrations of anions and TOC during R-28 purge on November 20, 2017**



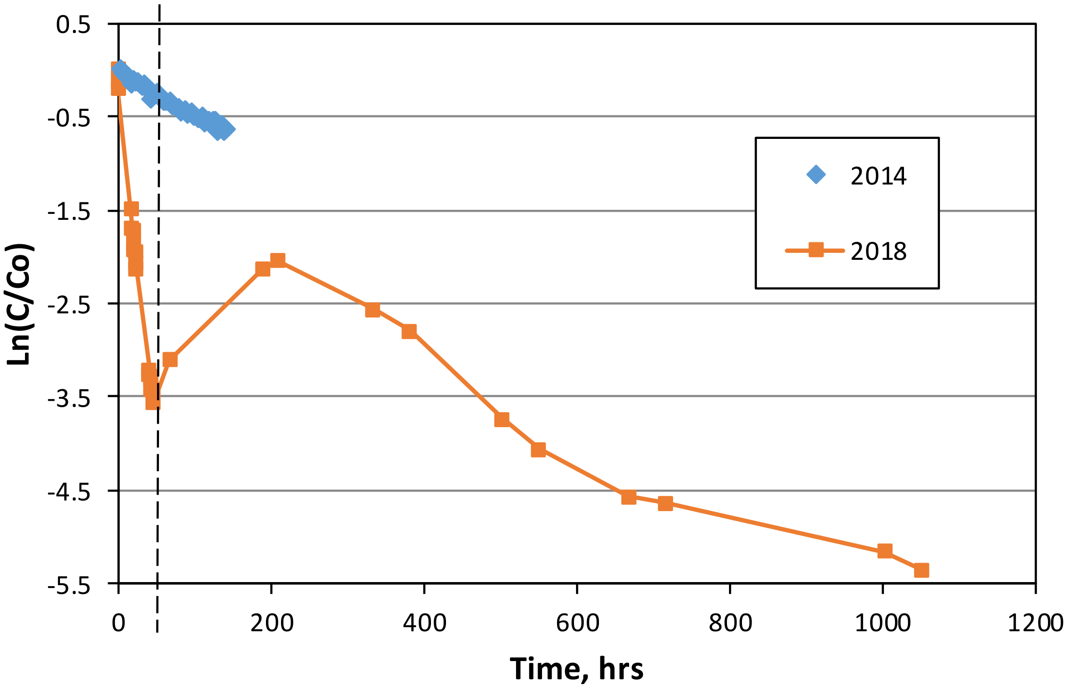
Note: Slopes are proportional to apparent groundwater flow rate through the well screen.

Figure 3.0-1 **Plot of log-normalized tracer concentration vs time for the 2014 and 2018 borehole dilution tracer tests in R-42**



Note: The injection port was at the top of the red-shaded area, and the pump intake was at the bottom of the red-shaded area.

Figure 3.0-2 **Schematic depiction of non-ideal situation during 2018 borehole dilution tracer test in R-42**



Note: Vertical dashed line corresponds to when circulation was stopped in 2018.

Figure 3.0-3 Plot showing long-term tracer concentration history during and after the 2018 R-42 borehole dilution tracer test (along with tracer concentration history in 2014)

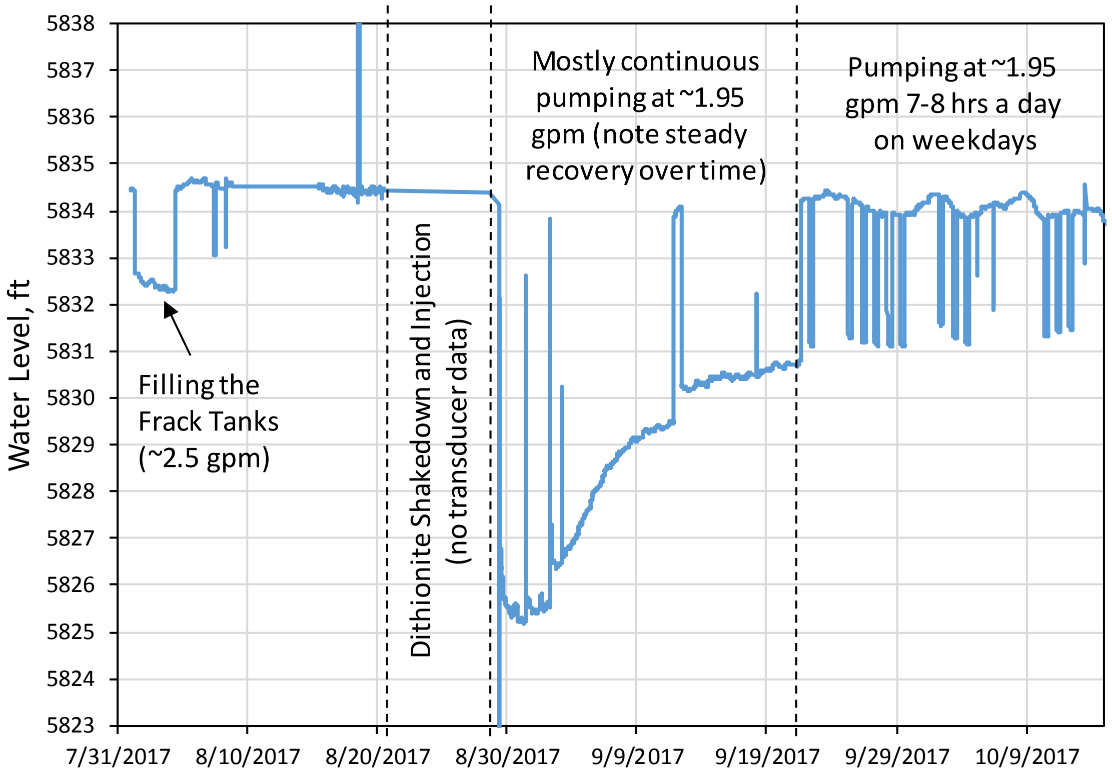
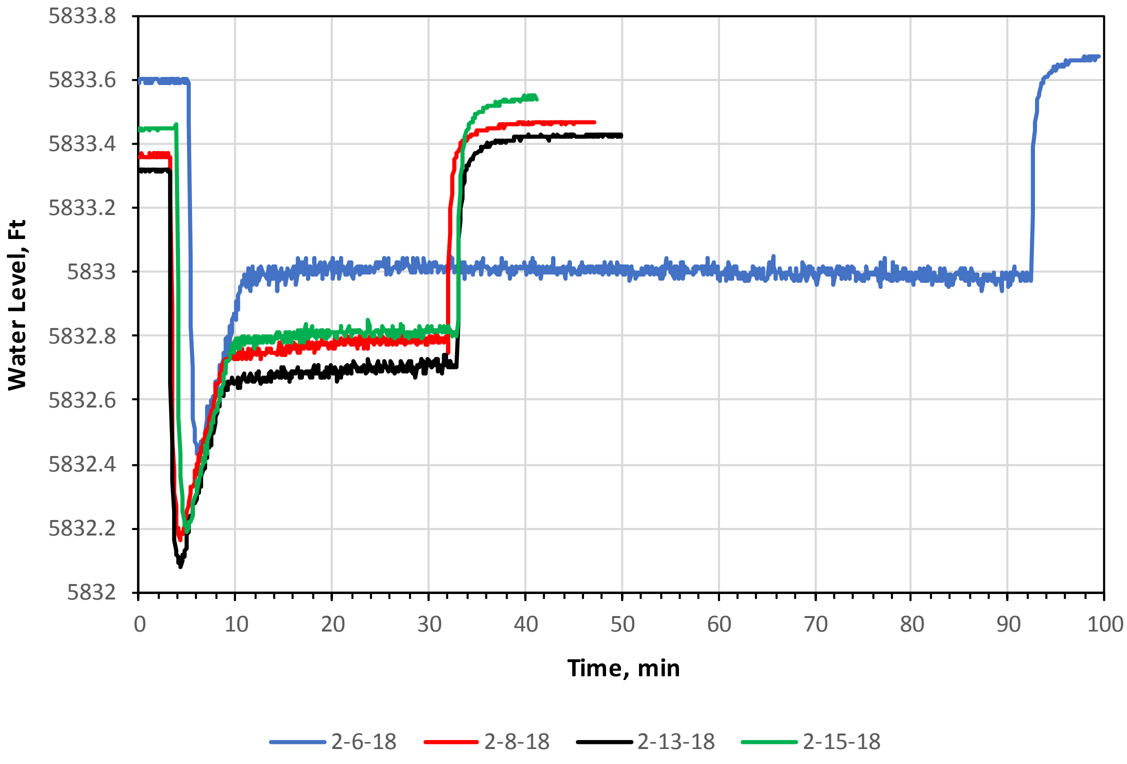


Figure 4.1-1 **Water levels in R-42 immediately before and after the dithionite injection**



Note: First purge was approximately 200 gal.

Figure 4.2-1 **Water levels in R-28 during the first four purging/sampling events**

Table 4.1-1
Pumping Tests Conducted at R-42 During Well Development, Pre-Amendment (Dithionite), and Post-Amendment

Test Type	Test Start	Test End	Flow Rate (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)
Pre-Injection					
Well Development*	11/14/2008	11/15/2008	5.5	7	0.79
Pumping Test	4/21/2014	4/30/2014	7.9	7.7	1.03
Collect Injection Fluid	8/1/2017	8/4/2017	2.5	2.2	1.09
Post-Injection					
Purge and Sample	9/22/2017	9/22/2017	1.9	3	0.63
Purge and Sample	9/26/2017	9/26/2017	1.9	3	0.63
Purge and Sample	2/6/2018	2/6/2018	3.9	4.5	0.66
Purge and Sample	2/15/2018	2/15/2018	3.9	4.5	0.66

* Data from R-42 well completion report (LANL 2009, 105026).

Table 4.2-1
Pumping Tests Conducted at R-28 During Well Development, Pre-Amendment (molasses), and Post-Amendment

Test Type	Test Start	Test End	Test Number	Flow Rate (gpm)	Specific Capacity (gpm/ft)
Pre-Injection					
Well Development*	3/7/2004	3/8/2004	13	0.95	13.7
Pump Test	5/28/2014	5/28/2014	17	1.2	14.2
Pump Test	5/28/2014	5/29/2014	27	2.2	12.3
Pump Test	5/30/2014	6/3/2014	27	2.3	11.7
Post-Injection					
Purge and Sample	2/6/2018	2/6/2018	2.6	0.6	4.3
Purge and Sample	2/8/2018	2/8/2018	2.6	0.6	4.3

* Data from R-28 well completion report (Kleinfelder 2005, 094042).

Attachment 1

Data Associated with Second Quarterly Report on Pilot-Scale Amendments Testing for Chromium in Groundwater Beneath Mortandad Canyon
(on CD included with this document)