**DEPARTMENT OF ENERGY**
Environmental Management Los Alamos Field Office (EM-LA)
Los Alamos, New Mexico 87544

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NMED Hazardous Waste Bureau

September 29, 2022

Mr. Rick Shean
Bureau Chief
Hazardous Waste Bureau
New Mexico Environment Department
2905 Rodeo Park Drive East, Building 1
Santa Fe, NM 87505-6313

Subject: Submittal of the Chromium Interim Measures and Characterization Work Plan

Dear Mr. Shean:

Enclosed please find two hard copies with electronic files of the "Chromium Interim Measures and Characterization Work Plan." Submittal of this report fulfills fiscal year 2022 Milestone #2 of Appendix B of the 2016 Compliance Order on Consent.

If you have any questions, please contact Joseph Sena at (505) 551-2964 (joseph.sena@em-la.doe.gov) or Cheryl Rodriguez at (505) 414-0450 (cheryl.rodriguez@em.doe.gov).

Sincerely,

ARTURO DURAN — Digitally signed by ARTURO DURAN Date: 2022.09.29 07:44:54 -06'00'

Arturo Q. Duran
Compliance and Permitting Manager
U.S. Department of Energy
Environmental Management
Los Alamos Field Office

Enclosure(s): Two hard copies with electronic files:

1. Chromium Interim Measures and Characterization Work Plan (EM2022-0582)

40129

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September 2022
EM2022-0582

# Chromium Interim Measures and Characterization Work Plan

N3B Los Alamos

EM2022-0582

# Chromium Interim Measures and Characterization Work Plan

September 2022

Responsible program director:

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|---|---|---|---|---|
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# 1.0 INTRODUCTION

This Chromium Interim Measures and Characterization Work Plan (hereafter work plan) is a campaign completion work plan that supports continued operations of the chromium interim measure (IM), as well as characterization activities that will close data gaps, supporting an evaluation and recommendation of remedial alternatives to be presented in a corrective measures evaluation (CME) report. This work plan includes the basis for the installation, testing, evaluation, and operation of IM wells and associated equipment needed to transition to the final remedy selected based on the CME. Whereas the primary objective of the IM is to hydraulically control the chromium plume, with an incidental benefit of removing chromium mass from the regional aquifer, the presumptive final remedy of pump and treat will have a primary objective of mass removal.

## 1.1 Work Plan Administrative History

Since several work plans have preceded this work plan, a brief description of previous work plans is provided as well as proposed actions to close the work plans, if needed. There are two categories of work plans. The first category is associated with characterization activities that advance the conceptual site model (CSM) and provide the technical basis for IM actions and the CME. The second category of work plans is associated with IM operations. The descriptions provided below have been organized by this categorization. The work plans associated with the chromium plume span a time frame from 2013 through 2018.

### 1.1.1 Characterization Work Plans

Hydrogeological and geochemical characterization activities have been carried out to provide the technical basis for decision-making with respect to hydraulic plume control and potential remedial approaches. Characterization activities have focused on the feasibility of extraction and injection, impacts of heterogeneity and dual porosity, and geochemical responses to amendments that support a CME. The administrative history of characterization-related work plans is provided below.

#### Interim Measures Work Plan for the Evaluation of Chromium Mass Removal

This work plan was prepared in response to requirements described in a letter from the New Mexico Environment Department (NMED), dated January 25, 2013 (LANL 2013, 241096; NMED 2013, 521862; NMED 2013, 522947). The NMED correspondence directed that the work described in this document assess the potential for active long-term removal of chromium from the regional aquifer via pumping with a pilot extraction test well, focusing on identifying the potential for mass removal within the regional aquifer beneath Mortandad Canyon and in perched-intermediate groundwater beneath Sandia Canyon. Aquifer tests were conducted to identify the location for a pilot extraction test well and to evaluate chromium removal efficiencies, with results reported in the 2013 “Chromium Groundwater Aquifer Tests Summary Report” (LANL 2014, 255110). The NMED correspondence also identified a supplemental work plan, resulting in the 2014 drilling work plan described below (LANL 2014, 254824). This drilling work plan will be administratively closed with a U.S. Department of Energy (DOE) Environmental Management Los Alamos Field Office (EM-LA) letter that documents the report where the data have been published.

**Drilling Work Plan for Groundwater Extraction Well CrEX-1**

The primary objective of this work plan was to evaluate pumping as a technical approach for an IM (LANL 2014, 254824). The installation and pumping at CrEX-1 was to demonstrate the potential to control chromium migration towards the Los Alamos National Laboratory (LANL or the Laboratory) boundary via hydraulic control. Mass removal was acknowledged as an incidental benefit of the system that focused on hydraulic control. This drilling work plan was closed with the CrEX-1 well completion report (LANL 2015, 600170).

**Work Plan for Chromium Plume Center Characterization**

The primary objective of this work plan, approved with modifications by NMED in October 2015, was to further characterize the area of highest known concentrations in the center of the chromium plume (LANL 2015, 600615; NMED 2015, 600958). These hydrogeologic and geochemical characterization activities were centered on four objectives: (1) determine the feasibility of chromium source removal from the center of the plume, (2) characterize key attributes of the aquifer, (3) identify hydrologic and geochemical conditions at proposed injection well locations that may adversely impact injection operations, and (4) characterize infiltration beneath the shallow alluvial groundwater in Sandia Canyon. Several activities were conducted under this work plan, including aquifer dilution-tracer tests, field-scale cross-hole tracer tests, and the installation and monitoring of piezometers. Concurrent with the plume-center characterization work, construction work for an IM to control plume migration was carried out under the 2015 "Interim Measures Work Plan for Chromium Plume Control" described below (LANL 2015, 600458; NMED 2015, 600959). Although results of the characterization activities were to be published in a CME report, results from activities conducted under the "Work Plan for Chromium Plume Center Characterization" (LANL 2015, 600615) were documented in the "Compendium of Technical Reports Conducted Under the Work Plan for Chromium Plume Center Characterization" (hereafter compendium) (LANL 2018, 602964). Results that are documented in the compendium include nine borehole dilution tracer tests; two push-pull tracer tests (R-42 and R-28); four long-term pumping tests in which geochemical transients were observed (R-42, R-28, R-62 and R-43 screen 1); one push-drift test (R-42); one cross-hole tracer test with three different tracer injection locations (CrPZ-2a, CrPZ-2b, and R-28); and one well in which tracers appeared (CrEX-3, with tracers from CrPZ-2a). The "Work Plan for Chromium Plume Center Characterization" (LANL 2015, 600615) will be administratively closed with an EM-LA letter that documents where data have been published within the compendium.

**Pilot-Scale Amendments Testing Work Plan for Chromium in Groundwater beneath Mortandad Canyon**

This work plan was approved by NMED (LANL 2017, 602505; NMED 2017, 602546) following extensive bench-scale and field tracer studies that supported pilot testing for the addition of a chemical reductant, sodium dithionite, and a biostimulant, molasses. 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. The objectives of the testing were to evaluate (1) the ability of the amendments to reduce dissolved-phase hexavalent chromium [Cr(VI)] to insoluble and immobile trivalent chromium [Cr(III)] 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. Seven quarterly reports documented the pilot testing deployment, geochemical response to the amendments, borehole dilution tracer testing to assess the effect of the amendments on aquifer permeability (LANL 2018, 602862; LANL 2018, 603031; N3B 2018, 700032; N3B 2018, 700108; N3B 2019, 700214; N3B 2019, 700420; N3B 2019, 700723). The "Pilot-Scale Amendments Testing Work

Plan for Chromium in Groundwater beneath Mortandad Canyon" will be administratively closed with an EM-LA letter that documents that data have been published within the quarterly reports and will also be documented in the CME.

### 1.1.2 Interim Measures Work Plans

The primary objective of the IM is hydraulic control of the chromium plume so that concentrations above the 50-µg/L standard remain within the Laboratory boundary. The approach for achieving this objective is to extract chromium-contaminated groundwater, treat it at the surface using ion exchange, and reinject treated water into the aquifer downgradient. To operate the IM, a water right needed to be obtained. In May 2016, DOE and Los Alamos County jointly filed with the New Mexico Office of the State Engineer (NMOSE) an application for a permit to change an existing water right in support of the chromium plume control interim measure (DOE 2016, 702319). A request for emergency authorization associated with the joint application was also submitted (DOE 2016, 702320). NMOSE approved the emergency authorization to operate the IM on September 10, 2016 (NMOSE 2016, 702329). On September 26, 2019, NMOSE approved a second application for permit application and emergency authorization submitted on January 24, 2019, to add additional points of diversion (i.e., extraction and injection wells, monitoring wells) (DOE 2019, 700203; DOE 2019, 700204; NMOSE 2019, 702321). This second emergency authorization was granted to support continued operation and expansion of the IM. In February 2020, DOE and Los Alamos County requested withdrawal of the initial 2016 permit and emergency authorization (DOE 2020, 700751).

Work plans associated with IM operations and performance monitoring are described below.

**Interim Measures Work Plan for Chromium Plume Control**

This work plan provided the basis for IM operations for chromium plume control, including the installation, testing, evaluation, and operation of wells and associated equipment (LANL 2015, 600458). Unlike the previous work plans associated with interim measures, the plume control IM identified metrics for performance, including decreasing chromium concentrations at R-50 to the 50-ppb New Mexico groundwater standard or less over a period of approximately 3 yr. Both extraction (at CrEX-1) and injection of treated water (at injection wells located primarily along the downgradient portion of the plume) occurred to achieve this goal. As in the 2014 drilling work plan (LANL 2014, 254824), mass removal was acknowledged as an incidental benefit of hydraulic control. Secondary goals also included achieving hydraulic control in the eastern downgradient region of the plume and continued characterization of the aquifer through observed system responses as well as activities designed for this purpose. The "Interim Measures Work Plan for Chromium Plume Control" (LANL 2015, 600458) will be administratively closed with the documentation provided in this work plan.

**Chromium Plume Control Interim Measure Performance Monitoring Work Plan**

The "Chromium Plume Control Interim Measure Performance Monitoring Work Plan" (LANL 2018, 603010) describes IM monitoring and reporting requirements based on the plume control work plan (LANL 2015, 600458). Specifically, the performance monitoring is to evaluate plume response associated with IM operations and adjust operational strategies, including the distribution and/or rates of injection, as needed. Performance monitoring reports are provided semiannually based on this performance monitoring work plan. Other IM-related studies (e.g., tracer studies) are also included in the performance monitoring reporting. The 2018 performance monitoring work plan (LANL 2018, 603010) will be administratively closed with the documentation provided in this work plan.

### 1.2 Work Plan Supersedence

Historically, work plans have separated characterization activities from IM operations and performance monitoring. However, this work plan combines both activities with two complementary objectives: (1) continue operation of the IM to prevent migration of the plume beyond the Laboratory boundary; and (2) close critical data gaps with characterization activities that provide sufficient information to perform a CME.

This work plan will supersede preceding work plans for IM plume control operations (LANL 2015, 600458) and performance monitoring (LANL 2018, 603010). The IM will continue to operate under the 2015 work plan (LANL 2015, 600458), with performance monitoring conducted under the 2018 plan (LANL 2018, 603010), until approval of this work plan.

### 1.3 Document Organization

The first section of this work plan describes the administrative history of work plans because it provides context on content presented in this document. Section 2 presents the objectives of this work plan, followed by a description of the CSM in section 3. Also included in section 3 is a description of how the IM has expanded since 2015, as well as CSM updates since that date. Section 4 presents activities associated with this work plan, largely addressing data gaps as organized by the milestone description in Appendix B of the 2016 Compliance Order on Consent (Consent Order). The methods for these activities are also provided in section 4. Documentation and frequency of reporting is addressed in section 5, followed by a brief overview of the schedule in section 6, and references and map data sources in section 7. Appendix A of this report includes preliminary responses to NMED comments associated with previous NMED notices of disapproval of two semiannual performance monitoring reports (NMED 2021, 701518; NMED 2021, 701594), with further input anticipated from the work plan activities described in section 4.

## 2.0 OBJECTIVES

This work plan presents proposed activities organized by the three objectives described in the fiscal year (FY) 2022 milestone description in Appendix B of the Consent Order. Investigation activities described in this work plan address data gaps that support (1) the chromium plume control IM primary objective and associated performance monitoring and (2) the implementation of the initial phases of the final remedy. The proposed activities support the basis for the installation and operation of wells and associated equipment necessary to meet three primary objectives:

- provide interim measures to prevent migration of the plume beyond the Laboratory boundary,
- perform scientific studies and aquifer testing to obtain data necessary to conduct a corrective measures evaluation including a data gap analysis, and
- develop a strategy to conduct a CME.

In support of the primary objectives referenced above, a principal objective of the IM is to continue to maintain the 50-ppb downgradient chromium plume edge within the Laboratory boundary and to evaluate IM impacts on plume control and aquifer hydraulics. Specifically, this translates into controlling the eastern and southern migration of the plume and determining present and future mass and mass flux at the Laboratory boundary with the Pueblo de San Ildefonso. Since IM operations were initiated in 2018, new data have emerged from new monitoring wells in locations that are either affected or unaffected by IM operations. Hence, a principal objective of this work plan will be to assess IM operations, including the effectiveness of the integrated capture zone created by the set of five extraction wells as well as the impacts associated with injection of treated water. A description of the conceptual site model and updates since IM operations began are provided in section 3.

The second objective of this work plan is to address data gaps, which were collaboratively identified by EM-LA and NMED in a series of working group discussions conducted in July 2022. Addressing these data gaps will support continued IM operations and assessment as well as provide characterization data needed for the CME.

The presumptive remedy for the chromium investigation area is pump and treat, with additional considerations associated with a strategy that adaptively manages the remedy based on performance monitoring data. The third objective is focused on a strategy to conduct the CME. An evaluation of the presumptive remedy and associated adaptive site management strategy will be provided in the CME.

## 3.0 BACKGROUND

Eight performance monitoring reports have been submitted to NMED, beginning with the September 2018 submittal and including the most recent submittal in June 2022 (N3B 2018, 700088; N3B 2019, 700356; N3B 2019, 700581; N3B 2020, 700815; N3B 2020, 701051; N3B 2021, 701366; N3B 2021, 701695; N3B 2022, 702170). These reports have provided a general assessment of the IM expressed primarily as temporal trends of chromium concentrations in IM performance monitoring wells. Some of the reports also include additional technical content related to IM operations that focus on information such as hydraulic analyses, spatial and temporal concentration trends, responses in monitoring wells caused by IM operations, cross-hole tracer test data, and other measures that inform IM performance. This section provides a brief summary of the CSM, IM operations to date, and performance relative to the IM objectives, along with an estimate of the current state of the chromium plume as affected by IM operations. An evaluation of IM performance will be carried out as part of this work plan (see section 5).

### 3.1 Conceptual Site Model

This section provides a brief overview of the hydrologic CSM for the Laboratory based on (Katzman et al. 2018, 702317), with a broad understanding of the main features of the hydrogeologic environment beneath the Pajarito Plateau, where the 36 $mi^2$ of Laboratory property is located. The plateau hosts a series of fingerlike mesas separated by deep narrow canyons. The canyons are mostly dry, but some reaches have supported ephemeral and perennial flows from natural runoff, spring discharge, or permitted effluent sources. If surface water does not infiltrate through the alluvium, it can continue to the canyons.

There are three saturated systems beneath the plateau, two within the vadose zone, which is approximately 600–1230 ft thick beneath mesas of the plateau (Broxton and Vaniman 2005, 090038; Robinson et al. 2005, 091682). Shallow groundwater occurs in alluvial systems beneath canyon sections with ephemeral and perennial flows. Under portions of Pueblo, Los Alamos, Mortandad, and Sandia Canyons, intermediate-perched groundwater occurs in the lower part of the Bandelier Tuff and within the underlying Puye Formation and Cerros del Rio basalt.

The third saturated system is the laterally continuous aquifer that exists at depths of 900 ft or more, referred to as the regional aquifer. The Puye Formation often hosts the top of the regional aquifer, but the aquifer at depth can also reside in the underlying pumiceous Puye and the lithologic units of the Santa Fe Group. Beneath Mortandad Canyon, the Chamita Formation, also known as Tcar, consists of axial-river deposits deposited by the ancestral Rio Grande.

### 3.1.1 Conceptual Site Model for Chromium Migration

The hexavalent chromium plume originated from releases of up to 159,000 lb of potassium dichromate—a corrosion inhibitor for a power plant—from cooling towers from 1956 to 1972 (Katzman et al. 2018, 702317). The CSM for chromium transport is that hydraulic head from the outfall discharge was present for enough time to move the contaminants through hydraulically conductive geologic strata. Initially, hexavalent chromium traveled rapidly via an effluent-supported stream for several kilometers. In Sandia Canyon, a wetland has flourished downstream of the cooling tower discharge and likely retains a sizeable amount of reduced trivalent chromium in the sediments. The effluent then infiltrated through a stratigraphically complex 900–1000-ft-thick vadose zone to arrive in the deep regional aquifer.

The distribution of contaminants within the groundwater system at LANL is strongly influenced by the complex hydrogeologic setting. Differences in permeability amongst cooling units within the tuff, lateral and vertical extent of facies within an alluvial fan depositional environment (Puye Formation), and interflow zones between sequential basalt flows all control vertical and horizontal movement of groundwater (Katzman et al. 2018, 702317). Different geologic units at the water table and structural dip of depositional bedding appear to have little effect on chromium migration and plume shape and thickness. Instead, chromium transport is a function of multiple breakthrough locations and interconnectedness of preferential hydraulic strata under a negligible vertical gradient.

The thick vadose zone has been historically viewed as protecting the regional aquifer from contamination at the surface. Away from wet canyons, infiltration rates on the Pajarito Plateau are small, and travel times to the regional aquifer are long. However, the current CSM for chromium transport is that effluent-enhanced recharge from the bottom of Sandia canyon leads to a combination of downward percolation through the tuff layers, feeding an array of circuitous saturated contaminant pathways that lead to the regional aquifer. The general flow direction of these saturated pathways is to the south, so that chromium-contaminated fluids originating in Sandia canyon migrate laterally and reach the regional aquifer beneath Mortandad canyon. Travel times as short as 5 to 10 yr to the regional aquifer are likely, and the presence of multiple pathways means that several contamination “source terms” are likely to exist at the water table of the regional aquifer. Hexavalent chromium then travels through the regional aquifer in a direction consistent with the hydraulic gradient, generally west to east in the chromium plume area. Chromium is not observed to undergo reduction under the oxidizing conditions in the upper portion of the regional aquifer, nor does sorption appear to be a significant factor. A reasonable assumption is that chromium travels as a nonsorbing, nonreactive species under these geochemical conditions.

## 3.2 IM Operations

Since the inception of the IM, key operational phases of the IM can be defined based on the operation of different injection and extraction combinations. Figure 3.2-1 shows the current layout of monitoring and infrastructure wells, and Figure 3.2-2 shows a schematic of the extraction and injection well screen locations. Figure 3.2-3, parts a and b, plots the cumulative quantities of fluid extracted and injected in the IM infrastructure wells for extraction wells CrEX-1, -2, -3, -4, and -5, and injection wells CrIN-1, -2, -3, -4, and -5, respectively. On a cumulative volume plot, the slope of the curve equals the flow rate: an upward slope indicates operation of the injection or extraction well, whereas a plateau indicates no injection or extraction. Also included in Figure 3.2-3 are the times of key IM operational phases:

- Initial operations in the southern plume area (January 2017), with only CrEX-1, CrIN-4, and CrIN-5 in operation
- Sustained initiation of operations in the southern plume area (May 2018); CrEX-1, CrEX-2, CrEX-3 (when available), CrIN-3, CrIN-4, and CrIN-5 in operation

- Initiation of eastern area operations (November 2019); all wells operational when available, including wells CrIN-1, CrIN-2, and CrEX-5 in the eastern plume area

Also illustrated is the extended pause in operation for COVID-19-related reasons (essential mission critical activities [EMCA] pause).

The combined extraction at CrEX-1, CrEX-2, CrEX-3, and CrEX-4 has resulted in an integrated area of groundwater capture in the upper portions of the aquifer, likely at depths to at least 60 ft below the water table, based on the depths and lengths of extraction-well and injection-well screens. This integrated capture zone provides for plume control through beneficial capture of chromium mass flux in the upper portions of the plume within the general centroid of the plume. Because of the lack of deeper monitoring points in the centroid of the plume, the depth of groundwater capture is unknown. Also unknown is whether chromium mass escapes the capture zones of the extraction wells and flooding zones of the injection wells.

Extraction well CrEX-4, drilled in 2017, was completed as a two-screen well with the screens separated by 10 ft of blank casing. Individual samples from these two screens, collected before the well's operation as an extraction well, revealed high chromium concentrations in both screens, the lower of which extends to approximately 75 ft below the water table. This finding provided a definitive indication of deeper contamination in a portion of the plume. In contrast, stratified sampling of chromium contamination in 2017 before the final completion of CrEX-2, located west-southwest of CrEX-4, demonstrated that the contamination, beginning close to the water table, extended no deeper than approximately 60 ft below the water table, with low concentrations measured below that depth (LANL 2017, 602595).

### 3.2.1 IM Operations and Operational Constraints

The current IM system consists of five extraction and five injection wells as pictured in Figure 3.2-1. There are two treatment train units, chromium treatment unit A (CTUA) and chromium treatment unit C (CTUC), containing three and two treatment trains, respectively. Each treatment train consists of a primary ion exchange (IX) column (lead) and a secondary IX column (lag). The primary IX column in the lead/lag configuration does most of the work in removing chromium The second IX column is the polisher vessel, acting as a safeguard against exhaustion of the primary vessel.

Figure 3.2-4 shows a conceptual diagram of the lead/lag configuration and the location of bag filters. Water from all five extraction wells is mixed in the pipeline before reaching CTUA and CTUC. Water is then diverted to each CTU, passing through one of three lead/lag treatment trains in CTUA, and one of two lead/lag treatment trains in CTUC. Currently, sampling is performed in the first sample valve location shown in Figure 3.2-4 to calculate mass removed by the treatment system. Total flow rates from all five extraction wells are used to determine the mass removed during treatment.

Each of the five ion exchange treatment units has a maximum treatment capacity of 60 gallons per minute (gpm), yielding a maximum total rate of approximately 300 gpm. The system nominally operates at 280 gpm, just under the maximum capacity to allow for potential variations in individual extraction and injection flow rates. The system design requires that CrEX-1 and CrEX-2 be operated in tandem, and CrIN-4 and CrIN-5 also perform best when run together. Historically, CrEX-3 flow rates are usually at least 50% (30–35 gpm) of the other extraction well rates because of residual biological mass that likely remains from molasses injection at R-28 (Willis et al. 2021, 702318).

The IM currently operates under an emergency authorization granted in September of 2019 (NMOSE 2019, 702321). Under this authorization, a maximum diversion of groundwater for the IM shall not exceed 679 acre-ft/yr. This translates into maximum extraction and injection rates of approximately

400 gpm for the IM system. Given both technical and permit constraints, some flexibility remains within the system to adjust extraction and injection rates.

Results of the capture and flood zone analyses described in this work plan will be used to identify alternative injection scenarios. However, because of limited system capacity, if injection rates are reduced (or ceased) in one or more injection wells, extraction rates will also need to be reduced. The alternative extraction and injection scenarios will consider the impact on chromium plume control.

## 3.3 Chromium Concentration Trends

This section describes chromium concentration trends at select wells since the initiation of the IM. Concentration trends that are indicative of meeting the primary IM objective are described in section 3.3.1, and concentration trends that have increased because of IM operations are described in section 3.3.2.

### 3.3.1 Chromium Concentration Trends Indicative of Meeting Primary IM Objective

Observations of chromium trends in performance monitoring and extraction wells also provide valuable insights into the distribution of chromium in the regional aquifer and hydraulic effects of extraction and injection conducted for the IM. Performance of the IM in the southern plume area along the Laboratory boundary with the Pueblo de San Ildefonso is manifested largely by chromium concentrations at monitoring well, R-50. That well is situated approximately 375 ft north of the Laboratory boundary.

Before initiation of IM operations in the southern plume area, chromium concentrations had reached approximately 140 µg/L in the upper screen (screen 1) in R-50 (Figure 3.3-1). Chromium concentrations in the lower screen (screen 2) have always remained below the upper limit for the background concentration for chromium, specifically below 7.48 µg/L (Figure 3.3-2). R-50 screen 1 is near the water table and screen 2 is centered at approximately 120 ft below the water table, thus providing the basis for the assumption that the chromium plume had a thickness within the regional aquifer of less than about 100 ft. Upon initiation of sustained operations in the southern plume area, chromium concentrations dropped precipitously and are currently at levels below background.

Tracer data from a study that involved a single deployment each of distinct sulfonates into CrIN-4 and CrIN-5 showed breakthrough, peak, and subsequent decreasing concentrations of the CrIN-4 tracer at R-50 screen 1, indicating a hydraulic connection associated with southern area IM operations. The CrIN-4 tracer also arrived at CrEX-1, confirming the redirection of the flow paths to the north toward CrEX-1 during IM operation in the southern plume area.

These tracer data, along with the decreasing chromium concentrations at R-50, provide the basis for changes (retreat) in the plume edge (as defined by the 50-µg/L NMED groundwater standard) over time. These data, along with monitoring information indicating continued maintenance of low chromium concentrations in R-44 screen 1 and screen 2 (Figures 3.3-3 and 3.3-4, respectively); R-13 (Figure 3.3-5); and SIMR-2 (Figure 3.3-6); indicate that the IM has achieved its objective of maintaining the southern edge of the plume within the Laboratory boundary. A residual uncertainty remains with respect to increasing chromium concentrations at well R-61 (Figure 3.3-7), which will be the subject of additional work proposed in this work plan.

### 3.3.2 Conceptual Site Model Updates Since Initiation of IM Operations

Along the eastern portion of the plume, geochemistry and hydraulic data from monitoring wells R-45 and R-70, and CrIN-6 (before its conversion to extraction well CrEX-5), provided new insights into the extent of the plume and the relation of IM operations and trends in chromium concentrations. In 2017, initial CrIN-6 concentrations of 250–300 µg/L indicated that the plume extended further east and was likely deeper than previously thought. In response to this finding, CrIN-6 and the surface infrastructure was then converted to extraction well CrEX-5. In mid-2019, samples collected from R-70 screen 1 and screen 2 showed that concentrations in excess of 200 µg/L extend significantly farther east than originally assumed (Figures 3.3-8 and 3.3-9, respectively), and those high concentrations were present at depths at least 90 ft below the water table (the depth of the top of R-70 screen 2). Conversely, R-70 screen 1, a screen closer to the water table, yields much lower chromium concentrations, which demonstrates that contamination is submerged and resides at greater depths in the eastern plume area (N3B 2019, 700715). Even though CrEX-5 is likely capturing chromium mass from this location, the current array of injection and extraction wells is screened at shallower depths and may not provide complete access to the depths required to fully control the plume in this area. However, there has been no indication of chromium contamination at wells R-35a (Figure 3.3-10) and R 35b (Figure 3.3-11), situated northeast of R-70 and serving as sentinel wells for municipal water supply well PM-3, either before or during the IM operational period. These concentrations remain at background with no upward trend.

### 3.3.3 Upward Trends in Chromium Concentration

Well R-45, a two-screen well located southwest of R-70 and flanked by injection wells CrIN-1 and CrIN-2 to the west, is a monitoring point that has provided important information on the influence of IM operations in the eastern plume area. Pre-IM concentrations in the shallow and deep screens were below 50 µg/L but above background and rising since the well was first sampled in 2009, climbing to about 40 µg/L in screen 1 (the shallow screen) and 20 µg/L in screen 2 (Figures 3.3-12 and 3.3-13, respectively). Data from CrIN-1 and CrIN-2, before initiation of the IM, indicate a chromium front has been migrating from the core of the plume into this region of the aquifer since at least the early 2000s and was present in concentrations as high as 100 µg/L. This portion of the plume resides at an intermediate depth between screen 1 and screen 2. Upon initiation of the IM in the eastern plume area in late 2019, the geochemical signature from injection was detected at R-45 screen 1 but has not been detected at screen 2. Hence, the moderate concentration increases observed at R-45 screen 2 since late 2019 are likely due to injection water pushing higher chromium concentrations present between the screens into the R-45 screen 2 interval. If concentrations greater than 50 ppb exist at depths significantly below screen 2, they would have had to migrate there before commencement of the IM. To date, there is no indication of chromium concentrations above the 50-ppb standard at these depths.

Trends in chromium at monitoring well R-61 (located to the southeast of the chromium investigation area) have also exhibited increases in chromium concentrations coincident with initiation of the IM (Figure 3.3-14). As indicated by the pressure responses in R-61 screens 1 and 2, primarily associated with extraction at CrEX-2 and injection at CrIN-5, the chromium concentration trend is likely associated with IM operations. This work plan proposes further investigation into the chromium trends and the relation to the IM.

### 3.3.4 Summary of Chromium Concentration Trends Based on Depth

The findings described above are summarized in Figures 3.3-15 and 3.3-16, depictions of the plume based on the knowledge available at the beginning of the IM (Figure 3.3-15) and today (Figure 3.3-16). Table 3.3-1 provides information on the supplemental information used to construct the plume figures.

The pre-IM plume (Figure 3.3-15) is based on the state of knowledge presented in the 2015 "Interim Measures Work Plan for Chromium Plume Control" (LANL, 2015, 600458). The southern edge of the plume extended to the boundary of LANL and Pueblo de San Ildefonso, and the eastern area was represented at the time as extending only as far east as CrIN-1, although uncertainties of the eastern extent were acknowledged.

For the present day, information summarized above from new two-screen wells R-70, CrEX-2, and CrEX-4 revealed the presence of contamination at greater depths than previously understood. For shallow single-screen wells, the judgement of whether the plume also exists at greater depths is based on factors such as proximity to other wells and the level of contamination of the shallow screen. For example, high chromium concentrations in a shallow screen are presumed to make it more likely that concentrations in excess of 50 μg/L have also penetrated to greater depths.

Comparison of the pre-IM and present-day plume depictions reveals both changes in the plume itself along with changes in the plume representation gained through a more complete understanding of nature and extent than was available at the initiation of the IM. The largest beneficial change occurred on the southern plume region, where the combination of extraction and injection resulted in a retreat of the 50-μg/L plume line a significant distance north of the boundary with Pueblo de San Ildefonso. This change constitutes a success of the primary objective of the 2015 IM chromium plume control work plan (LANL, 2015, 600458).

In contrast, new wells R-70 and CrEX-5, along with recent trends at R-45, have led to a new plume depiction in the eastern plume area, with a deep component of the plume extending further east than was originally thought. Other new wells and measurements to the west (wells CrEX-2 and CrEX-4) have led to a more complete picture of the presence or absence of deep contamination—deeper contamination likely extends from the core of the plume to at least as far east as R-70 but does not appear to be present in the southern plume area. Residual uncertainties on the nature and extent of chromium contamination remain and are considered in the development of this work plan.

## 3.4 Tracer Tests

Several field tracer tests have been conducted to examine flow velocities, hydraulic connections, and natural attenuation capacity of the regional aquifer. This testing is documented in the compendium (Addendum 1), and was conducted from 2013 to 2017 (LANL 2018, 602964). The text below is an abbreviated description from the compendium. The tests documented in the compendium include

- nine borehole dilution tracer tests,
- two push-pull tracer tests (R-42 and R-28),
- four long-term pumping tests in which geochemical transients were observed (R-42, R-28, R-62 and R-43 screen 1),
- one push-drift test with a solution buffered to pH ~9.8 introduced to promote desorption of anion-exchanged Cr(VI) (R-42), and
- one cross-hole tracer test with three different tracer injection locations (CrPZ-2a, CrPZ-2b, and R-28) and one well in which tracers appeared (CrEX-3, with tracers from CrPZ-2a).

The borehole dilution tracer tests indicated that there is a wide range of natural flow velocities in the regional aquifer within the chromium plume. R-28 and R-43 screen 1 stand out as having the highest flow velocities intersecting their wellbores, with R-28 on the order of 1 m/day and R-43 screen 1 on the order of 2 m/day. The flow velocity estimates deduced from the push-pull tracer tests in R-42 and R-28 were in good agreement with the estimates obtained from the borehole dilution tracer tests in those wells.

One of the primary objectives of the push-pull tracer testing, the long-term pumping tests, and the cross-hole tracer test was to interrogate diffusive mass transfer between rapidly flowing and non-flowing (or slower flowing) strata in the regional aquifer. The push-pull tracer test in R-28 and the cross-hole tracer responses between CrPZ-2a and CrEX-3 both showed evidence of diffusion between preferential hydraulic strata and hydraulically tight, or slower-flowing, strata, but the push-pull test in R-42 and the geochemical responses to long-term pumping of R-42 and R-28 did not show definitive evidence of diffusive mass transfer within the aquifer.

Another objective of the push-pull, cross-hole tracer, and long-term pumping tests was to identify the natural attenuation capacity of chromium in the regional aquifer [in this case, natural attenuation is considered to be reduction of Cr(VI) to Cr(III) under naturally occurring aquifer conditions]. Collectively, the tests produced little evidence of chromium natural attenuation.

The rapid cross-hole tracer responses at CrEX-3 resulting from the tracers injected into CrPZ-2a, coupled with the lingering of the same tracers in CrPZ-2a long after they reached peak concentrations in CrEX-3, suggest a large contrast in hydraulic conductivity of various zones or lithologic layers near CrPZ-2a. Apparently, a significant fraction of the tracer mass was pushed into high-conductivity flow pathways that carried the tracers almost all the way to CrEX-3 in the 84 days after injection and before CrEX-3 began pumping. However, a significant fraction of tracer mass was also apparently pushed into low-conductivity zones or pathways near CrPZ-2a, where the tracers lingered for many months before slowly drifting back into the piezometer.

The field test results collectively indicate that the chromium plume is heterogeneous, both hydrologically and geochemically. Chromium concentrations are spatially complex, as suggested by the responses of chromium concentrations to pumping at various locations in the aquifer. It is apparent that pumping of CrEX-3 at approximately 40 gpm captures groundwater with chromium in the vicinity of CrPZ-2a, but it does not capture much water from CrPZ-2b, which is completed just 15 ft below the bottom of CrPZ-2a. Pumping of CrEX-3 at approximately 40 gpm also does not appear to capture any of the Cr(VI) contamination present in the vicinity of R-28, which is screened starting at approximately 40 ft below the water table.

### 3.4.1 Tracer Testing in Injection Wells

The "Chromium Plume Control Interim Measure Performance Monitoring Work Plan" (LANL 2018, 603010) described tracers that were to be redeployed in CrIN-3, CrIN-4, and CrIN-5, and first-time deployments into CrIN-1 and CrIN-2 once those injection wells were brought online. When IM operations began, naphthalene sulfonate tracers were introduced into CrIN-3, CrIN-4 and CrIN-5 (50 kg of sodium salts) with the intent of sampling for these tracers in nearby monitoring wells and extraction wells so that induced flow patterns could be determined, especially near the plume periphery where injection wells are located. Naphthalene sulfonate tracers were also introduced into CrIN-1 and CrIN-2 on March 31, 2021, and March 30, 2021, respectively.

The tracer injected into CrIN-4 was detected at CrEX-1, the extraction well closest to R-50 screen 1 and CrIN-4. The tracer mass recovery at CrEX-1 was approximately 10%, which is surprisingly large considering the flow direction under natural gradient conditions is believed to be in almost the opposite direction from CrIN-4 to CrEX-1. For tracers injected into CrIN-1 and CrIN-2, their signal was never measured at nearby monitoring and extraction well locations. However, given that the tracers were deployed just before the EMCA pause, this may have resulted in the tracer moving downgradient.

The principal test objective was to establish hydraulic connectivity. Given the outcome of previous tracer testing in the chromium investigation area, hydraulic connectivity is heterogeneous, making it difficult to quantitatively account for all of the injected tracer. Hence, the proposed approach for estimating mass flux in this work plan—integrating large-scale aquifer testing, high-resolution local-scale flow and concentration measurements, and capture and flood zone analyses—is recommended over tracer testing.

### 3.5 Data Gap Categories

Data gaps addressed in this work plan can be binned into three broad categories of information needed to support the continued operation of the IM and transition to the CME. EM-LA and NMED collaboratively identified data gaps in meetings held in July 2022. The data gaps associated with the goals of the IM and transition to the CME include the following:

- Hydraulic analyses
- Plume horizontal and vertical extents
- Aquifer and mass flux characterization

A fourth category of data gaps, associated with the final remedy, was also identified in these meetings. These data gaps are not included as active areas of investigation in this work plan, but the outcome of the activities proposed in this work plan will provide a technical basis to address their closure. The following data gaps will be addressed in the CME and ongoing evaluation of the selected final remedy:

- Detailed capture zone analysis and engineering design of the final remedy system
- Evaluation of long-term impacts of continuing contaminant sources to groundwater

## 4.0 INVESTIGATION ACTIVITIES AND METHODS

The proposed investigation activities are based on the work plan objectives outlined in section 2, which in turn are based on the Consent Order Appendix C Chromium Interim Measures and Characterization Campaign and the Appendix B FY 2022 milestone description and objectives. Hence, the activities are presented in the context of the IM goal of plume control and/or knowledge needed for the preparation and submittal of the CME.

Each work activity is described with respect to the data gap it will address (listed in section 3.4), with the understanding that some of the activities may require standalone work plans addressing the need for and benefit of the activity, which will be submitted for NMED approval and concurrence. All field-based activities are assumed to require standalone work plans for submission to NMED.

### 4.1 Objective 1: Provide Interim Measures to Prevent Migration of the Plume Beyond the Laboratory Boundary

To support continued interim IM operations, hydraulic and concentration data will be collected and analyzed to determine the effectiveness of plume control. Whereas the 2015 IM work plan for chromium plume control identified specific metrics (LANL 2015, 600458), the proposed activities within this work plan provide additional measures to evaluate IM operations. Whereas a metric is a quantifiable measure used to track and assess the status of a specific process (e.g., decreasing chromium concentrations at R-50 to below 50 ppb within 3 yr), the activities described in this work plan (e.g., estimates of mass extracted through treatment) are measures that provide useful information and insight with respect to IM operations but do not have specific quantitative target value that denotes success.

#### 4.1.1 Hydraulic Analysis

Hydraulic analyses will be performed to support the assessment of IM operations, specifically addressing hydraulic containment, attaining hydrodynamic control at both the horizontal and vertical outer limits of the chromium plume such that hydraulic gradients are inward toward the extraction wells (https://clu-in.org/download/contaminantfocus/dnapl/Treatment_Technologies/Monitoring_P_and_T_systems.pdf). Containment performance can be measured by setting performance criteria and monitoring to assess these criteria.

##### 4.1.1.1 Capture Zone Analysis

Inward hydraulic gradients within the containment area can demonstrate that groundwater flow is inward, thereby achieving capture. To assess the IM system ability to achieve capture, hydraulic head and gradient data will be interpreted within the context of a capture zone analysis. Capture zones for extraction wells and flood zones for injection wells at the chromium investigation site will be assessed based on the methodology described in the U.S. Environmental Protection Agency (EPA) sentinel document, “A Systematic Approach for Evaluation of Capture Zones at Pump and Treat Systems” (https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NRMRL&dirEntryId=187788). This document describing the following six steps:

1. Assessing site data and formulating a CSM,
2. Defining targeted capture zones,
3. Interpreting water levels by developing potentiometric surface maps and hydraulic gradients,
4. Calculating flow rates and tracking particles by means of analytical or numerical modeling to identify capture zone widths,
5. Evaluating concentration trends, and
6. Interpreting final capture zones based on steps 1–5.

Given that the IM has been in operation for 4 yr, the focus of the capture and flood zone analysis (referred to as capture zone analysis [CZA] in this document) will be focused on steps 2–6 above but will be based on the CSM and data obtained since the IM began operating in 2018. To this end, the CZA will create synoptic potentiometric surface maps at a minimum of two depths in the aquifer, based on the availability of data at depth, since three-dimensional data (e.g., hydraulic head, hydraulic conductivity distribution, contaminant distribution) are required to evaluate and monitor three-dimensional capture. Transient influences on water levels will be considered in the selection of dates used for developing the potentiometric surface maps. The potentiometric surface maps and hydraulic gradient analysis (both horizontal and vertical) will provide evidence on the extent of capture/flooding occurring with existing IM operations.

To provide additional lines of evidence of IM operational impacts on capture and flooding, simple horizontal analyses, such as estimated flow rate, and capture zone width calculations will also be performed (step 4 above). Travel times will also be determined based on hydraulic gradients and groundwater velocity calculations. Groundwater travel times will be estimated using the groundwater velocity from the Darcy equation (Fetter 1994, 070942) (Fetter, 2001). Although these methods have limiting assumptions (e.g., isotropic and homogeneous hydraulic conductivity, fully penetrating wells, no recharge, no vertical flow component, and constant transmissivity), the assumptions and simplifications do not negate their value in approximating field conditions at a screening level. These preliminary evaluations are expected to provide a technical basis and confirmation of other approaches that can account for the partially penetrating wells and non-steady, heterogeneous flow conditions recognized to exist at the site.

EPA also recommends numerical particle tracking approaches to determine capture zones using the IM actual extraction and injection rates (https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NRMRL&dirEntryId=187788). A common approach is to track many particles from different regions of the aquifer, including injection wells, and examine visualizations of particle traces to determine the boundaries between assemblages of particles that end up in extraction wells. However, the capture zone identified with particle tracking is only as accurate as the underlying head predictions from the simulation model. Hence, a well-calibrated model is needed to calculate hydraulic heads needed for the CZA. EPA encourages the use of groundwater models at complex sites to support the CSM and provide a technical basis for CZA. However, field monitoring is a critical component in evaluating the model predictions and assessing capture zone effectiveness.

The Finite Element Heat and Mass Transfer Code (FEHM) (https://fehm.lanl.gov/) simulator can account for complexities associated with partially penetrating wells, aquifer heterogeneity, and complex boundary conditions. To this end, the FEHM-based model of the site will be calibrated to available field data (e.g., heads, hydraulic gradients, and chromium concentrations) to support the CZA.

The first part of the CZA will include an assessment of the potentiometric surface with the IM off and also an assessment of the potentiometric surface and capture and flood zones when all five extraction wells and five injection wells are operating. In this way, the analyses can be compared with the EPA screening calculations described above. If there is reasonable agreement among approaches, then the second part of the CZA will be conducted to assess the ability of the IM to prevent migration of the chromium plume beyond the Laboratory boundary under alternative pumping scenarios, considering any operational IM constraints. This analysis will include identifying alternative scenarios that consider exclusion of one or more extraction and injection wells in different combinations. In particular, the role of injection with respect to hydraulic containment and mass extraction efficiency will be investigated. These scenarios will provide insight into flow patterns generated by alternative extraction and injection rates and aid in identifying additional monitoring locations.

#### 4.1.1.2 IM Mass Extraction

Influent and effluent water quality analysis will be performed to (1) determine concentration loadings to the treatment system, (2) estimate the mass removed from the regional aquifer, (3) ensure compliance with applicable discharge requirements, and (4) identify the need to adjust system components. For measurements supporting mass removal, concentrations will be measured one time per week using Hach test kits, but duplicate samples will also be sent to a state-approved laboratory for analysis. The Hach data will continue to provide rapid results on chromium influent and effluent concentrations, whereas analytical laboratory results will be used in the mass removal calculations. Sampling will occur at the extraction well head. Chromium concentrations and other metals are planned to be analyzed by EPA Method 200.8 (trace metals) and EPA Method 200.7 (major cations), and the sulfate, nitrate, and other general inorganic compounds will be analyzed using EPA Method 300.1. These data will be reported in the Environmental Information Management (EIM) database, along with influent and effluent flow rates. Collectively, these data can be used to estimate a rate of mass removal, an incidental benefit of the hydraulic chromium plume control.

In addition to aqueous concentration measurements, the ion exchange resin used for chromium treatment may be analyzed to determine its functional capacity and to obtain another line of evidence to estimate chromium mass removed from the regional aquifer, if needed. The analysis may also identify other ions that are captured by the resin, which can support optimization of chromium capture during the design of the final remedy.

## 4.2 Objective 2: Perform Scientific Studies and Aquifer Testing to Obtain Data Necessary to Conduct a Corrective Measures Evaluation Including a Data Gap Analysis

There are two key characterization activities needed to support the second objective of this work plan (perform scientific studies and aquifer testing to obtain data necessary to conduct a corrective measures evaluation including a data gap analysis). The first activity, scientific studies, is to support identifying the nature and extent of chromium plume in the regional aquifer. Identifying the horizontal and vertical extent of chromium plume not only supports the selection of the final remedy in the CME but can also inform the operation of the IM.

The second activity, aquifer testing, supports chromium mass flux characterization within the regional aquifer, a measure that combines two key features of the chromium plume: (1) the amount of chromium mass in the groundwater and (2) how fast the water is moving through any given cross-sectional area. This is equivalent to combining the contaminant concentration and the groundwater flux (https://maf-1.itrcweb.org). Concentration data alone are not sufficient to identify chromium plume control, nor are they sufficient for the design of a final remedy. Given the known heterogeneities in the regional aquifer, mass flux estimates are needed for multiple locations within the aquifer.

### 4.2.1 Plume Horizontal and Vertical Extent

To evaluate the success of the IM system in maintaining chromium concentrations <50 ppb beyond the Laboratory boundary, both the horizontal and vertical extents of the chromium plume need to be established. To this end, the monitoring needed to establish the plume spatial extents has been categorized into four different regions, including the center, south, east, and northeast. These regions are described below with respect to existing wells (see Figure 3.2-1). Data collected from these new monitoring wells are expected to contribute to an evaluation of IM plume control, as well as aid in the design of the final remedy. Drilling work plans will be submitted for proposed new well locations. The prioritization of the order in which wells will be drilled will be established in consultation with NMED.

**Horizontal and vertical extent of plume in southern region of plume.** To assess the vertical extent of the plume to the south, fixed-laboratory geochemical sampling will be conducted at CrEX-1 screen 2. This screen initially showed <50 ppb as measured from Hach data, and characterizing the extent of contamination in this region of the plume will be an important new data point.

**Horizontal and vertical extent of eastern portion of plume.** To assess the horizontal and vertical extent to the east, a new well east/southeast of R-45 will be drilled to refine extent of deep contamination. The need for this well is driven by recent concentration trends at R-45 screen 2 and also the well's role in providing additional chromium plume control IM-related performance monitoring.

**Depth of contamination for northeastern portion of plume.** To assess the vertical extent to the northeast, a new well will be drilled east of R-11 with screens located deeper than the existing screens at R-11, but more consistent with depths monitored with R-70 and R-73.

**Depth of contamination in the center of plume.** To assess the depth at the center of the plume, new wells R-76 and R-77 will be drilled. Concentration data from these new wells will provide vertical resolution of extent of contamination in the R-28 area, where concentrations have historically been in the 400–500 ppb range.

The exact locations of the monitoring wells will be established in collaboration with NMED and will be dependent on local topography, cultural site locations, and infrastructure constraints. The targeted depth for the monitoring wells will also be determined collaboratively with NMED and based on defining the bottom of the plume.

### 4.2.2 Evaluation of Monitoring Well Network

Monitoring is a critical component for evaluating IM system performance. Not only is adequate spatial and temporal collection of groundwater levels and water quality needed for this purpose, but water samples representative of ambient groundwater are needed as well. Hence, an evaluation of the existing monitoring well network will be conducted to evaluate well locations and screened intervals to determine if they meet site characterization and decision support objectives. This analysis may include the following activities:

- Identifying possible data gaps in evaluating plume control
- Evaluating the reliability of data from wells within the monitoring well network, including wells that NMED has identified for inclusion (e.g., R-13, R-36, R-42, CrPZ-2b, R-11, and R-15)
- Generating a groundwater monitoring priority map that incorporates information from the first two activities, as well as physical constraints on future monitoring well locations

The assessment will result in recommendations on modifications to the monitoring well network, potentially supporting new monitoring wells described in section 4.2.1.

### 4.2.3 Mass Flux Distribution Characterization

Regulatory oversight and associated decision-making is based on concentrations of chromium and concentration trends. Mass flux information can provide complementary information by quantifying the strength and mobility of the chromium plume in space and time. Estimates of mass flux can identify areas of a plane through which the majority of the contaminant mass is transported, supporting system design and site management (https://connect.itrcweb.org/HigherLogic/System/DownloadDocumentFile.ashx?DocumentFileKey=607edbe7-86ea-423c-907a-3f70118cc3e7).

Two direct methods will be used to characterize chromium mass flux within the regional aquifer, including the transect method (concentration and flow data measured at individual monitoring points) and aquifer testing (groundwater is extracted and total flow and mass discharge are measured). The former method will make use of an electromagnetic borehole flow meter (EBF), coupled with grab sampling, to conduct high-resolution stratified mass flux characterization) at short (~5-ft) intervals in existing long-screen (>40-ft) wells (e.g., R-70 screen 1, CrEX-1, CrEX-2, CrEX-3, CrEX-4, CrEX-5). Separate work plans will be submitted for the field-based activities described below.

#### 4.2.3.1 Local Scale Mass Flux

An EBF will be used to generate a flow profile at every foot over the length of 40-ft well screens for wells within the chromium investigation area. Water samples will also be collected at each position of the EBF, which in conjunction with the hydraulic conductivity data, provide data on the location of higher chromium mass flux zones within the regional aquifer. These survey results will be used to identify zones for the remedy design.

The operation of the EBF is based on Faraday's Law of Induction (https://www.pnnl.gov/publications/aquifer-testing-recommendations-well-299-w15-225-supporting-phase-i-200-zp-1). An electromagnet generates a magnetic field in a hollow cylinder within the tool. Water moves through this magnetic field at a right angle, which induces a voltage measured by electrodes within the tool. The voltage is directly proportional to the moving conductor velocity. This voltage is then translated to a volumetric flow rate by calculating the water flow velocity through a fixed-diameter chamber https://www.pnnl.gov/publications/aquifer-testing-recommendations-well-299-w15-225-supporting-phase-i-200-zp-1.)The relative flow rates versus depth profile will be directly related to the vertical profile of hydraulic conductivity outside the well screen within the surrounding aquifer formation. The actual hydraulic conductivity depth profile will be determined with estimates of hydraulic conductivity obtained through the large-scale aquifer tests (see section 4.2.3.2).

EBF flowmeter measurements will be made successively from the bottom to the top of the well screen. At the beginning of the survey, a zero flow point will be measured within the well at the sump section below the bottom of the well screen. At the end of the survey, a second zero flow point will be determined at the top of the water column. These measurements will be used as reference points for ambient flow measurements within the screen and can account for any drift that may occur during the survey. Ambient flow measurements will be corrected to the zero flow point measured at the top of the water column.

An inflatable packer is used to channel flow in the well through the EBF measurement cylinder and to minimize any bypass flow between the probe and the surrounding well screen (https://www.pnnl.gov/publications/aquifer-testing-recommendations-well-299-w15-225-supporting-phase-i-200-zp-1). The inflatable packer consists of a rubber sleeve attached to a stainless-steel assembly, sealed on its ends with hose clamps. Once the EBF probe cylinder is placed inside the stainless-steel assembly, the packer and fittings of the assembly are checked for gas leaks before the assembly is lowered into the well. An in-well profile of ambient, in-well vertical flow is developed by systematically raising and lowering the EBF to known depth intervals, inflating the packer assembly, and recording stabilized flow meter readings. At each measurement depth setting, inflation of the packer is controlled using compressed nitrogen gas, a regulator, and inflation tubing. After inflating the packer, the integrity of the packer seal is qualitatively checked by lifting the attached EBF equipment cable to verify packer tension and stability within the well-screen section. In-well flow conditions will be allowed to stabilize generally for a period of 5 to 10 min to dissipate any disturbances caused by movement of the packer/probe assembly within the well screen. After the flow measurement has been recorded, the packer will be deflated using a vented surface valve, the EBF probe will then be raised slowly to the next depth, and the measurement procedure repeated.

Two surveys will be performed in each well, one under ambient flow conditions (IM off) and another under pumping conditions (IM on). This will help determine zones of relatively high mass flux conditions that may be created by the IM and provide information for the design of the final remedy. Under dynamic conditions, the survey will provide direct measurements of groundwater flow along the saturated well screen during a constant rate of pumping (e.g., with pump placed near the top of the well screen). The normalized relative hydraulic-conductivity value can be determined directly from measuring specific depth inflow rates as they relate to total flow pumped from the entire test interval. An absolute or actual hydraulic-conductivity-value depth profile, however, can be developed if an estimate of the average hydraulic conductivity has been determined from large-scale pumping tests also described in the work plan (see section 4.2.3.2). Careful coordination and scheduling will be needed for both the large-scale aquifer testing and the high-resolution local-scale stratified testing to minimize IM downtime needed for water table quiescence.

In addition to measuring the vertical groundwater flow distribution, the high-resolution stratified characterization will be augmented by collection of water samples at each position of the flow meter. These data may be collected only when IM operations have been paused due to the potential for significant mixing to occur under dynamic pumping conditions.

#### 4.2.3.2 Aquifer Testing: Plume-Scale Hydraulic Properties and Mass Flux

The general approach to be used for large-scale aquifer testing is described in this work plan but separate work plans with more details on the approach will be submitted to NMED prior to their execution. The NMED Hazardous Waste Bureau (HWB) Aquifer Test Guidance will be followed, if available during the time period for the work plan preparation.

The aquifer testing is expected to provide additional spatial resolution of plume-scale hydraulic properties and will be used to evaluate applicability of smaller-scale aquifer-test data previously collected. These data will support calibration of the numerical flow and transport model used to assess capture and alternative extraction and injection strategies. As described above, the aquifer testing will also be used to identify the distribution of chromium mass flux in the aquifer and support conceptual and numerical model development.

Pumping tests will be conducted in all of the infrastructure wells, except CrEX-3, which has demonstrated limited pumping capacity, which would indicate a smaller perturbance to the water table and subsequent impact in nearby monitoring wells.

The industry-standard pumping test approach will include

- measuring background water level trends before and throughout testing.
- obtaining barometric pressure data to use for applying correction factors to water-level data if applicable and necessary.
- pumping at a constant rate.
- recording recovery data following shutdown.
- analyzing the resulting data using applicable analytical methods.

Separate constant-rate tests will be conducted in each of the screens of the selected infrastructure wells following industry standards described in Driscoll (1986, 098254); Kruseman and De Ridder (1991, 106681); Osborne (https://www.epa.gov/sites/default/files/2015-06/documents/sopaqu.pdf); U.S. Department of the Interior (https://pubs.usgs.gov/wri/1996/4293/report.pdf); Lohman (https://pubs.er.usgs.gov/publication/pp708); Ferris et al. (https://pubs.usgs.gov/wsp/wsp1536-E/); and American Society for Testing and Materials (ASTM) D4043 and ASTM D6034. Pumping rates that can be sustained in each screen will be determined as part of the testing. The test duration for each screen will be dependent on individual test conditions but is anticipated to be approximately 7 days long to (1) increase the probability of capturing the hydraulic response that occurs after delayed yield effects dissipate and to (2) enhance the response in the observation (monitoring) wells. The recovery period will be 2 days to provide some post-delayed-yield data as well as provide an extra day of downtime between the two 1-wk tests. Water produced from testing will be treated to remove hexavalent chromium and injected into injection wells. The use of different injection locations can be used to evaluate pressure responses in nearby monitoring wells associated with each injection event. To the extent possible, injection of extracted water will begin when test pumping begins and at the same flow rate. Water-level monitoring at surrounding wells will enable observation of system responses to both the pumping and the injection events.

IM extraction and injection will likely be shut down for 2 wk before testing to allow aquifer water levels to recover and stabilize, thereby reducing the impact of IM operations on water levels. Note that there may still be water-level rebound in the extraction well area and water-level declines in the injection area; the proposed 2-wk downtime should help minimize the amount of any residual water-level recoveries. All regional aquifer monitoring wells/screens, extraction wells, and injection wells in the chromium plume area will be set to 1-min transducer recording frequency several days before deployment of the packer system (see below). Monitoring is expected to continue for a few days after the final pumping test. This same measurement frequency will be used for recording barometric pressure. Samples will be collected during each aquifer test for geochemistry, following sampling and analysis plans that will be specifically developed for these tests.

It is important to remove the effects of barometric pressure changes on the water levels measured at the site. Therefore, in addition to the pressure transducers installed to monitor pressures, barometric pressure will be monitored throughout the testing process.

#### 4.2.3.3 Quantitative Analysis of Mass Flux Data

One measure of plume control is associated with an integration of the plume concentration data with hydraulic property measurements to estimate mass flux across select transects within the chromium investigation area. Select transects are defined as vertical planes through the chromium plume that are perpendicular to groundwater flow. Mass flux across each plume transect will be calculated using data measured as described above and will include both the hydraulic flow gradient and the hydraulic conductivity. For example, the groundwater flow direction and hydraulic gradient for each segment of a transect line can be determined from a potentiometric surface contour map.

Since the network of measurements may not be sufficiently dense to capture the heterogeneity of the plume in the Y-Z plane, uncertainty will be explored, identifying appropriate statistical distributions and values that best describe the distribution. A graded approach, which applies progressively increasing rigor appropriate for predictive assessments associated with aquifer testing and mass flux estimates, may be used to determine impacts of alternative extraction and injection scenarios on mass flux estimates with respect to IM objectives.

## 4.3 Potential Tracer Testing

Although tracer testing is not proposed in this work plan, tracer tests may be required to establish a baseline of information needed to transition to the CME. If additional information is needed to estimate mass flux, additional tracer testing may be considered. Tracer tests may also be used to identify chromium source locations. For example, a tracer test could be used at R-11 to determine if it is captured at CrEX-2, or at R-70 to determine if a hydraulic connection exists with CrEX-5. However, the potential to disturb the viability of the monitoring well will need to be considered if tracer testing is desired.

## 4.4 Objective 3: Develop A Strategy To Conduct A Corrective Measures Evaluation

As described in the 2016 Consent Order, the CME will be performed to identify, develop, and evaluate potential corrective measures alternatives for removal, containment, and/or treatment of site-related contamination. The CME will focus on remedies based on consideration of site conditions and the extent, nature, and complexity of releases and contamination.

The information and knowledge gained from operating the IM will be critical in developing the CME. The IM is designed for hydraulic plume control, with mass extraction as an incidental benefit associated with the existing pump-and-treat system. Once sufficient characterization data have been obtained, a transition to a CME is needed to a remedial alternative focused on chromium mass removal, and a secondary goal of hydraulic plume control. Although the presumptive remedy is pump and treat, the CME will provide a rigorous analysis of potential remedial alternatives to achieve remedial action objectives and required risk reduction. Cost, schedule, public acceptability, and other factors will also be considered, with the primary decision point of the selection of the most appropriate corrective measure for the site. Work plan activities that support a transition from the IM to the CME are described below.

The first step in the strategy is to complete site characterization to the extent that EM-LA and NMED agree sufficient to conduct the CME. After the baseline site characterization has been established, the strategy for conducting the CME includes gathering all pertinent data and information to assemble applicable technologies into remedial alternatives. Based on site conditions and site information, alternatives will be evaluated for their effectiveness, implementability, and cost.

In summary the strategy for conducting the CME includes the following activities:

- Establish baseline site characterization activities needed to initiate the CME.
- Gather all pertinent site information.
- Assemble appropriate technologies into viable remedial alternatives.
- Describe in detail each remedial alternative including its effectiveness, implementability, and cost.
- Compare each alternative with the other alternatives and with a no-action alternative.
- Select a proposed remedial alternative.

Sources of information and data that will be used to conduct the CME include, but are not limited to,

- site characterization information, including information obtained after implementing this work plan,
- chromium mass distribution,
- IM operations and performance,
- information from the implementation of the in-situ pilot tests, and
- information described in the compendium (LANL 2018, 602964).

Information on using an adaptive site management approach is described in section 4.4.2.

#### 4.4.1 Chromium Mass Distribution in Sandia and Mortandad Canyons

The transport pathways for chromium aqueous transport are complex and not easily identified given the depth to the regional aquifer. However, identifying potential migration pathways is important for estimating the location and mass of chromium within the subsurface and identifying any future impacts to the regional groundwater. To this end, a paper study will be conducted to estimate the subsurface distribution of chromium mass based on (1) existing conceptual models of chromium migration in the wetlands (located downstream of the cooling tower discharge) and (2) matrix and fracture flow in the vadose and perched-intermediate groundwater zones and in the regional aquifer.

The IM goal is plume control via hydraulic containment. However, information on subsurface mass distribution will also support the CME. Estimates of the subsurface distribution of chromium mass provide a technical basis to identify and evaluate potential remedial alternatives and support the design of a system that meets contaminant mass removal objectives.

#### 4.4.2 Adaptive Site Management Plan

Adaptive site management (ASM) is a systematic and iterative management approach that is used to accelerate site remediation. The ASM framework allows for a remedy to be initiated with sufficient knowledge of nature and extent but also provides feedback adjustments needed to the remedy as new information and technologies become available. ASM requires an initial CSM and an understanding of its uncertainties. Rigorous planning is a critical element of ASM, with a flexible framework to iteratively evaluate and prioritize site remedial actions and characterization activities (https://rmcs-1.itrcweb.org/).

Although this work plan will address data gaps associated with the horizontal and vertical extent of the chromium plume, total mass within the regional aquifer, and potential continuing chromium sources to the regional aquifer, complexities associated with the regional aquifer will preclude attainment of complete knowledge of the site. The ASM plan will provide a set of proposed site objectives for ASM implementation as a basis for discussion with NMED. Subsequent identification of interim objectives will also be defined to yield measurable incremental progress toward site remedy goals. Providing both short- and long-term planning within an ASM framework will support transition to the CME. The goal of ASM is to coordinate among stakeholders for decision-making under uncertain conditions, with the purpose of advancing chromium cleanup and incorporating lessons learned.

#### 4.4.3 CME Development

To execute the chromium CME, EM-LA will assemble appropriate technologies into potentially viable remedial alternatives. Once assembled, each alternative will be evaluated using the threshold and balancing criteria presented below. A corrective measure alternative recommended in the CME document will meet the threshold criteria, which are derived from standards in the EPA "RCRA [Resource Conservation and Recovery Plan] Corrective Action Plan," OSWER Directive 9902.3-2A (https://www.epa.gov/sites/default/files/2013-10/documents/rcracactionpln-rpt.pdf). The CME also uses balancing criteria to evaluate alternatives that meet the threshold criteria.

Threshold Criteria:

- Protects human health and the environment
- Achieves media cleanup objectives
- Controls the source(s) of releases
- Complies with applicable standards for management of wastes

Balancing Criteria:

- Achieves long-term reliability and effectiveness (including sustainability, long-term stewardship considerations, and long-term environmental impacts)
- Reduces toxicity, mobility, or volume of waste and contaminated media
- Addresses short-term effectiveness (including near-term environmental impacts)
- Is practical
- Is cost-effective

After each alternative is evaluated for meeting the threshold and balancing criteria, the alternatives will be put through a comparative analysis to determine and select a proposed remedial alternative for NMED's consideration. DOE will seek a remedy that (1) can be implemented quickly, safely, and easily; (2) poses fewer and less significant difficulties; (3) is cost efficient; and (4) does not sacrifice protection of human health and the environment. If all other criteria are equal, preference will be given to the remedy that most quickly reduces short-term risks and near-term environmental impacts, without creating significant additional risks.

The CME will document the results of the evaluation and recommend a preferred alternative for remediation. A CME report will be submitted to the NMED after closure of this work plan.

## 5.0 Chromium Interim Measure and Characterization Reporting

Performance monitoring and characterization progress will be provided annually in four quarterly monitoring reports and one annual monitoring report, which may contain historical analysis of IM operations to date, as well as ongoing IM performance monitoring. This reporting supports IM operations. Although the characterization activities do not directly support operations, brief progress reports will be provided in the quarterly/annual reports as results become available. A closure report will document the characterization activities described in this work plan and close the characterization portion of the work plan.

A brief description of the objectives of the reporting and corresponding content is provided below.

### 5.1 Quarterly Monitoring Reports

The principal objectives of the Chromium Interim Measures and Characterization quarterly monitoring reports are (1) to provide a mechanism for early identification of concentration trends that may indicate a need to adjust IM operations and (2) facilitate communication on emergent data for both IM monitoring and progress associated with characterization activities. The information documented in the quarterly reports will also provide potential topics for discussion in EM-LA and NMED technical team meetings.

Documentation in the quarterly reports will focus on recent monitoring data, and delivery dates will be within 30 days of the reporting period.

1. October–December, delivered by January 31
2. January–March, delivered by April 30
3. April–June, delivered by July 31
4. July–September, delivered by October 30

Historical monitoring data and analyses may also be included, especially if these data provide insights into more recent trends and data needed for adjusting IM operations. For example, updates to the two previous semiannual IM performance monitoring reports will be incorporated into the quarterly reporting, consolidating both historical and current results into a single reporting mechanism (see Appendix A).

The content in the quarterly reports will include the following:

- Evaluation of the IM influence on the water table configuration, hydraulic gradients, and chromium plume response using
    - ❖ Graphical and tabular presentations of water level data at each performance monitoring well

  - ❖ Synoptic potentiometric surface maps using dates collaboratively identified with NMED, generated for three depths, if possible, based on the availability of data
  - ❖ Chromium and other concentration data needed to support the analysis

- Estimates of chromium mass extracted at each extraction well based on chromium concentrations measured at the well head and determined through laboratory analyses
- Conceptual and numerical model updates based on new characterization data or IM operations
- Documentation on progress and assessment to date of characterization activities described in this work plan
- Documentation of extraction and recovery rates for wells impacted by aquifer testing, providing data both graphically and in tabular form
- Documentation of any tracer tests conducted including tracer recovery and locations, travel times, and derived parameters estimates

The quarterly reports may also provide recommendations on operational changes, thereby serving as the technical basis for a revision of this work plan to address IM operations.

### 5.2 Annual Monitoring Reports

The principal objectives of the Chromium Interim Measures and Characterization annual monitoring report are to provide evaluation of data collected over an annual period of performance and to provide comprehensive, integrated analyses relative to IM performance monitoring for the previous four quarters (April1 through March 31 with delivery by June 30). The content of the annual report will provide a more comprehensive, integrated analysis of concentration and hydraulic data and include the following:

- A more comprehensive evaluation (relative to quarterly reporting) of the IM influence on the water table configuration, hydraulic gradients, and chromium plume response, including
  - ❖ Data-driven analyses and predictive assessments to support CZA and alternative extraction and injection strategies
  - ❖ Identification of any trends in measured data that are triggers for action, based on EM-LA and NMED technical team discussions
- A more comprehensive discussion (relative to quarterly reporting) of chromium mass within the regional aquifer and mass extracted, using information obtained from work plan activities when available (e.g., total mass removed, total relative to regional estimates, and total chromium dissolved mass estimates and uncertainty bounds in regional aquifer)
- Time-series plots that include data for chromium, perchlorate, nitrate, and tritium and trend analyses as appropriate (e.g., Mann-Kendall)
- Progress reports on characterization activities described in this work plan over the annual period of performance, including both field-based and non–field-based activities (e.g., tracer tests, aquifer tests, mass distribution analyses, etc.)
- Progress toward an adaptive site management strategy that supports establishing baseline information to transition to the CME

### 5.3 Closure Report

The Chromium Interim Measures and Characterization closure report will document the outcome of the data gap activities described in section 4, document IM operations under this work plan, and support closure of this work plan. The closure report will document the data collected and subsequent updates to the CSM and will describe any operational changes that may have occurred as documented in the quarterly and annual reports. The content of the report will include the following:

- Documentation of all activities conducted under the IM operations, summarizing data gap outcomes and establishing baseline information needed to support the CME
    - ❖ Chromium mass distribution within the regional aquifer, percent mass recovered, and associated uncertainties
    - ❖ Pertinent graphics from annual reports relevant to final remedy design, such as chromium concentration trends and chromium mass flux estimates
- Submittal schedule for the CME
- Adaptive site management strategy that supports transition to the CME

The Chromium Interim Measures and Characterization closure report will include a statement of sustained IM operations until final remedy implementation.

## 6.0 SCHEDULE

The start date for implementation of activities described in this work plan is contingent upon receiving NMED approval. However, the reporting is anticipated to be initiated in the first quarter of fiscal year 2023.

The activities presented in this work plan are anticipated to be executed over approximately a 2–3-yr period, provided that funding is available to execute the work plan activities and no significant technical challenges arise with drilling monitoring wells in the regional aquifer. The goal is to complete aquifer testing and mass flux analyses within the first year of executing this work plan, but this will be dependent on NMED approval of separate work plans and agreement on pauses in IM operations to obtain water-table quiescence before testing.

## 7.0 REFERENCES AND MAP DATA SOURCES

### 7.1 References

*The following reference list includes documents cited in this report. Parenthetical information following each reference provides the author(s), publication date, and ERID, ESHID, or EMID. ERIDs were assigned by Los Alamos National Laboratory's (the Laboratory's) Associate Directorate for Environmental Management (IDs through 599999); ESHIDs were assigned by the Laboratory's Associate Directorate for Environment, Safety, and Health (IDs 600000 through 699999); and EMIDs are assigned by N3B (IDs 700000 and above).*

Broxton, D.E., and D.T. Vaniman, August 2005. "Geologic Framework of a Groundwater System on the Margin of a Rift Basin, Pajarito Plateau, North-Central New Mexico," *Vadose Zone Journal,* Vol. 4, No. 3, pp. 522–550. (Broxton and Vaniman 2005, 090038)

DOE (U.S. Department of Energy), May 12, 2016."Request of Emergency Authorization under NMSA 1978, § 72-12-24 with respect to the Co-Application for Permit to Change an Existing Water Right (Non 72-12-1) as submitted by the Department of Energy and Incorporated County of Los Alamos in Support of the Chromium Plume Control Interim Measure and Chromium Plume Center Characterization at Los Alamos National Laboratory," U.S. Department of Energy letter to R. Martinez (NMOSE) from D. Hintz (EM-LA) and T. Glasco (Los Alamos County), Los Alamos, New Mexico. (DOE 2016, 702320)

DOE (U.S. Department of Energy), May 12, 2016. "Application for Permit to Change an Existing Water Right (Non 72-12-1) in Support of the Chromium Plume Control Interim Measure and Chromium Plume Center Characterization at Los Alamos National Laboratory," U.S. Department of Energy letter to R. Martinez (NMOSE) from D. Hintz (EM-LA) and T. Glasco (Los Alamos County), Los Alamos, New Mexico. (DOE 2016, 702319)

DOE (U.S. Department of Energy), January 24, 2019. "Request of Emergency Authorization under NMSA 1978, § 72-12-24 with respect to the Co-Application for Permit to Change an Existing Water Right (Non 72-12-1) as submitted by the U.S. Department of Energy and Incorporated County of Los Alamos in Support of the Chromium Plume Control Interim Measure and Chromium Plume Center Characterization at Los Alamos National Laboratory," U.S. Department of Energy letter (EM-LA-40DH-00367) with enclosures to R. Martinez (NMOSE) from T. Glasco (LAC) and D.E.  Hintze (EM-LA), Los Alamos, New Mexico. (DOE 2019, 700203)

DOE (U.S. Department of Energy), January 24, 2019. "Application for Permit to Change an Existing Water Right (Non 72-12-1) in Support of the Chromium Plume Control Interim Measure and Chromium Plume Center Characterization at Los Alamos National Laboratory," U.S. Department of Energy letter (EM-LA-40DH-00371) with enclosures to R. Martinez (NMOSE) from T. Glasco (LAC) and D.E. Hintze (EM-LA), Los Alamos, New Mexico. (DOE 2019, 700204)

DOE (U.S. Department of Energy), February 6, 2020. "Request to Withdraw the Emergency Authorization dated September 10, 2016, and the Application for Permit to Change an Existing Water Right (Non 72-12-1) in Support of the Chromium Plume Control Interim Measure and Chromium Plume Center Characterization at Los Alamos National Laboratory dated May 12, 2016," U.S. Department of Energy letter (EMLA-2020-1236-04-001) to R. Martinez (NMOSE) from P.S. Shelton (LAC) and D.E. Hintze (EM-LA), Los Alamos, New Mexico. (DOE 2020, 700751)

Driscoll, F.G., 1986. Excerpted pages from *Groundwater and Wells*, 2nd Ed., Johnson Filtration Systems Inc., St. Paul, Minnesota. (Driscoll 1986, 098254)

Fetter, C.W., *Applied Hydrogeology*, Third ed., Prentice Hall, Upper Saddle River, New Jersey. (Fetter 1994, 070942)

Katzman, D., V. Vesselinov, P. Reimus, D. Broxton, J. Heikoop, G. WoldeGabriel, M. Everett, K. Birdsell, and C. Rodriguez, "Chromium Plume at LANL – From Conceptual Site Model to Development of Complex Remediation Strategies," paper 18682 presented at WM2018 Conference, March 18–22, 2018; Phoenix, Arizona. (Katzman et al. 2018, 702317)

Kruseman, G.P., N.A. de Ridder, and J.M. Verweij, 1991. Excerpted page from *Analysis and Evaluation of Pumping Test Data*, International Institute for Land Reclamation and Improvement, Netherlands. (Kruseman et al. 1991, 106681)

LANL (Los Alamos National Laboratory), April 2013. "Interim Measures Work Plan for the Evaluation of Chromium Mass Removal," Los Alamos National Laboratory document LA-UR-13-22534, Los Alamos, New Mexico. (LANL 2013, 241096)

LANL (Los Alamos National Laboratory), March 2014. "Summary Report for the 2013 Chromium Groundwater Aquifer Tests at R-42, R-28, and SCI-2," Los Alamos National Laboratory document LA-UR-14-21642, Los Alamos, New Mexico. (LANL 2014, 255110)

LANL (Los Alamos National Laboratory), March 2014. "Drilling Work Plan for Groundwater Extraction Well CrEX-1," Los Alamos National Laboratory document LA-UR-14-21478, Los Alamos, New Mexico. (LANL 2014, 254824)

LANL (Los Alamos National Laboratory), January 2015. "Completion Report for Groundwater Extraction Well CrEX-1," Los Alamos National Laboratory document LA-UR-15-20165, Los Alamos, New Mexico. (LANL 2015, 600170)

LANL (Los Alamos National Laboratory), May 2015. "Interim Measures Work Plan for Chromium Plume Control," Los Alamos National Laboratory document LA-UR-15-23126, Los Alamos, New Mexico. (LANL 2015, 600458)

LANL (Los Alamos National Laboratory), July 2015. "Work Plan for Chromium Plume Center Characterization," Los Alamos National Laboratory document LA-UR-15-24861, Los Alamos, New Mexico. (LANL 2015, 600615)

LANL (Los Alamos National Laboratory), July 2017. "Pilot-Scale Amendments Testing Work Plan for Chromium in Groundwater beneath Mortandad Canyon," Los Alamos National Laboratory document LA-UR-17-25406, Los Alamos, New Mexico. (LANL 2017, 602505)

LANL (Los Alamos National Laboratory), September 2017. "Completion Report for Groundwater Extraction Well CrEX-2," Los Alamos National Laboratory document LA-UR-17-27466, Los Alamos, New Mexico. (LANL 2017, 602595)

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)

LANL (Los Alamos National Laboratory), March 2018. "Compendium of Technical Reports Conducted Under the Work Plan for Chromium Plume Center Characterization," Los Alamos National Laboratory document LA-UR-18-21450, Los Alamos, New Mexico. (LANL 2018, 602964)

LANL (Los Alamos National Laboratory), April 2018. "Chromium Plume Control Interim Measure Performance Monitoring Work Plan," Los Alamos National Laboratory document LA-UR-18-23082, Los Alamos, New Mexico. (LANL 2018, 603010)

LANL (Los Alamos National Laboratory), April 2018. "Second Quarterly Report on Pilot-Scale Amendments Testing for Chromium in Groundwater Beneath Mortandad Canyon," Los Alamos National Laboratory document LA-UR-18-23418, Los Alamos, New Mexico. (LANL 2018, 603031)

N3B (Newport News Nuclear BWXT-Los Alamos, LLC), July 2018. "Third Quarterly Report on Pilot-Scale Amendments Testing for Chromium in Groundwater Beneath Mortandad Canyon," Newport News Nuclear BWXT-Los Alamos, LLC, document EM2018-0019, Los Alamos, New Mexico. (N3B 2018, 700032)

N3B (Newport News Nuclear BWXT-Los Alamos, LLC), September 2018. "Annual Progress Report on Chromium Plume Control Interim Measure Performance," Newport News Nuclear BWXT-Los Alamos, LLC, document EM2018-0028, Los Alamos, New Mexico. (N3B 2018, 700088)

N3B (Newport News Nuclear BWXT-Los Alamos, LLC), October 2018. "Fourth Quarterly Report on Pilot-Scale Amendments Testing for Chromium in Groundwater Beneath Mortandad Canyon," Newport News Nuclear BWXT-Los Alamos, LLC, document EM2018-0069, Los Alamos, New Mexico. (N3B 2018, 700108)

N3B (Newport News Nuclear BWXT-Los Alamos, LLC), January 2019. "Fifth Quarterly Report on Pilot-Scale Amendments Testing for Chromium in Groundwater Beneath Mortandad Canyon," Newport News Nuclear BWXT-Los Alamos, LLC, document EM2019-0011, Los Alamos, New Mexico. (N3B 2019, 700214)

N3B (Newport News Nuclear BWXT-Los Alamos, LLC), March 2019. "Semiannual Progress Report on Chromium Plume Control Interim Measure Performance," Newport News Nuclear BWXT-Los Alamos, LLC, document EM2019-0059, Los Alamos, New Mexico. (N3B 2019, 700356)

N3B (Newport News Nuclear BWXT-Los Alamos, LLC), April 2019. "Sixth Quarterly Report on Pilot-Scale Amendments Testing for Chromium in Groundwater Beneath Mortandad Canyon," Newport News Nuclear BWXT-Los Alamos, LLC, document EM2019-0133, Los Alamos, New Mexico. (N3B 2019, 700420)

N3B (Newport News Nuclear BWXT-Los Alamos, LLC), September 2019. "Semiannual Progress Report on Chromium Plume Control Interim Measure Performance, January through June 2019," Newport News Nuclear BWXT-Los Alamos, LLC, document EM2019-0230, Los Alamos, New Mexico. (N3B 2019, 700581)

N3B (Newport News Nuclear BWXT-Los Alamos, LLC), December 2019. "Assessment Work Plan for the Evaluation of Conditions in the Regional Aquifer Around Well R-70," Newport News Nuclear BWXT-Los Alamos, LLC, document EM2019-0458, Los Alamos, New Mexico. (N3B 2019, 700715)

N3B (Newport News Nuclear BWXT-Los Alamos, LLC), December 2019. "Seventh Report on Pilot-Scale Amendments Testing for Chromium in Groundwater Beneath Mortandad Canyon, April to September 2019," Newport News Nuclear BWXT-Los Alamos, LLC, document EM2019-0427, Los Alamos, New Mexico. (N3B 2019, 700723)

N3B (Newport News Nuclear BWXT-Los Alamos, LLC), March 2020. "Semiannual Progress Report on Chromium Plume Control Interim Measure Performance, July through December 2019," Newport News Nuclear BWXT-Los Alamos, LLC, document EM2020-0041, Los Alamos, New Mexico. (N3B 2020, 700815)

N3B (Newport News Nuclear BWXT-Los Alamos, LLC), September 2020. "Semiannual Progress Report on Chromium Plume Control Interim Measure Performance, January through June 2020," Newport News Nuclear BWXT-Los Alamos, LLC, document EM2020-0392, Los Alamos, New Mexico. (N3B 2019, 701051)

N3B (Newport News Nuclear BWXT-Los Alamos, LLC), March 2021. "Semiannual Progress Report on Chromium Plume Control Interim Measure Performance, July through December 2020," Newport News Nuclear BWXT-Los Alamos, LLC, document EM2021-0110, Los Alamos, New Mexico. (N3B 2021, 701366)

N3B (Newport News Nuclear BWXT-Los Alamos, LLC), September 2021. "Semiannual Progress Report on Chromium Plume Control Interim Measure Performance, January through June 2021," Newport News Nuclear BWXT-Los Alamos, LLC, document EM2021-0520, Los Alamos, New Mexico. (N3B 2021, 701695)

N3B (Newport News Nuclear BWXT-Los Alamos, LLC), June 2022. "Semiannual Progress Report on Chromium Plume Control Interim Measure Performance, July 2021 through March 2022," Newport News Nuclear BWXT-Los Alamos, LLC, document EM2022-0355, Los Alamos, New Mexico. (N3B 2022, 702170)

NMED (New Mexico Environment Department), January 25, 2013. "Response, Proposal to Submit Interim Measures Work Plan for Chromium Contamination in Groundwater," New Mexico Environment Department letter to P. Maggiore (DOE-LASO) and J.D. Mousseau (LANL) from J.E. Kieling (NMED-HWB), Santa Fe, New Mexico. (NMED 2013, 521862)

NMED (New Mexico Environment Department), June 26, 2013. "Approval with Modification, Interim Measures Work Plan for the Evaluation of Chromium Mass Removal," New Mexico Environment Department letter to P. Maggiore (DOE-LASO) and J.D. Mousseau (LANL) from J.E. Kieling (NMED-HWB), Santa Fe, New Mexico. (NMED 2013, 522947)

NMED (New Mexico Environment Department), October 15, 2015. "Approval with Modifications, Work Plan for Chromium Plume Center Characterization," New Mexico Environment Department letter to D. Hintze (DOE-NA-LA) and M. Brandt (LANL) from J.E. Kieling (NMED-HWB), Santa Fe, New Mexico. (NMED 2015, 600958)

NMED (New Mexico Environment Department), October 15, 2015. "Approval with Modifications, Interim Measures Work Plan for Chromium Plume Control," New Mexico Environment Department letter to D. Hintze (DOE-NA-LA) and M. Brandt (LANL) from J.E. Kieling (NMED-HWB), Santa Fe, New Mexico. (NMED 2015, 600959)

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)

NMED (New Mexico Environment Department), July 9, 2021. "Notice of Disapproval, Semiannual Progress Report on Chromium Plume Control Interim Measure Performance, January through June 2020," New Mexico Environment Department letter to A. Duran (EM-LA) from R. Maestas (NMED-HWB), Santa Fe, New Mexico. (NMED 2021, 701518)

NMED (New Mexico Environment Department), August 26, 2021. "Notice of Disapproval, Semiannual Progress Report on Chromium Plume Control Interim Measure Performance, July through December 2020," New Mexico Environment Department letter to A. Duran (EM-LA) from R. Maestas (NMED-HWB), Santa Fe, New Mexico. (NMED 2021, 701594)

NMOSE (New Mexico Office of the State Engineer), September 10, 2016. "Re: Emergency Authorization, RG-00485 et al.," New Mexico Office of the State Engineer letter to C. Rodriguez (EM-LA) from R. Martinez (NMOSE), Santa Fe, New Mexico. (NMOSE 2016, 702329)

NMOSE (New Mexico Office of the State Engineer), September 27, 2019. "Re: Emergency Authorization of Application No. RG-00485 et al.," New Mexico Office of the State Engineer letter to C. Rodriguez (EM-LA) from R. Martinez (NMOSE), Santa Fe, New Mexico. (NMOSE 2019, 702321)

Robinson, B.A., D.E. Broxton, and D.T. Vaniman, 2005. "Observations and Modeling of Deep Perched Water beneath the Pajarito Plateau," *Vadose Zone Journal,* Vol. 4, pp. 637–652. (Robinson et al. 2005, 091682)

Willis, B., G. WoldeGabriel, D. Katzman, and P. Reimus, "Biofouling in a Chromium Plume-Control Interim Measure Extraction Well at Los Alamos National Laboratory," paper 21269 presented at WM2021 Conference, March 8–12, 2021; Phoenix, Arizona. (Willis et al. 2021, 702318)

### 7.2 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

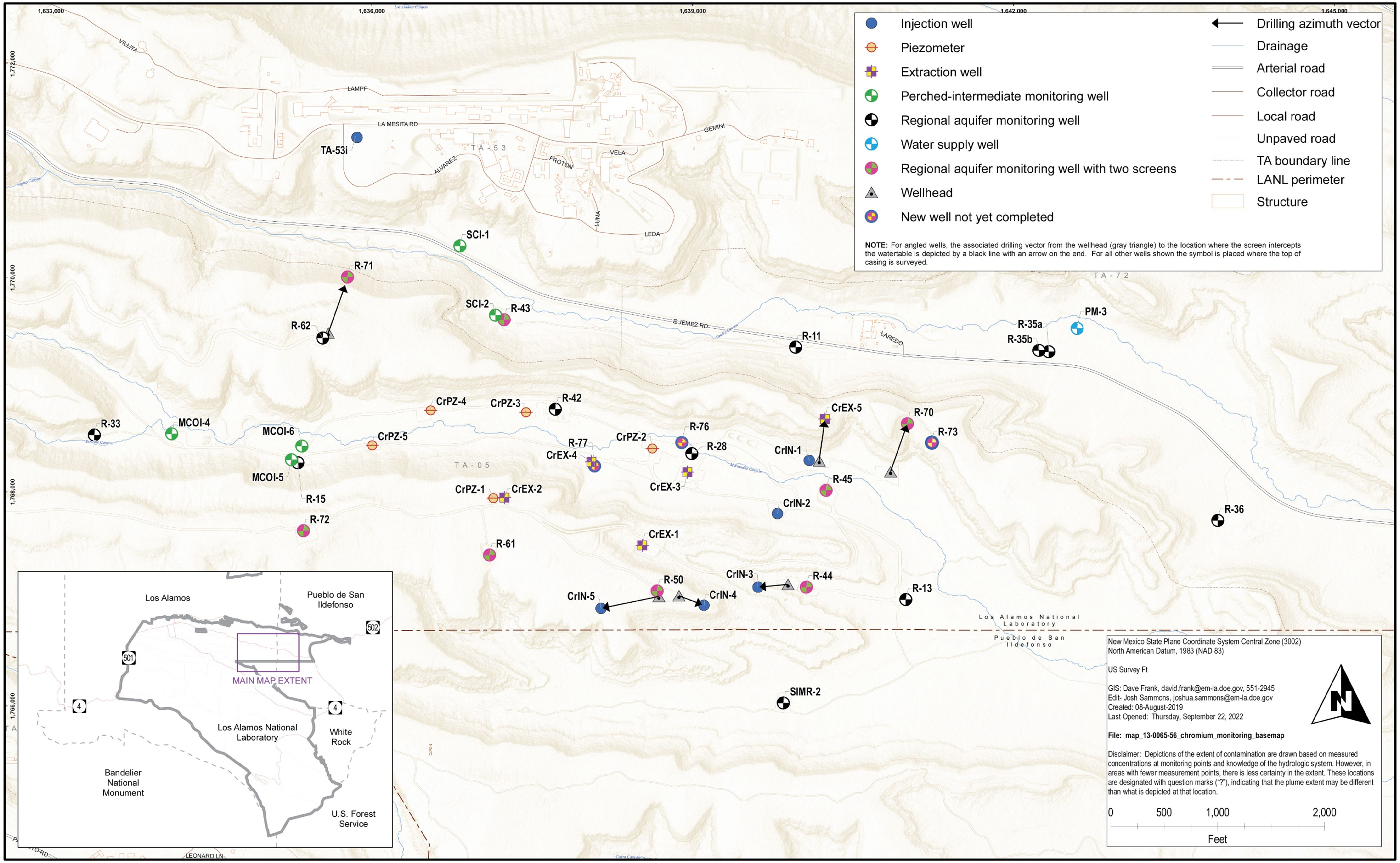



**Figure 3.2-1 Layout of monitoring and infrastructure wells in the chromium plume area**

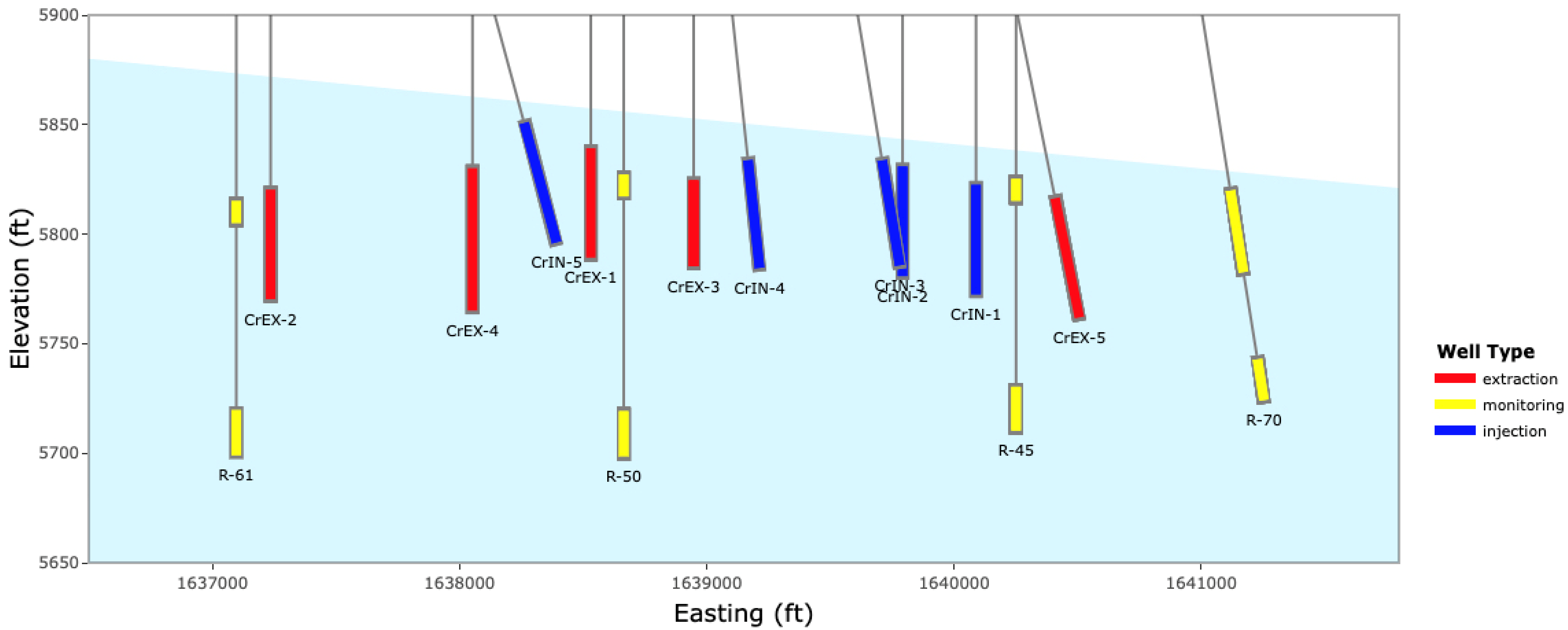
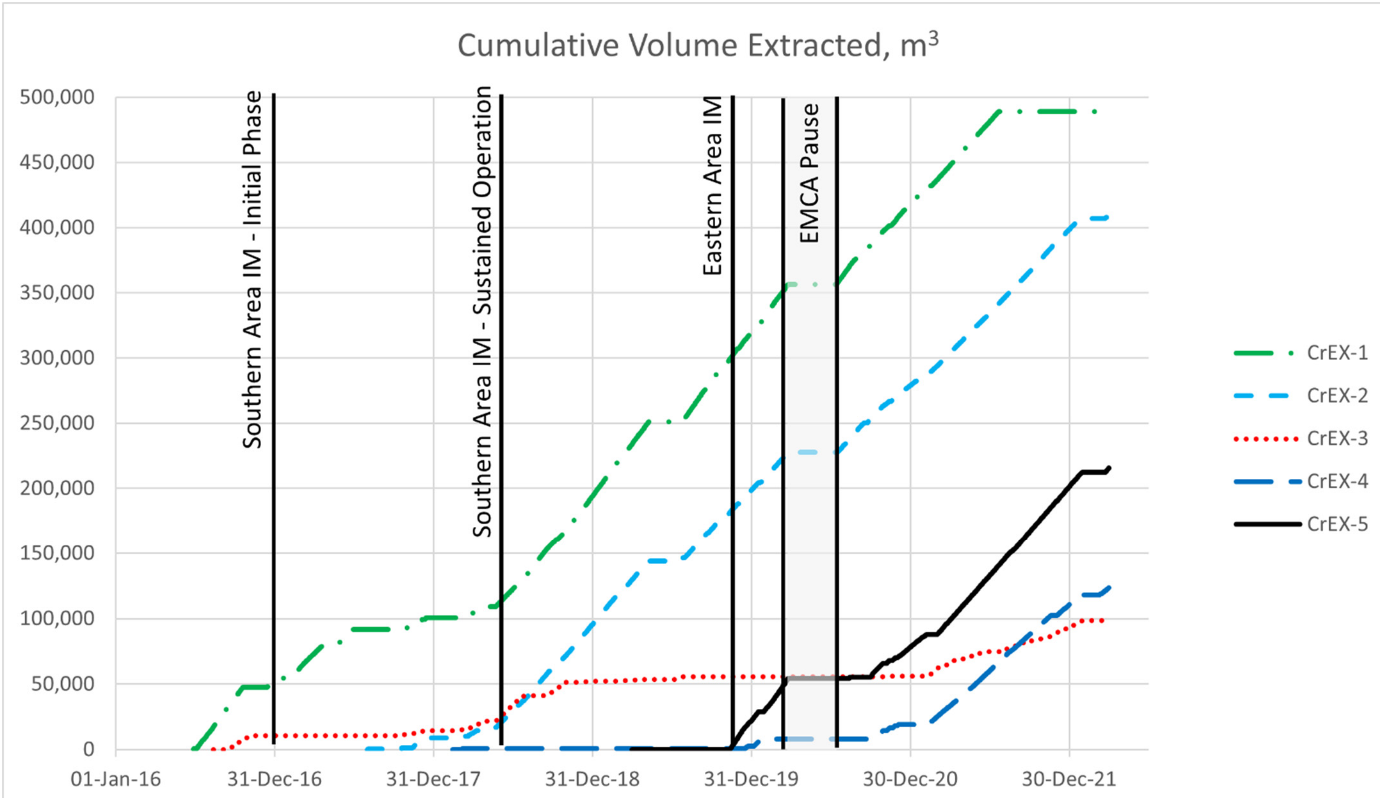



**Figure 3.2-2 Schematic of infrastructure well screen locations**




Vertical lines represent time markers for key changes in IM operations.

**Figure 3.2-3a Cumulative extraction volumes throughout the operation of the IM**

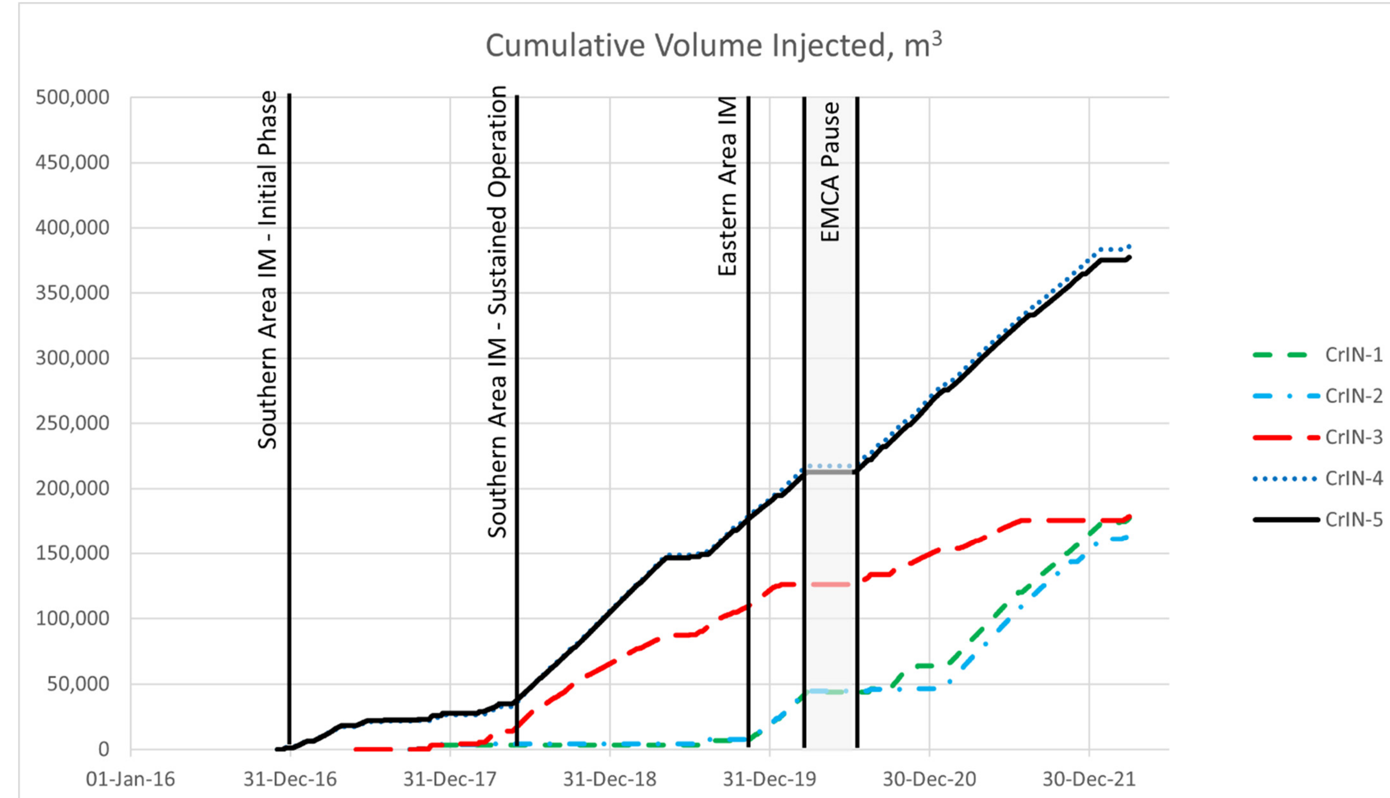
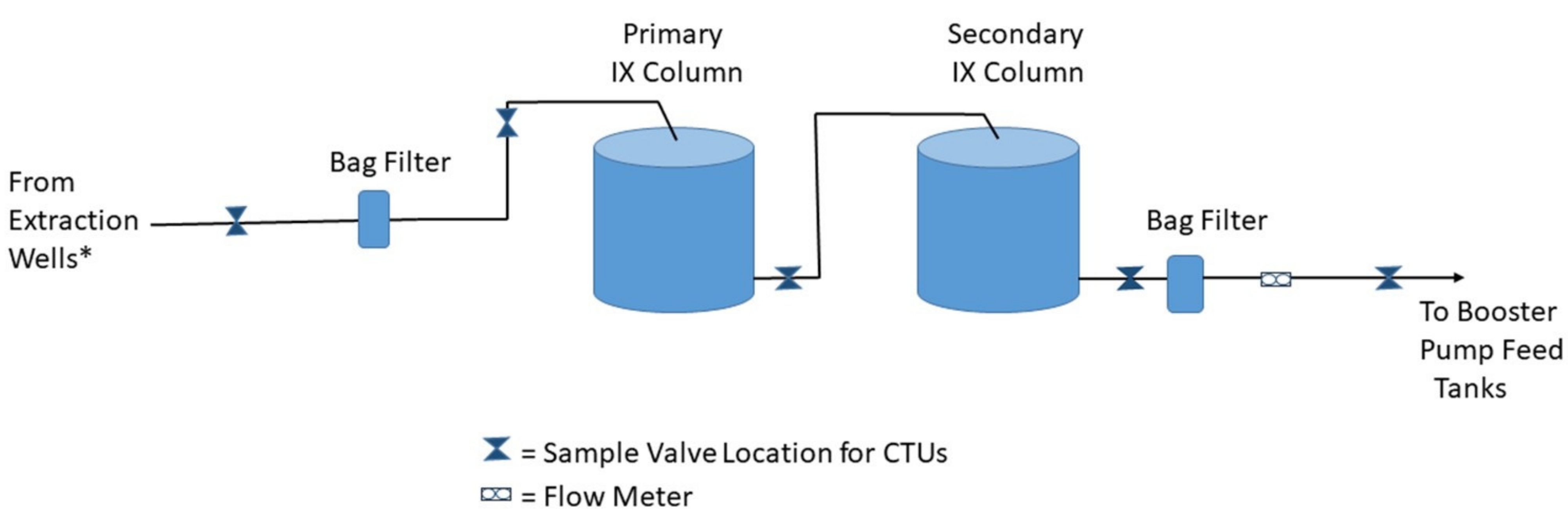



**Figure 3.2-3b Cumulative injection volumes throughout the operation of the IM**




Note: Water from extraction wells is mixed in the pipeline and diverted to two different chromium treatment units (CTUA and CTUC). CTUA contains 3 treatment trains and CTUC contains 2 treatment trains.

**Figure 3.2-4 Chromium treatment train**

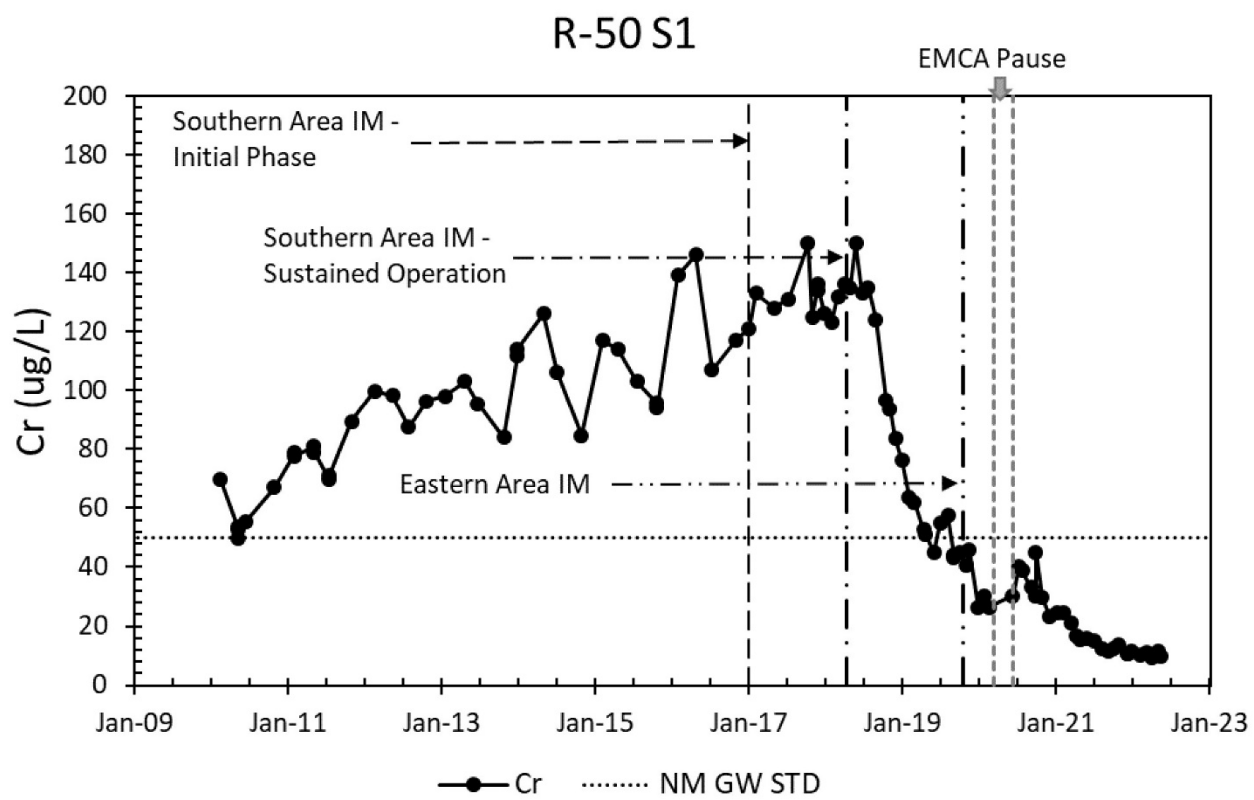



**Figure 3.3-1 Chromium concentrations at R-50 screen 1**

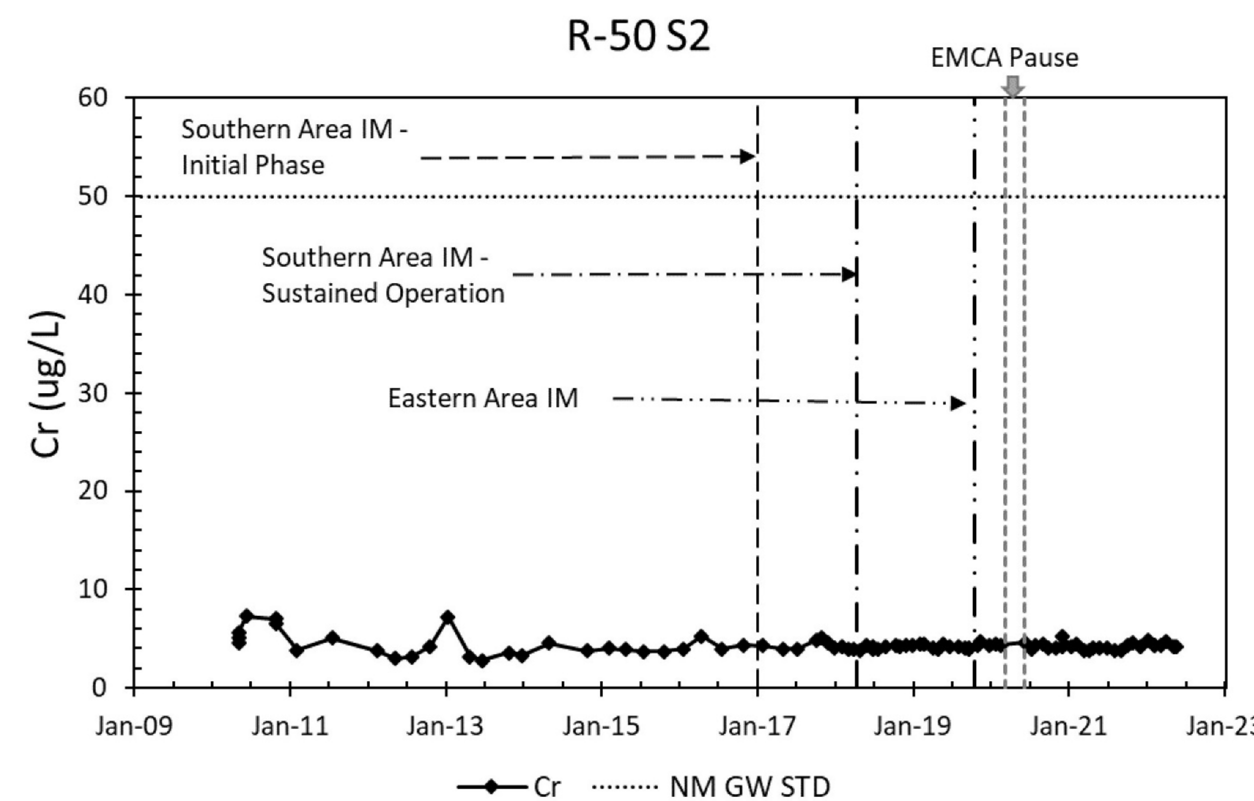



**Figure 3.3-2 Chromium concentrations at R-50 screen 2**

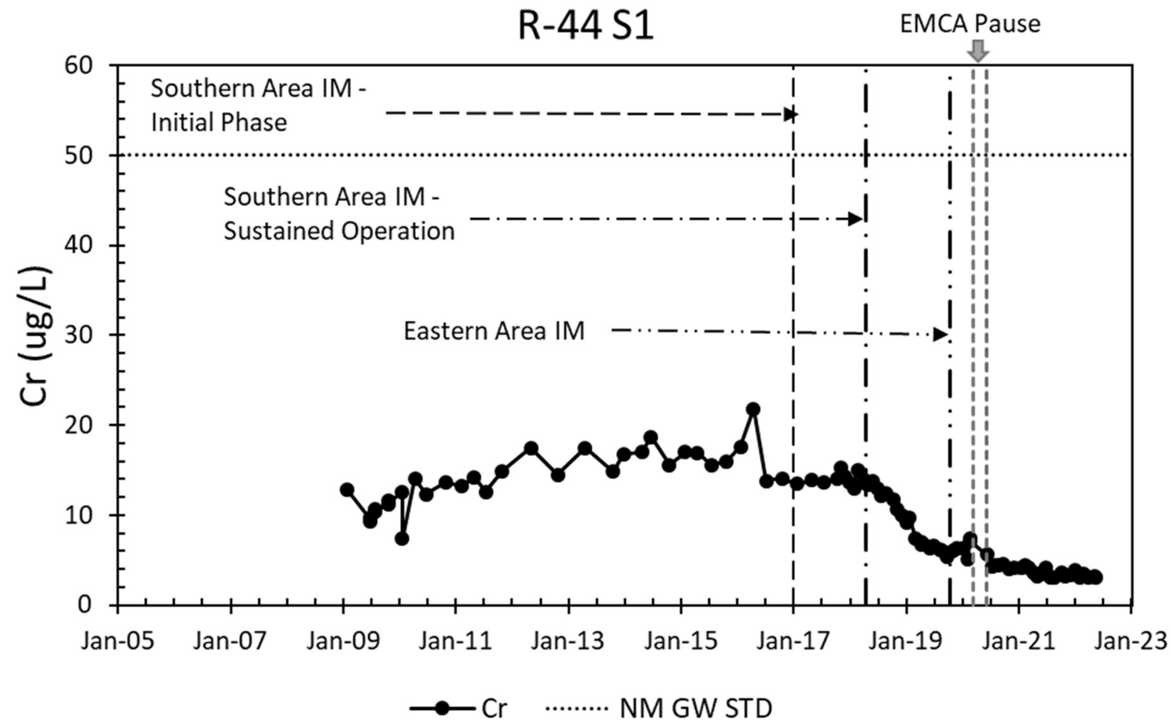



**Figure 3.3-3 Chromium concentrations over time at R-44 screen 1**

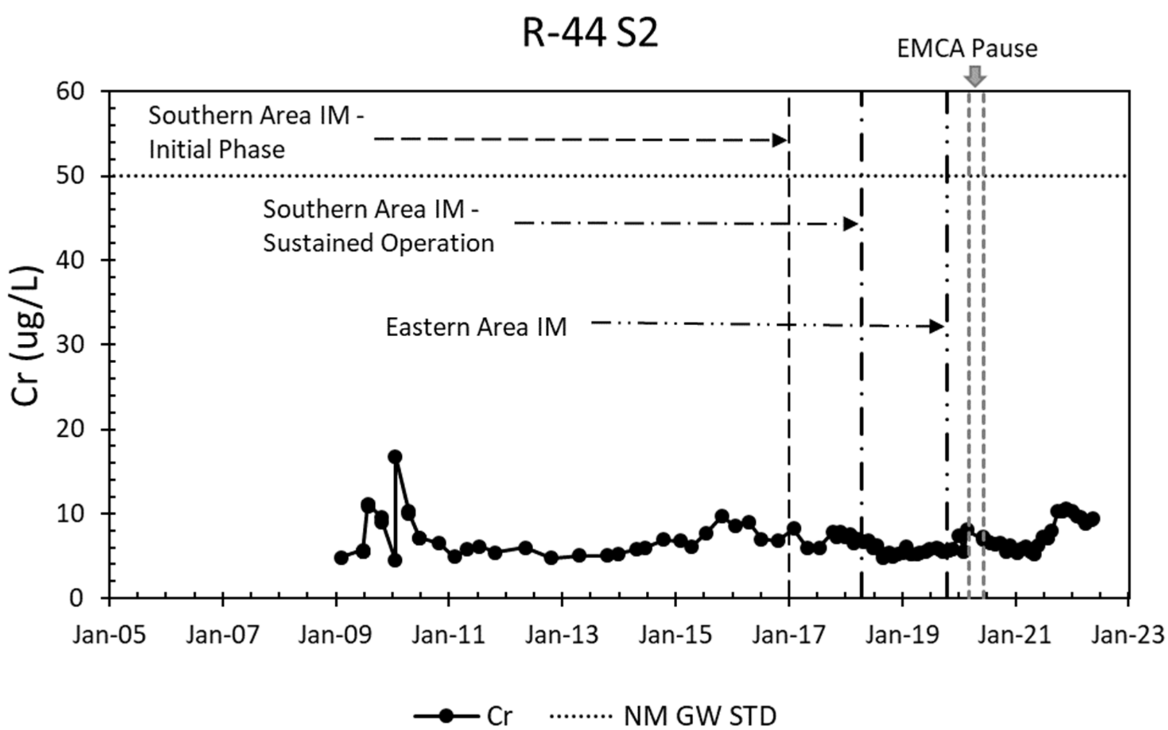



**Figure 3.3-4 Chromium concentrations over time at R-44 screen 2**

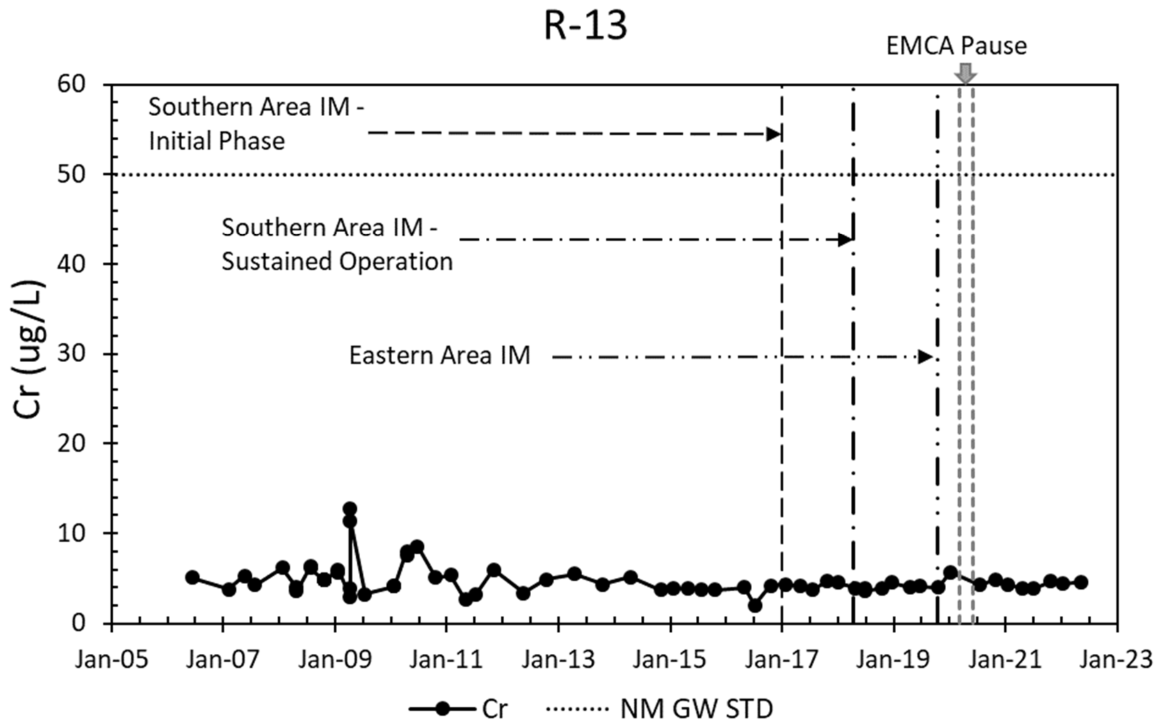



**Figure 3.3-5 Chromium concentrations over time at R-13**

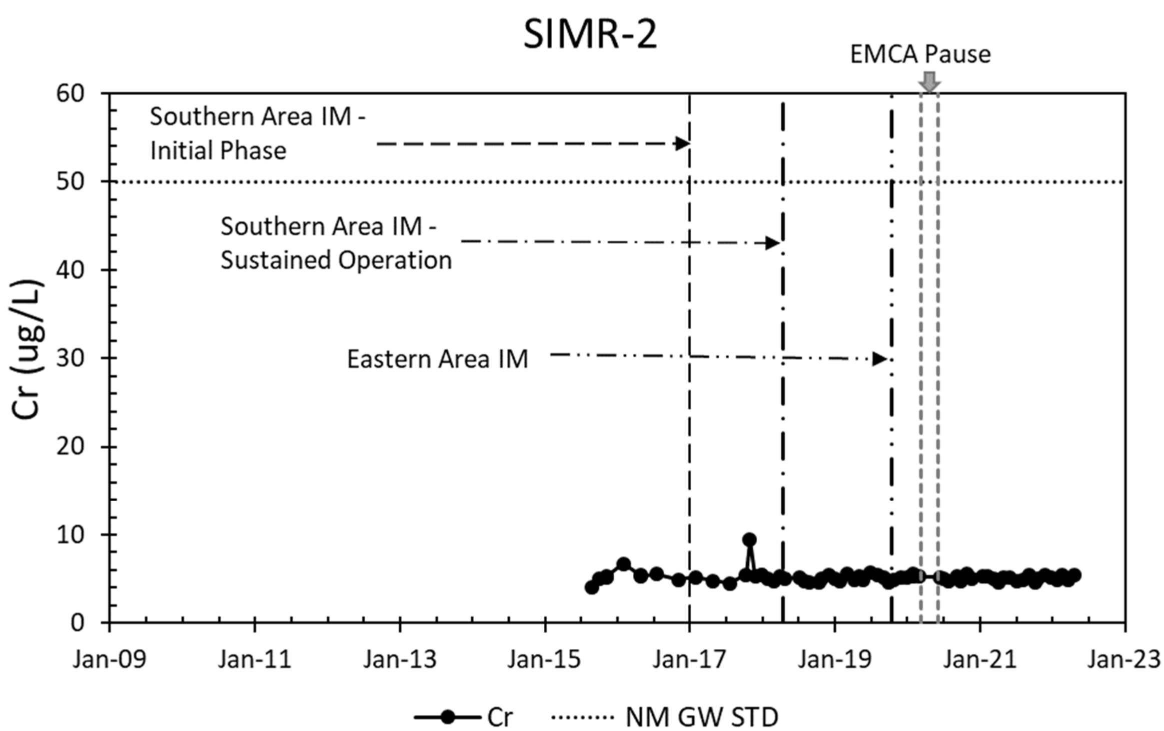



**Figure 3.3-6 Chromium concentrations over time at SMIR-2**

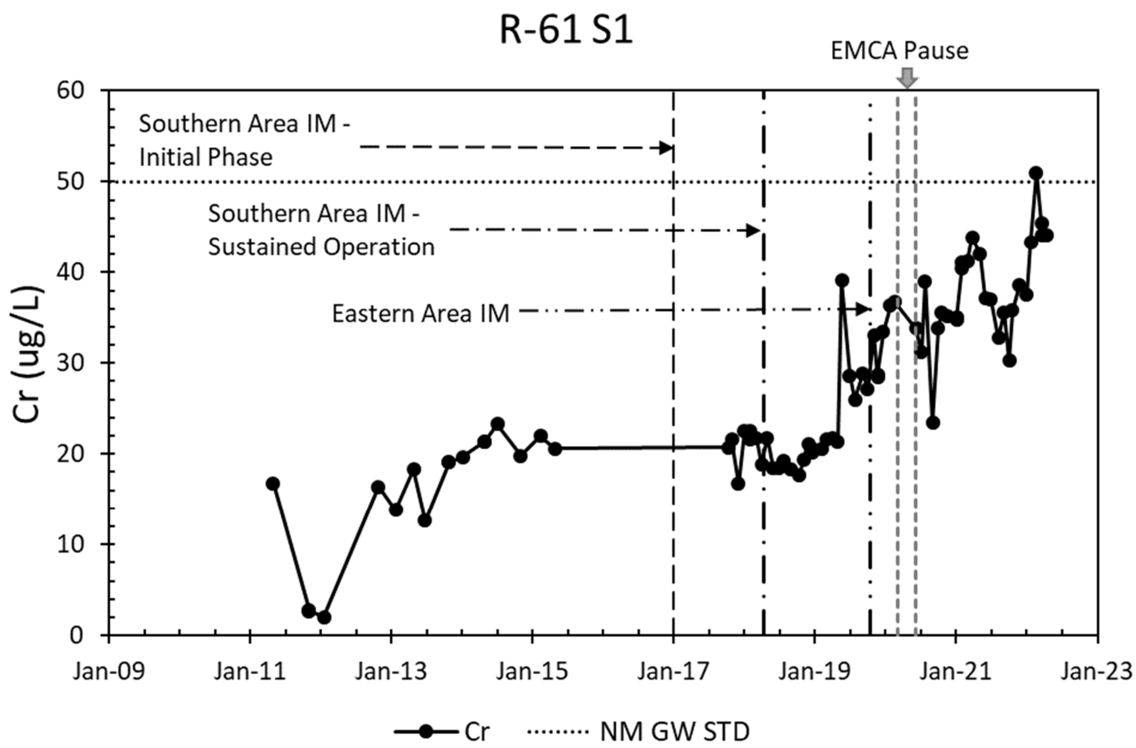



**Figure 3.3-7 Chromium concentrations over time at R-61**

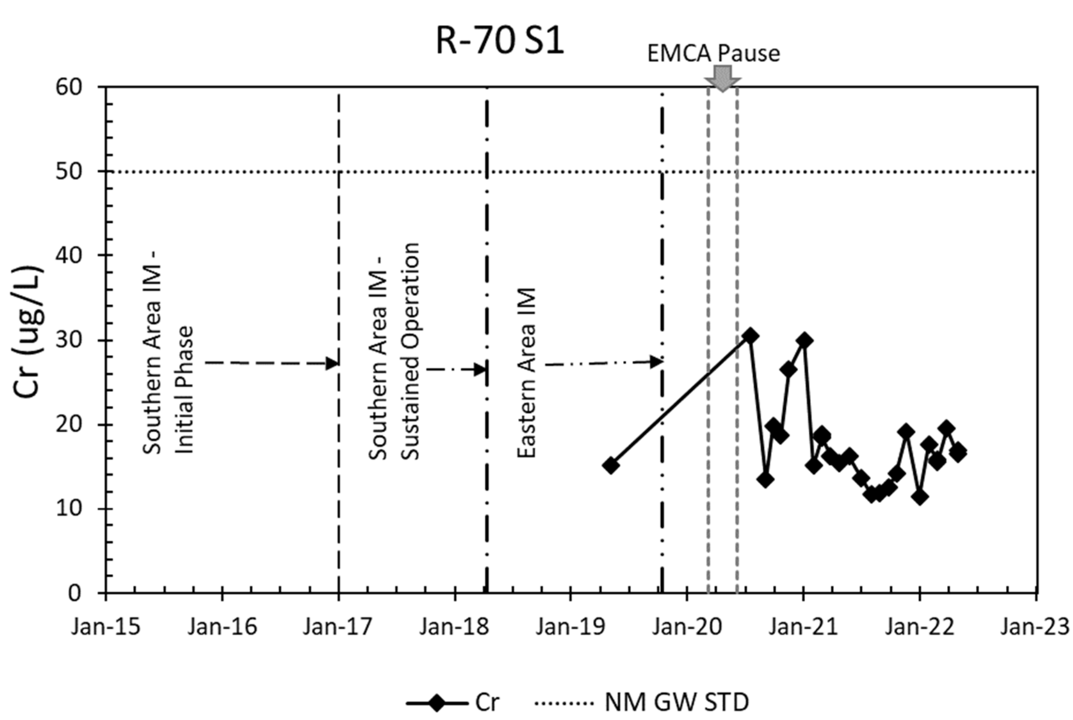



**Figure 3.3-8 Chromium concentrations over time at R-70 screen 1**

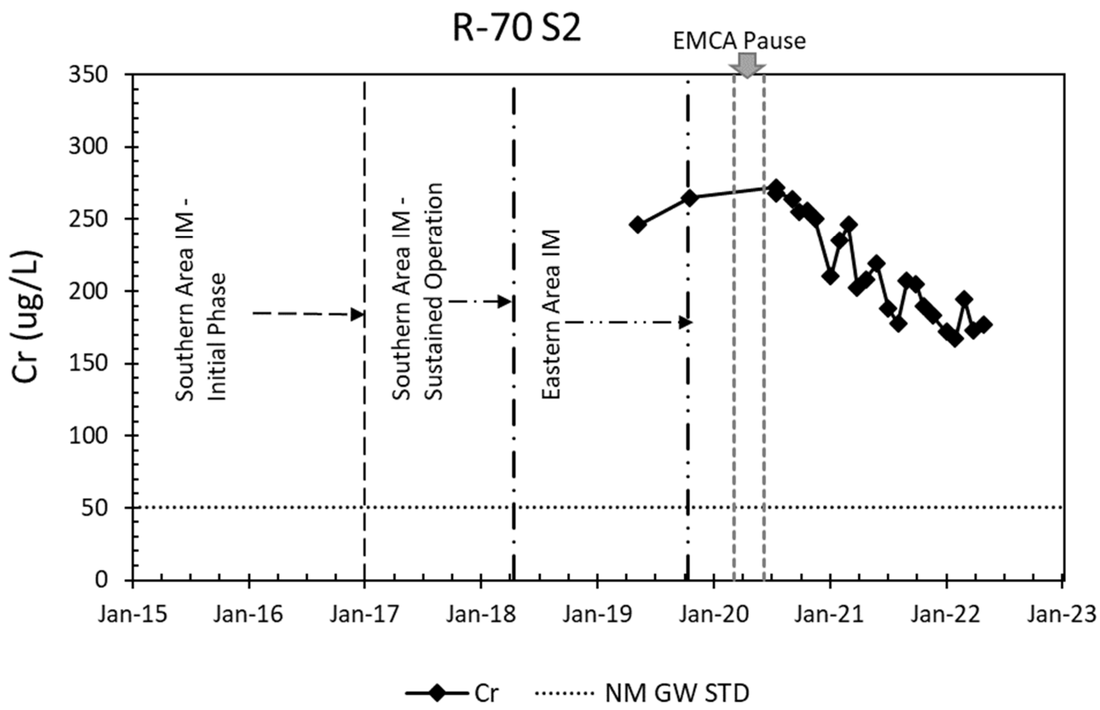



**Figure 3.3-9 Chromium concentrations over time at R-70 screen 2**

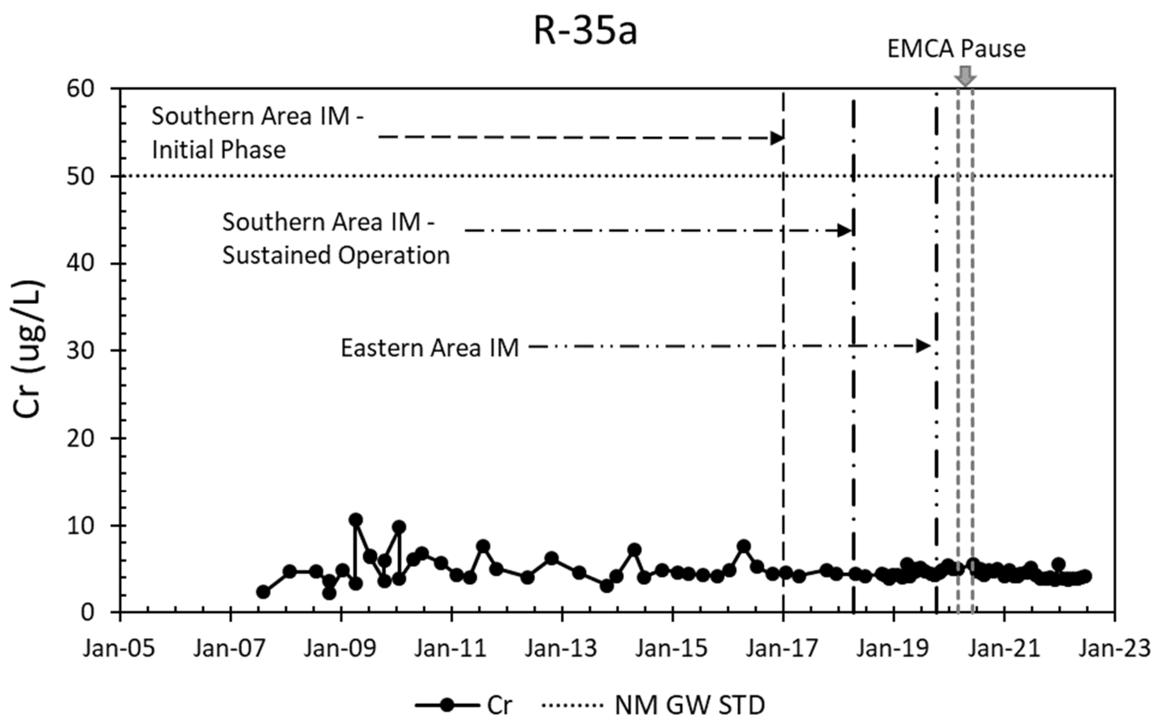



**Figure 3.3-10 Chromium concentrations over time at R-35a**

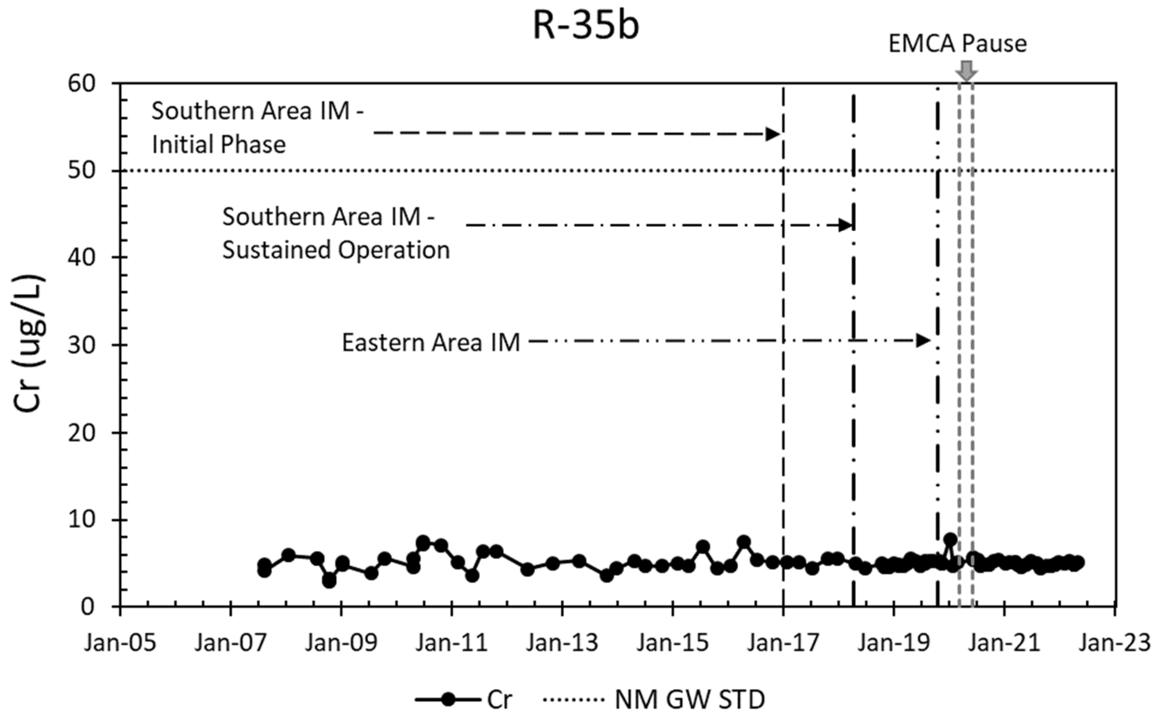



**Figure 3.3-11 Chromium concentrations over time at R-35b**

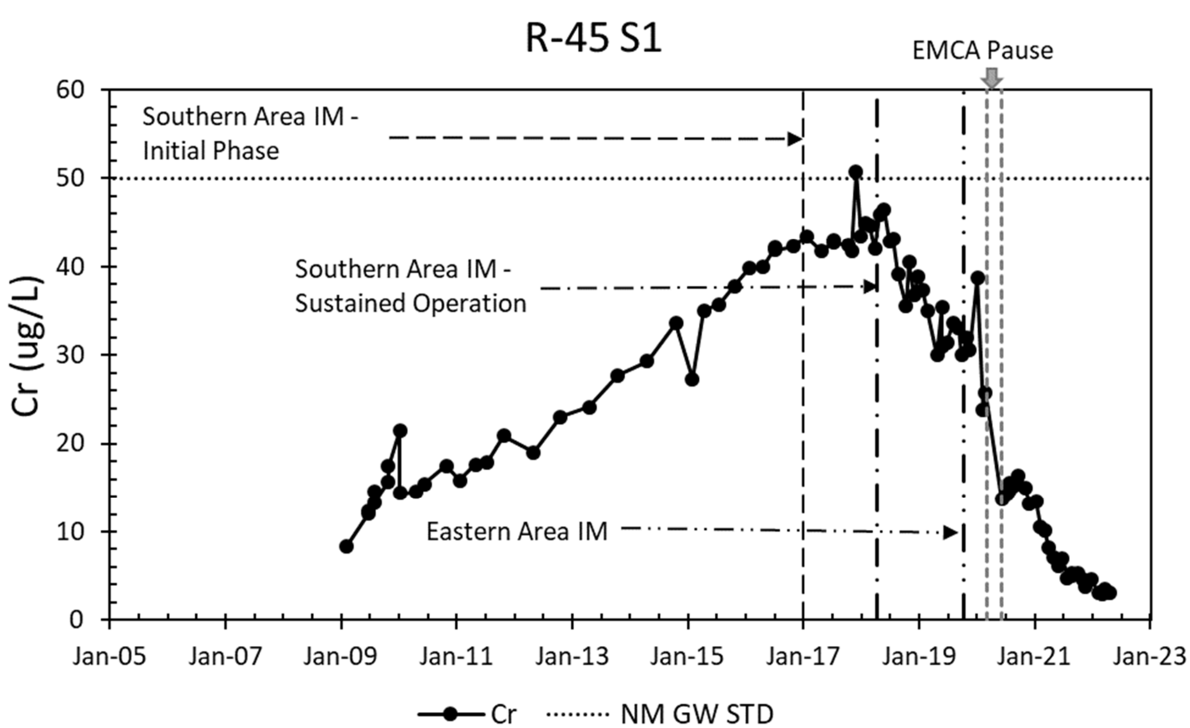



**Figure 3.3-12 Chromium concentrations over time at R-45 screen 1**

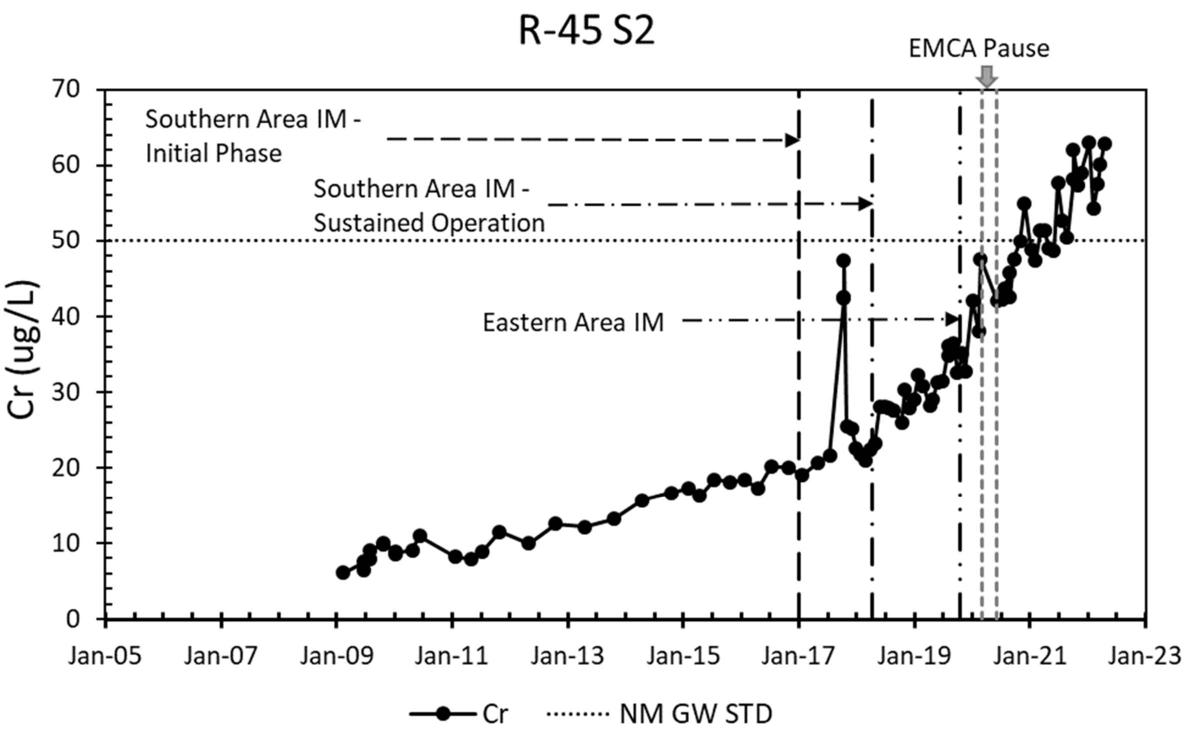



**Figure 3.3-13 Chromium concentrations over time at R-45 screen 2**

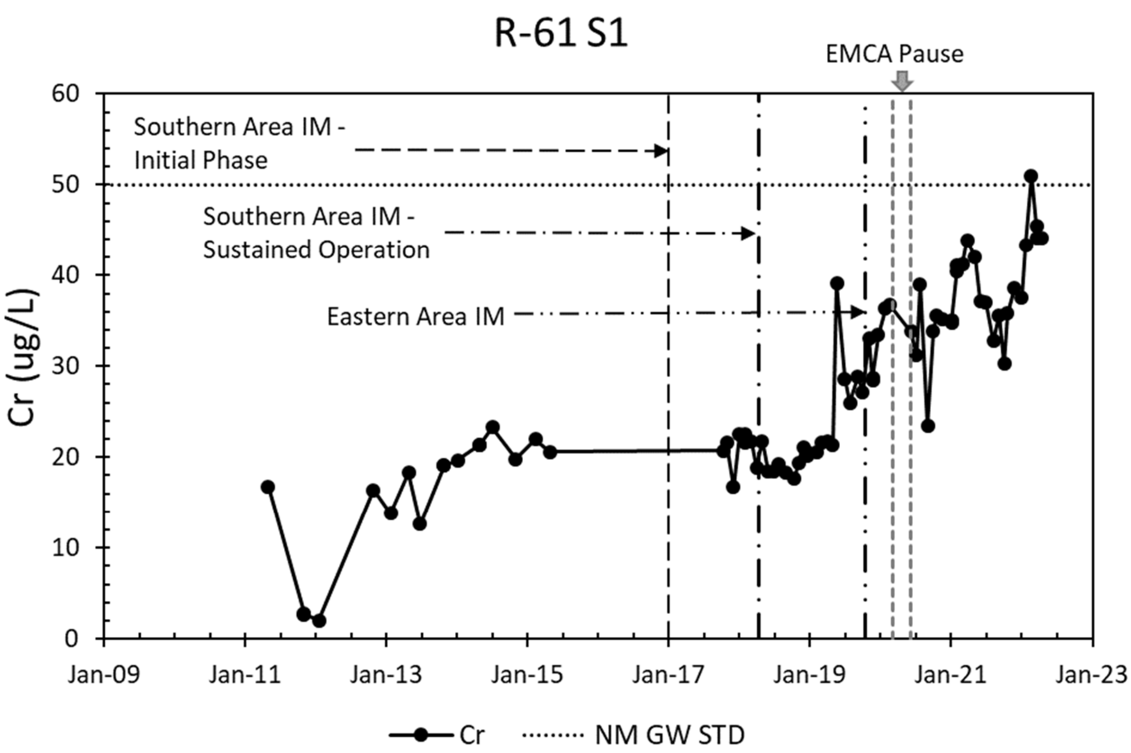
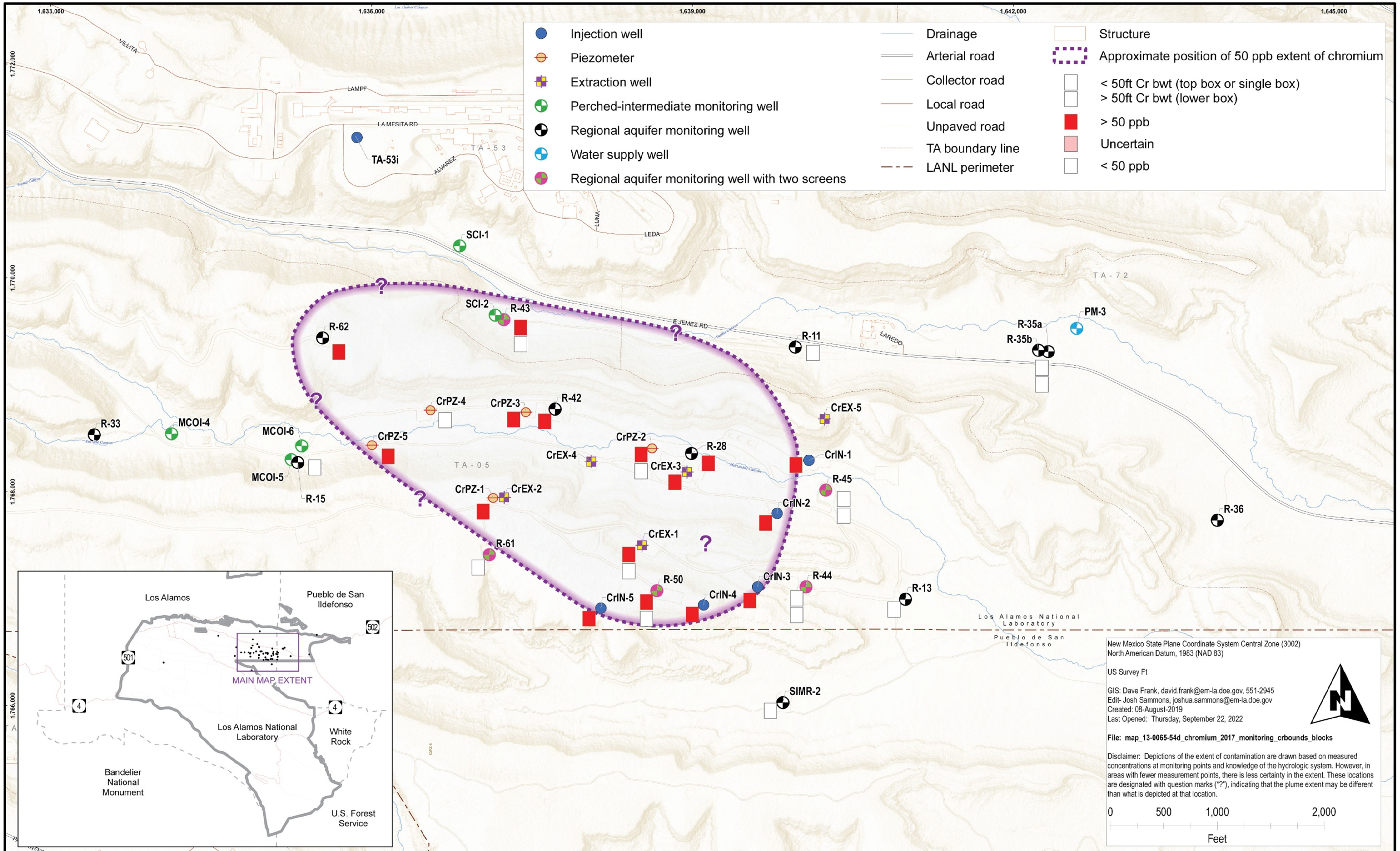
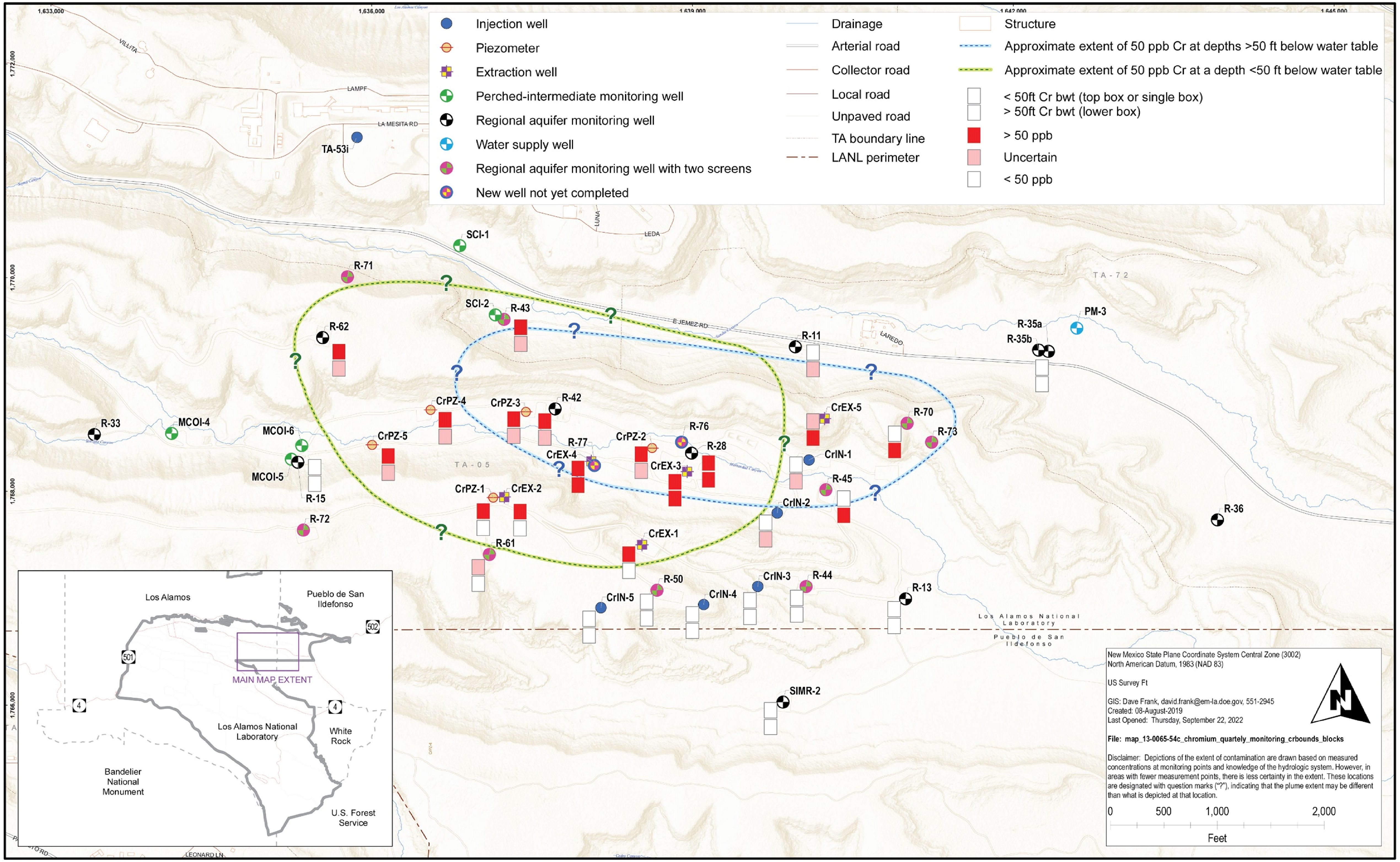



**Figure 3.3-14 Chromium concentrations over time at R-61**




Notes: The rectangular symbols by each well indicate whether chromium concentrations in January 2017 (the initiation of the IM) were above (red fill) or below (white symbol) the 50-µg/L standard. Data from two-screen wells available at the time (R-43, R-44, R-45, and R-50), the tandem sampling points CrPZ-2a and 2b and R-35a and b, and two screens in extraction well CrEX-1 are represented by two stacked rectangles, with the upper and lower rectangles denoting the upper and lower screens, respectively.

**Figure 3.3-15 Plume depiction published in the 2015 IM work plan for chromium plume control**




Notes: A shallow (<50 ft below the water table) and deep (>50 ft below the water table) plume is presented, along with rectangular boxes indicating the presence or absence of chromium concentrations at 50 µg/L or greater. In contrast to Figure 3.3-15, shallow and deep indicators are included at all wells, not just two-screen wells. Uncertainties in the depth of the plume are indicated with pink rectangles.

**Figure 3.3-16 Present-day plume depiction, along with symbols depicting the level of chromium concentration (>50 or <50 µg/L) at sampling locations**

**Table 3.3-1**
**Chromium Sampling Information Used to Develop the Pre-IM and Present-Day Chromium Plumes**

| Well Screen | Screen Length (ft) | Shallow or Deep Screen | Current Depth from Water Table to Top of Screen (ft) | Current Depth from Water Table to Bottom of Screen (ft) | Present Day Shallow: Is chromium concentration >50 ppb within the top 50 ft below the water table? | Present Day Deep: Is chromium concentration >50 ppb at depths greater than 50 ft below the water table? | Present Day: Comments | Jan 2017 Shallow: Is chromium concentration >50 ppb within the top 50 ft below the water table? | Jan 2017 Deep: Is chromium concentration >50 ppb at depths greater than 50 ft below the water table? | Jan 2017: Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| Monitoring Wells | | | | | | | | | | |
| R-11 | 22.8 | Shallow | 11.7 | 34.5 | no | no | Significant concentration above background, but never >50 ppb. Given its proximity to deeper plume, and to R-70 with inverted concentration profile, there could perhaps be higher concentrations at greater depths. Deep plume labeled as "no" but uncertain. | no | —[a] | Significant concentration above background but never >50 ppb. |
| R-13 | 60.4 | Deep | 113.9 | 174.3 | no | no | Low (background) chromium concentrations in deep screen; somewhat less certain about shallower points, but very likely low since R-13 is downgradient from R-44, which rarely exceeded 20 ppb in screen 1. | — | no | Low (background) chromium concentrations in deep screen. |
| R-15 | 61.7 | Shallow | −20.7 | 41.0 | no | no | Cr present but low concentrations (<20 ppb). Screen extends more than 41 ft below the water table (bwt), so despite some uncertainty, it is very likely that both shallow and deep concentrations are < 50 ppb. | no | — | Chromium present, but low concentrations (<20 ppb). Screen extends more than 41 ft bwt. |
| R-28 | 23.8 | Shallow/ Deep | 36.2 | 60.0 | yes | yes | High chromium (before amendments deployment) in screen that spans the shallow and deep intervals. Very likely to be >50 ppb both above and below the 50-ft bwt elevation. | yes | — | High chromium (before amendments deployment) in screen that spans the shallow and deep intervals. |
| R-35a | 49.1 | Deep | 218.1 | 267.2 | — | no | Background concentrations in R-35a (deep screen). | — | no | Background concentrations in R-35a (deep screen). |
| R-35b | 23.1 | Shallow | 31.2 | 54.3 | no | — | Background concentrations at R-35b (shallow screen). | no | — | Background concentrations at R-35b (shallow screen). |
| R-36 | 23.0 | Shallow | 14.9 | 37.9 | no | no | Background concentrations in shallow screen, no indication of deep plume this far east. | no | — | Background concentrations in shallow screen. |
| R-42 | 21.1 | Shallow | 3.5 | 24.7 | yes | yes | High chromium in screens near the water table. Likely to be above 50 ppb at depths >50 ft bwt, but this is uncertain due to lack of data. | yes | — | High chromium in screens near the water table. |
| R-43 S1[b] | 20.7 | Shallow | 2.9 | 23.6 | yes | — | 200 ppb in shallow screen. | yes | | 150 ppb in shallow screen in 2016. |
| R-43 S2[c] | 10.0 | Deep | 67.9 | 77.9 | — | no | Rising concentrations, nearing 50 ppb but perhaps leveling off in both screens. No concentration >50 ppb, but some uncertainty on whether there is a zone >50 ppb somewhere >50 ft. Deep plume contour should be drawn very close to R-43. | — | no | Low concentrations (~10 ppb) in 2016. |
| R-44 S1 | 10.0 | Shallow | 9.7 | 19.7 | no | — | Chromium present but <20 ppb before IM, reduced to low levels by injection. | no | — | Chromium present but <20 ppb in shallow screen. |
| R-44 S2 | 9.9 | Deep | 100.0 | 109.9 | — | no | Concentrations <10 ppb. | — | no | Concentrations <10 ppb in deep screen. |
| R-45 S1 | 10.0 | Shallow | 5.7 | 15.7 | no | — | Concentrations approached 50 ppb but are now low due to IM operations. | no | — | Concentrations ~35–40 ppb in shallow screen in 2016. |

**Table 3.3-1 (continued)**

| Well Screen | Screen Length (ft) | Shallow (or Deep Screen | Current Depth from Water Table to Top of Screen (ft) | Current Depth from Water Table to Bottom of Screen (ft) | Present Day Shallow: Is chromium concentration >50 ppb within the top 50 ft below the water table? | Present Day Deep: Is chromium concentration >50 ppb at depths greater than 50 ft below the water table? | Present Day: Comments | Jan 2017 Shallow: Is chromium concentration >50 ppb within the top 50 ft below the water table? | Jan 2017 Deep: Is chromium concentration >50 ppb at depths greater than 50 ft below the water table? | Jan 2017: Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| R-45 S2 | 20.0 | Deep | 100.5 | 120.5 | — | yes | Recent concentrations >50 ppb. | — | no | Concentration ~20 ppb in deep screen in 2016. |
| R-50 S1 | 10.0 | Shallow | 4.0 | 14.0 | no | — | Concentrations previously >100 ppb, but more recently reduced due to IM actions. | yes | — | Concentrations >100 ppb in shallow screen. |
| R-50 S2 | 20.6 | Deep | 111.6 | 132.2 | — | no | Background chromium concentrations. No indication of deep plume. | — | no | Background chromium concentrations. No indication of deep plume. |
| R-61 S1 | 10.0 | Shallow | 16.7 | 26.7 | no | — | Concentrations in screen < 50 ppb but rising, perhaps due to IM activity. Trends suggest shallow contour line should be very close to R-61. | no | — | Concentrations in screen ~20 ppb in 2016. |
| R-61 S2 | 20.6 | Deep | 111.1 | 131.7 | — | no | Low chromium concentrations but screen is compromised geochemically. Instead, lack of deep plume in nearby wells suggests that there is not a deep plume at R-61. | — | | Low chromium concentrations but screen is compromised geochemically. |
| R-62 | 20.7 | Shallow | 7.9 | 28.6 | yes | no | Recent chromium >300 ppb in existing (shallow) screen, which extends to 36 ft bwt. It is possible that deep contamination is present; this is unconfirmed, but uncertain. | yes | — | Concentration ~200 ppb in existing shallow screen, which extends to 36 ft bwt. |
| R-70 S1 | 41.0 | Shallow | 11.3 | 48.5 | no | — | Concentrations are above background but below 50 ppb (~20 ppb), similar to upgradient well R-11. | — | — | Data not yet available in Jan 2017. |
| R-70 S2 | 20.5 | Deep | 88.6 | 107.2 | — | yes | Concentrations as high as 200 ppb. | — | — | Data not yet available in Jan 2017. |
| R-71 S1 | 20.0 | Shallow | 12.2 | 30.4 | no | — | Initial results suggest low concentration. Not yet enough data to be definitive, but low concentrations are consistent with the current plume depictions. | — | — | Data not yet available in Jan 2017. |
| R-71 S2 | 10.3 | Deep | 70.9 | 80.2 | — | no | Initial results suggest low concentration. Not yet enough data to be definitive, but low concentrations are consistent with the current plume depictions. | — | — | Data not yet available in Jan 2017. |
| R-72 S1 | 20.0 | Shallow | 31.3 | 51.3 | no | — | Initial results suggest low concentration. Not yet enough data to be definitive, but low concentrations are consistent with the current plume depictions. | — | — | Data not yet available in Jan 2017. |
| R-72 S2 | 20.0 | Deep | 101.3 | 121.3 | — | no | Initial results suggest low concentration. Not yet enough data to be definitive, but low concentrations are consistent with the current plume depictions. | — | — | Data not yet available in Jan 2017. |
| SIMR-2 | 20.4 | Shallow | 12.8 | 33.2 | no | no | Background chromium concentration. | no | — | Background chromium concentration in shallow screen. |
| Piezometers | | | | | | | | | | |
| CrPZ-1 | 10.0 | Shallow | 3.7 | 13.7 | yes | no | Initial concentrations 400 ppb; still above 50 ppb. CrEX-2 very close by. Contamination vertical profile very likely to be the same as CrEX-2. | yes | — | Initial concentrations 400 ppb. |
| CrPZ-2a | 10.0 | Shallow | 1.9 | 11.9 | yes | — | Concentrations consistently >50 ppb. | yes | | Concentrations at ~100 ppb. |
| CrPZ-2b | 20.0 | Shallow/ Deep | 35.3 | 55.3 | — | yes | Some concentrations >50 ppb but not consistently so. The well is in a portion of the plume where one would expect concentrations >50 ppb deeper in the aquifer based on other nearby wells, but at this location the deep plume is uncertain. | — | — | Unknown |

**Table 3.3-1 (continued)**

| Well Screen | Screen Length (ft) | Shallow (or Deep Screen | Current Depth from Water Table to Top of Screen (ft) | Current Depth from Water Table to Bottom of Screen (ft) | Present Day Shallow: Is chromium concentration >50 ppb within the top 50 ft below the water table? | Present Day Deep: Is chromium concentration >50 ppb at depths greater than 50 ft below the water table? | Present Day: Comments | Jan 2017 Shallow: Is chromium concentration >50 ppb within the top 50 ft below the water table? | Jan 2017 Deep: Is chromium concentration >50 ppb at depths greater than 50 ft below the water table? | Jan 2017: Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| CrPZ-3 | 20.0 | Shallow | 3.7 | 23.7 | yes | yes | Concentrations >300 ppb at the relatively shallow screen. Assume concentrations >50 ppb at greater depths, but there is some uncertainty. | yes | — | Concentrations >300 ppb at the relatively shallow screen. Assume concentrations >50 ppb at greater depths, but there is some uncertainty. |
| CrPZ-4 | 20.0 | Shallow | −0.6 | 19.4 | yes | no | Concentrations about 100 ppb; uncertain whether deeper plume exists here. | no | — | Low concentrations in initial samples. |
| CrPZ-5 | 20.0 | Shallow | 5.3 | 25.3 | yes | no | Concentrations rising and currently >300 ppb. Screen is shallow. Uncertain whether the deeper plume exists here. | yes | — | Concentrations ~200 ppb in shallow screen. |
| **Extraction Wells** | | | | | | | | | | |
| CrEX-1 | 50.0 | Shallow | −7.2 | 42.8 | yes | — | Values as high as 200 ppb before IM; current values ~50 ppb. | yes | — | Values as high as 200 ppb before IM. |
| CrEX-1 | 20.0 | Deep | 72.8 | 92.8 | — | no | Low concentrations before plugging the well above this screen. | — | no | Low concentrations before plugging the well above this screen. |
| CrEX-2 | 50.0 | Shallow/ Deep | 16.2 | 66.2 | yes | no | Concentrations 200−300 ppb; screen extends to depths >50 ft. However, stratified sampling before final construction constrains the depth of the plume to about 50 ft. | — | — | No information in Jan 2017. |
| CrEX-3 | 39.2 | Shallow | 11.1 | 50.3 | yes | yes | Concentrations between 150 and 200 ppb, well close to R-28 where concentrations are high. Screen reaches 50 ft depth bwt. Very likely that concentrations >50 ppb are shallow and deeper. | yes | — | Concentration data available mid-2016. Screen extends to ~50 ft, indicating a shallow screen. |
| CrEX-4 | 35.0 | Shallow | 9.9 | 44.9 | — | yes | Concentration of 350 ppb in individual sampling of upper screen. | — | — | No information in Jan 2017. |
| CrEX-4 | 20.0 | Deep | 54.9 | 74.9 | yes | — | High concentrations near plume centroid. Deep screen: 540 ppb during individual sampling. | — | — | No information in Jan 2017. |
| CrEX-5 | 60.0 | Shallow/ Deep | 12.2 | 66.6 | no | yes | Concentrations 250−300 ppb when the well was drilled (CrIN-6); screen extends deeper than 50 ft bwt. Profile likely to be similar to R-70 (inverted), but there is some uncertainty about the shallower depths. | — | — | No information in Jan 2017. |
| Injection Wells | | | | | | | | | | |
| CrIN-1 | 50.0 | Shallow/ Deep | 12.5 | 62.5 | no | yes | Concentrations between 50 and 100 ppb before injection. injection has reduced chromium concentration to very low value. Screen extends below 50 ft bwt. Assume concentration at or >50 ppb at depth based on nearby R-45 screen 2 results, but this is uncertain. | yes | — | Mid-2016 − Pre-IM concentrations of 80−90 ppb. No information suggesting higher concentrations at greater depths. |
| CrIN-2 | 50.0 | Shallow | 3.4 | 53.4 | no | yes | Concentrations at 100 ppb before injection. Injection has reduced chromium concentration to very low value. Screen extends below 50 ft bwt. Assume concentration at or >50 ppb at depth based on nearby R-45 screen 2 results, but this is uncertain. | yes | — | Mid-2016 − Concentrations up to 100 ppb. |

**Table 3.3-1 (continued)**

| Well Screen | Screen Length (ft) | Shallow (or Deep Screen | Current Depth from Water Table to Top of Screen (ft) | Current Depth from Water Table to Bottom of Screen (ft) | Present Day Shallow: Is chromium concentration >50 ppb within the top 50 ft below the water table? | Present Day Deep: Is chromium concentration >50 ppb at depths greater than 50 ft below the water table? | Present Day: Comments | Jan 2017 Shallow: Is chromium concentration >50 ppb within the top 50 ft below the water table? | Jan 2017 Deep: Is chromium concentration >50 ppb at depths greater than 50 ft below the water table? | Jan 2017: Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| CrIN-3 | 50.0 | Shallow | 1.5 | 49.3 | no | no | Concentrations ~50 ppb before injection. Injection has reduced chromium concentration to very low value. This, along with proximity to R-44, with shallow and deep concentrations <50 ppb, suggests deep concentrations <50 ppb. | yes | — | Concentrations ~50 ppb before injection in late 2016. |
| CrIN-4 | 50.0 | Shallow | 4.0 | 53.1 | no | no | Concentrations ≤50 ppb before injection. Injection has reduced chromium concentration to very low value. This, along with proximity to R-50, suggests deep concentrations <50 ppb. | yes | — | Mid-2016 – Concentrations up to 100 ppb.[d] |
| CrIN-5 | 60.0 | Shallow | 2.6 | 57.0 | no | no | Concentrations <100 ppb before injection. Injection has reduced chromium concentration to very low value. This, along with proximity to R-50, suggests deep concentrations <50 ppb. | yes | — | Concentrations >50 ppb in early 2017.[d] |

Note: Pink shading indicates chromium concentration is uncertain.

[a] — = Not applicable.

[b] S1 = Screen 1,

[c] S2 = Screen 2.

[d] Indicates a different level of understanding in January 2017 than today.

# Appendix A

*Preliminary U.S. Department of Energy Responses to the New Mexico Environment Department's Comments Provided in the July 8, 2020, and August 26, 2021, Notices of Disapproval*

The New Mexico Environment Department (NMED) has issued the two notices of disapproval (NODs) listed below. These NODs will be fully addressed once activities described in this work plan are completed. The U.S. Department of Energy Environmental Management Los Alamos Field Office will engage NMED in technical team meetings to discuss the outcome of the characterization activities.

The performance monitoring reports listed below have received NODs because NMED has identified a disparity in the assessment and management of IM performance. This has resulted in the propagation of unresolved issues from previous submittals.

- NOD issued on July 8, 2020, on the "Semiannual Progress Report on Chromium Plume Control Interim Measure Performance, January through June 20"
- NOD issued on August 26, 2021, on the "Semiannual Progress Report on Chromium Plume Control Interim Measure Performance, July through December 2020 Report"

This appendix includes preliminary dispositioning of comment responses to the two NODs listed above.

**Response to the Notice of Disapproval Comments on the Semiannual Progress Report on Chromium Plume Control Interim Measure Performance, January through June 2020, September 2021 Los Alamos National Laboratory EPA ID#NM0890010515, HWB-LANL-20-080 Dated July 9, 2021**

## INTRODUCTION

To facilitate review of this response, the New Mexico Environment Department's (NMED's) comments are included verbatim. The U.S. Department of Energy (DOE) Environmental Management Los Alamos Field Office responses follow each NMED comment. These responses are the initial disposition of the comment responses, with final responses to be provided once activities proposed in the "Chromium Interim Measures and Characterization Work Plan" have been completed.

## GENERAL COMMENTS

### NMED Comment

***1. <u>General Comment No. 1</u>***

*One of the original objectives of the chromium plume control interim measures (IM) is to capture and remove the hexavalent chromium mass from the regional aquifer[1]. Subsequent IM work plans stressed achieving and maintaining the 50-ppb downgradient chromium plume edge within the laboratory boundary over a period of approximately three years[2]. Since 2016, DOE's IM has removed approximately 300 pounds of chromium from the regional aquifer. As of April 2021, this three-year period elapsed and adjustments to the system performance are now necessary to refocus the IM to its original goal of mass removal via groundwater extraction to build toward the final remedy.*

*In their Response, DOE makes the case that injection does little to form and maintain hydraulic control along the laboratory's southern boundary because no discernable mound developed over the three-year period, and that cones of depression may develop around extraction wells. This apparent uncertainty indicates a lack of insight regarding the IM performance. To evaluate the IM performance, NMED mapped synoptic water level data from the January through June 2020 monitoring period by triangulation of the three-point problem across all monitoring wells – a standard contouring method in geology and hydrogeology. (NMED's maps and the three-point problem triangulation technique can be shared with DOE in technical team meetings.) The results show the ineffectiveness of injection to reverse the hydraulic gradient and the effectiveness of the IM extraction operation to form an effective cone of depression. The ability to detect this has been previously hampered by DOE's mapping technique of the regional aquifer water table surface at the chromium site. (See NMED's original and follow-up specific comment 4 in Attachment 1 and below, respectively).*

*DOE cites the tracer test results from CrIN-4 to be proof that injection aided by extraction is the cause of the reversal of the natural hydraulic gradient. The tracer detection at CrEX-1 is evidence that extraction, not injection, is the more effective remediation mechanism because it is physically impossible to reverse the natural hydraulic gradient via injection without a discernable mound. It is more plausible that an injection-dominated operation would have simply diluted the tracer mass to*

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[1] LANL, April 30, 2013, IM Work Plan for the Evaluation of Chromium Mass Removal. 35819.

[2] LANL, April 2018, Chromium Plume Control IM Performance Monitoring Work Plan (LA-UR-18-23082). 38423.

*below detection in all directions from the injection source, specifically downgradient away from CrEX-1 and R-50. This would result in a non-detectable concentration at CrEX-1. Considering that wells are more efficient in extraction than injection and that the injection operation resulted in no discernable mounding, NMED concludes that it is the extraction operation that is the more plausible cause of the reversal of the hydraulic gradient and the tracer detection at R-50 and CrEX-1. Consequently, there is a need to adjust the plume control IM to focus on chromium mass removal as stated in the 2013 work plan[1] and related documents[3,4,5].*

*DOE must hold technical team meetings with NMED to discuss and implement the needed changes to the IM system to achieve all objectives formulated since 2013. As part of the readjustment to the IM system, NMED requires DOE to conduct the required capture zone and flooding zone analyses and numerical groundwater modeling[6]. This work must be conducted with NMED's input. Technical details shall be discussed in a pre-submittal meeting prior to the submittal of the next semi-annual IM progress report.*

**DOE Response**

1. The principal objective of the interim measure (IM) continues to be hydraulic control of the chromium plume, with an incidental benefit of mass extraction. Once nature and extent of the chromium plume are sufficiently defined through activities identified in the "Chromium Interim Measures and Characterization Work Plan," the presumptive pump-and-treat remedy principal objective will be mass extraction. The 2013 work plan that NMED has referenced (LANL 2013, 241096) examined the feasibility of mass extraction, including hydraulic property characterization, to support the 2015 IM work plan (LANL 2015, 600458). The 2015 work plan defines the IM objectives, not the 2013 work plan.

   DOE has implemented synoptic potentiometric surface maps based on the three-point method at the water table surface and at depth, based on the available data. Hydraulic gradient reversal and evidence of mounding will be included in the capture/flood zone analyses. Potentiometric surface maps will be published quarterly to evaluate IM impacts. The impacts of injection will be evaluated based on both data-driven and model-supported analyses based on U.S. Environmental Protection Agency (EPA) guidance (https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NRMRL&dirEntryId=187788).

   DOE will engage NMED in the interpretation of both data- and model-based analyses before quarterly and annual report submittal. These discussions will form the technical basis for identifying alternative extraction and injection scenarios that optimize system operations. DOE proposes that updates to this semiannual report be consolidated into future quarterly/annual reports. All updates will be discussed with NMED technical experts before publication and submittal.

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[3] NMED, January 25, 2013, Response letter to the Proposal to Submit IM Work Plan for Chromium Contamination in Groundwater (HWB-LANL-12-022). 35714.

[4] LANL, September 27, 2013, Response to the Approval with Modification for the IM Work Plan for the Evaluation of Chromium Mass Removal-Status Report for Pumping Test at Well R-42. (LA-UR-13-27 463). 36020.

[5] LANL, March 31, 2014, Summary Report for the 2013 Chromium Groundwater Aquifer Tests at R-42, R-28, and SCI-2 (LA-UR-14-21642). 36274.

**NMED Comment**

2. ***General Comment No. 2***

*DOE's response does not address this comment and defers a meaningful resolution to an uncommitted future meeting. However, NMED's comment focused on content missing from the Report, which needs resolution now, not in future. NMED's approval of the document cited by DOE was contingent upon DOE involving NMED in the pre-submittal meetings to guide the direction of the IM, on whether to incorporate modeling results in each semi-annual report, and whether monitoring wells are responding favorably.[6] DOE has not held pre-submittal meetings with NMED concerning the content of the Report. DOE also has not addressed the fact that R-45 S2 is not responding favorably to the injection operation, which NMED identified in the Comments in Attachment 1.*

*The initial chromium concentration trends at R-45 S2 suddenly surged once CrIN-3 injection began on May 23, 2018, and then again immediately following CrIN-1 and CrIN-2 injection on November 13, 2019, to a point where chromium now exceeds the 50 ug/L NMED groundwater standard (Attachment 2). The initial trend indicates this should not have occurred until 2035. This assertion is supported by the opposite response in chromium concentration at R-45 S1. DOE's exclusion of NMED in the IM planning and reporting has resulted in the deterioration of IM monitoring quality, effectiveness, and purpose since NMED approved the work plan in December 2019[7]. Of specific concern to NMED is DOE's inability to monitor and capture the chromium it has pushed down to R-45 S2 because there are no IM infrastructure wells completed at that depth. To rectify this, DOE must implement NMED's modifications to the continued operation and reporting of the IM including submitting numerical modeling scenario runs to evaluate extraction capture zones and injection flood zones (see General Comment No. 1 above). Cessation of all injection operations should take place over a semi-annual monitoring period at a minimum to evaluate whether the trends recorded at R-45 reverse.*

**DOE Response**

2. Capture and flood zone analyses will be based on the multiple lines of evidence approach presented in the EPA guidance document as presented in the Chromium Interim Measure and Characterization Work Plan (https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NRMRL&dirEntryId=187788). Alternative extraction and injection strategies will be simulated, using simulation scenarios developed in collaboration with technical experts at NMED. The simulation results will provide the technical basis for decision-making associated with alternative IM operations and the need for additional monitoring locations. Cessation of any IM operations needs to be carefully evaluated to avoid any unintended consequences and will be determined in collaboration with NMED based on the aforementioned analyses.

   DOE proposes that updates to this semiannual report be consolidated into future quarterly/annual reports.



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[6] NMED, October 3, 2019, Approval Letter to the Semiannual Progress Report on Chromium Plume Control Interim Measure Performance. 39134. "*Applicability and incorporation of numerical modeling for semiannual reporting might be appropriate to guide IM operational strategies if performance monitoring wells are not responding favorably. The use of modeling for the chromium project should be further discussed with NMED in presubmission meetings for future semiannual progress reports*."

[7] NMED, January 7, 2019, Approval Chromium Plume Control Interim Measure Performance Monitoring Work Plan. 38745.

## SPECIFIC COMMENTS

### NMED Comment

***1a. <u>Specific Comment No. 1a</u>***

*DOE's response does not adequately address NMED's comment on this issue because no facts are provided to support their opinions. Contrary to NMED's observations, DOE does not consider PM-3 pumping and the year-long continual injection at CrIN-3, CrIN-4, and CrIN-5 that commenced on May 23, 2018, as possible causes of the corresponding sudden decrease and increase in chromium concentration trends detected at R-45 S1 and R-45 S2, respectively. There is evidence that supports there being a relationship between the documented changes in chromium concentration at R-45 and the commencement of CrIN-3, CrIN-4, and CrIN-5 injections (Attachment 2). CrIN-3 and CrIN-4 are about 1,100 and 1,500 feet southwest of R-45, respectively, and chromium that is not detected by the existing monitoring well network is likely present at depth between CrIN-3/CrIN-4 and R-45 because vertical delineation in this area has not been demonstrated by DOE. While tracers from these injection wells have not been detected at R-45, it is not necessary for the injected water to reach the monitoring well to cause the observed change in trends because the injection will displace groundwater between the two points toward the distant monitoring well and it is highly likely that the tracer would have been diluted to the point of non-detection before it traveled that distance. Consequently, NMED does not concur with the DOE statement: "The increased rate of change in chromium concentration in screen 2, starting in the 2018 timeframe, began before any continuous IM operational activities in the area…".*

*NMED also does not concur with the statements DOE provided to explain the responses shown in Attachment 2. The site data in the form of measured water levels, vertical gradients, and an absence of overlying perched groundwater, indicate infiltration is not present in this area as "recent post-Cr infiltration" toward R-45 S2. As a result, NMED does not agree that the decreasing chromium at R-45 S1 is due to "young water with very low chromium concentrations infiltrating in that area", but instead to the IM injection operations. DOE must perform capture zone and flood zone analyses and conduct groundwater modeling to provide insight to the R-45 chromium concentration trends and NMED will consider whether to allow the injection strategy at CrIN-1, CrIN-2, and CrIN-3 to continue. Technical details must be discussed in a technical team meeting prior to the submittal of the next semi-annual IM progress report.*

***1b. <u>Specific Comment No. 1b</u>***

*NMED does not find DOE's response to this comment acceptable because DOE deflects the request to reference past submittals, a future publication and meetings and does not consider the fact that the work plan requires aquifer properties and migration rates from tracer tests be provided in the IM performance reports. Each submittal is an update on the performance of the chromium plume IM and that the tracer detections DOE discussed in the Report are recent and ongoing. Additionally, the required aquifer properties are not presented in the previous report, when two tracers were documented to have been first detected. DOE acknowledged in its response that tracer responses provided information on "…how fast injected water has migrated through the regional aquifer…" and "…have been used to estimate effective porosity in the regional aquifer…". The information is required by the work plan for inclusion in the semiannual reports[2] including the Report.*

*NMED does not concur with DOE's statement that tracer responses do not provide information that can be used to directly quantify aquifer properties or to calculate groundwater flow velocity. DOE's reference to natural flow is moot because the purpose of the Report is to evaluate the performance of the plume control IM not natural flow patterns. As such, DOE must provide the aquifer parameters for* *each tracer detection in the revision as required by the work plan. NMED also does not concur with DOE that aquifer parameters like hydraulic conductivity are best inferred from aquifer tests. Hydraulic conductivity is not directly derived from aquifer tests but is indirectly calculated from transmissivity that is directly derived from aquifer tests. Additionally, DOE typically performs single-well pumping tests, not well interference aquifer tests that test the formation hydraulics between wells. Single well pumping tests do not provide meaningful storativity values as DOE claimed in the Response, and hydraulic conductivity is an estimate for conditions around the well only. In this case, the cited tracer test results would provide better aquifer information than the single-well pumping tests. Consequently, DOE must calculate hydraulic conductivity from each tracer test for inclusion in the revision and provide a comparison to all the proximal pumping tests as requested in the original Comments (Attachment 1).*

*DOE contradicts itself in the final paragraph of its response "The paper also summarizes effective/flowing porosity estimates and flow distribution estimates (i.e., cumulative fractions of flow occurring in cumulative fractions of total porosity) that have been derived from the tracer and geochemical signature responses to date. DOE must provide the manuscript of that paper and discuss the findings in a future technical team meeting." The inclusion of this information in the report revision is required[2]. DOE must adequately address NMED's request to characterize aquifer properties (e.g., effective porosity, hydraulic conductivity) and provide the travel time, groundwater flow velocity and radius of influence between injection wells and performance monitoring wells for each tracer detection. These data will be used to refine the chromium groundwater model and the capture zone and flood zone analyses to evaluate the actual effects DOE's IM injection operations are having on the groundwater hydraulics of the regional aquifer (see General Comments Nos. 1 and 2 above).*

**DOE Response**

1a. DOE has prepared a white paper that analyzes concentration trends at R-28, R-45, CrIN-1, and CrIN-2, both before IM operations and after IM operations had been initiated. This white paper, which has been shared with NMED, does support the statement that concentration trends at R-45 screen 2 were increasing before IM operations. However, DOE agrees that IM operations have moved chromium mass already located between screens 1 and 2 to the measurement point at screen 2. Based on the analyses presented in the white paper, DOE agrees that concentrations in R-45 screen 1 are due to injection operations, as other analytes (e.g., chloride, sulfate, etc.) show an injection water signature.

The work proposed in the "Chromium Interim Measures and Characterization Work Plan" (e.g., capture and flood zone analyses, alternative extraction and injection strategies), will provide the technical basis for decision-making associated with IM operations. The results and potential alternative extraction and injection strategies will be discussed with technical experts at NMED in technical team meetings before the submittal of quarterly and annual reports.

DOE proposes that updates to this semiannual report be consolidated into future quarterly/annual reports.

1b. DOE proposes that the historical tracer test results (as referenced above) be documented in upcoming quarterly/annual reports associated with IM performance monitoring. Interpretation of these data will be discussed with NMED in a pre-submittal before their publication in the quarterly and annual reports and will include the results provided in the manuscript. If additional tracer testing is conducted, then these results will be published in the quarterly and annual performance monitoring reports.

The "Chromium Interim Measures and Characterization Work Plan" proposes two types of characterization activities that address NMED concerns with hydraulic property characterization: (1) large-scale aquifer testing; and (2) high-resolution stratified flow measurements (using an electronic borehole flow meter). Both of these activities are expected to complement existing hydraulic property data.

**NMED Comment**

***2a. Specific Comment No. 2a***

*NMED does not accept DOE's response to this comment because the comment does not pertain to the upcoming semiannual report, but to the semiannual report in review. NMED requires a revision to the Report with the narrative that DOE claimed in its response will address NMED's comment concerning verification that "…injection water had been pushed sufficiently upgradient of each injection well during IM operations conducted before the EMCA pause. Furthermore, by the end of the pause, upgradient groundwater with higher concentrations of chromium had not migrated back into portions of the plume where the injection wells are located." The numerical groundwater model is to be updated in accordance with the October 3, 2019, approval letter[6] with the recent tracer detection results to provide a more suitable tool to assess DOE's claim. As stated in the original comment, if DOE cannot support this statement, it must be removed from the Report in the revision.*

***2b. Specific Comment No. 2b***

*NMED does not accept DOE's response to this comment because the "conceptualization" of the fate and transport of chromium from injection to extraction wells is based on conjecture whereas the required updated modeling conducted in accordance with the October 3, 2019, approval letter[6] would provide a more tenable response. DOE's conceptualization provides insights to complexities, such as the effects dispersion and layering, have on an advancing front that a model would be best suited to explain. Additionally, DOE again defers the response to the upcoming semiannual report even though NMED's comment pertains to the semiannual report in review.*

*DOE's conceptualization that it is reasonable to expect the chromium mass from R-50 S1 and CrIN-4 will be captured by CrEX-1 is unsupported because the tracer in CrIN-4 was first detected in CrEX-1 in late 2018 as shown by Figure 3.2-29 of the Report, yet the chromium mass recovered did not correspondingly increase but decreased over the same timeframe as shown in Figure 3.2-20 of the Report. It is more reasonable that the two-dimensional movement of the tracer and chromium from CrIN-4 to CrEX-1 would arrive at similar times in similar mass (flux) with respect to the initial mass. Additionally, if dilution were a factor in explaining the lack of chromium response at CrEX-1, the tracer would also have been equally diluted. However, the arrival of the tracer at CrEX-1 exhibited a classic breakthrough curve, not a decreasing trend as with the chromium. In the revision, DOE must provide a quantitative evaluation of the mass injected to the mass recovered for both the original tracer and chromium at CrIN-4 to CrEX-1 using the updated numerical groundwater model or remove the "conceptualization" from the revised Report.*

*It is plausible that injection is interfering with ability to accurately measure recovered chromium via dilution. Table 2.1-3 of the Report indicates that DOE bases the chromium mass recovery on averages from field screening using HACH colorimetric field test method. This method only has a resolution of ±10 ug/L and is not suitable for an accurate mass recovery estimate. DOE should be collecting and submitting samples for laboratory analysis to determine the chromium mass removal. DOE must use laboratory analytical data and more frequent measurements to make the recovery estimates more accurate through integration over time and not averages.*

*NMED does not concur with DOE's statement "that the decreasing Cr concentration trends in the extraction wells also reflect a removal of Cr at a faster rate than it is being replenished by upgradient sources". The Report indicates only 296.6 pounds of chromium mass have been removed from 169,991,100 gallons of groundwater extracted since the fourth quarter of 2016. The plots in Attachment 3 positively show that the chromium mass recovery rate is directly proportional to the volume extracted, that the recovery rate has not increased but is quite linear, and that the source has had nothing to do with the reported recovery rates. It is more likely that over time, the extraction wells are pulling clean water from storage outside the plume and from the IM injection operations as the radius of influence increases. This would dilute the chromium concentration at the point of recovery. A revised model run should have been used to verify this statement before its inclusion in the Report. DOE must include such a model run to demonstrate the validity of their statement that chromium mass recovery is occurring at a faster rate than the upgradient source can provide or remove the statement from the revision. It should be noted that chromium concentration increases with depth at CrEX-4 and R-70 and the recovery wells do not fully penetrate the chromium plume. Additionally, with the effective removal of the two monitoring wells that formerly monitored the highest chromium concentrations presumably near the source(s) from the groundwater monitoring plan, the source areas are no longer being monitored.*

**DOE Response**

2a. The activities proposed in the "Chromium Interim Measures and Characterization Work Plan" will provide the technical basis for identifying injection water flow directions. Both data- and model-based analyses will be used to support this analysis. Several data sources, including data derived from tracer tests, are used to support numerical model development. These data sources will be documented and consolidated in the quarterly/annual performance monitoring reports. Updates will be discussed with NMED technical experts before their publication.

2b. The capture/flood zone analysis described in the "Chromium Interim Measures and Characterization Work Plan" will provide the technical basis to assess groundwater flow directions at R-50 and CrIN-4. Tracer test results will also be used to support capture and flood zone delineation, based on the 2008 EPA guidance document (https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NRMRL&dirEntryId=187788). DOE proposes that updates to this semiannual report be consolidated into future quarterly/annual reports, after consultation with NMED technical experts as part of pre-submittal meetings.

As NMED suggests, simulations will be used to identify flow patterns that could transport mass toward extraction wells. Additionally, the effects of dilution from clean injection water will also be evaluated. DOE proposes to document these analyses in the quarterly/annual reports.

DOE will be using analytical methods to estimate mass removal as outlined in the "Chromium Interim Measures and Characterization Work Plan." The frequency of measurement will be established collaboratively with NMED.

**NMED Comment**

***3. Specific Comment No.3***

*DOE incorrectly states in their response that no specific graphical presentation format was discussed with NMED. In fact, NMED provided DOE explicit written directions in what was required in the approval letter[8] and again verbally during the subsequent May 21, 2020, meeting. Proper hydrographs prepared as NMED originally directed and as discussed over the phone on February 9, 2021, and in a follow-up email on February 25, 2021, must be included in the revision, not only in the subsequent reports. DOE must comply with these requirements and include the proper hydrographs in the revision.*

**DOE Response**

3. DOE will comply with the hydrograph specification for all future reporting. DOE proposes that NMED requests for revisions be published in future quarterly/annual reports to consolidate consistent historical data analyses executed per NMED input and guidance.

**NMED Comment**

***4a. Specific Comment No. 4a***

*The three-point problem is the standard contouring method in geology and hydrogeology. In the response, DOE did not address the issue of the 5830-foot closed contour line between CrEX-4 and CrEX-1 in Figure 3.3-1 of the Report as requested in the Comments (Attachment 1). Data do not support this interpretation because all adjacent wells have water table elevations higher than 5830 feet. Conversely, contour lines must be present when data supports such a need such as DOE's omission of a 5830-foot contour line between R-13 and R-44 S1. This is another mapping error that needs to be corrected in the revision. Contour lines generated by automated geostatistical software must have values that lie within the upper and lower data limits to constrain the interpolation otherwise errant results can occur because the software method's inability to deal with data gaps and anomalies.*

*The methodology used by DOE to construct the water table contour map in the Report is not appropriate as indicated by the facts provided in the preceding paragraph and the contrast in results obtained by NMED using the three-point problem. The three-point problem satisfies the method requirement for mapping the water table surface of the regional aquifer[9] whereas kriging does not necessarily align with industry standards, nor does it provide any more consistency over time than other methods of interpolation. While kriging honors the data at the measurement locations, it assumes a normal distribution of the data and no trend to the data, and an autocorrelation of the data. Consequently, kriging is prone to misrepresent the groundwater flow system if not properly constrained to the data limits and if the assumptions are not satisfied. Kriging is also highly prone to interpolation artifacts that cause excessive smoothing of the surface, abrupt changes in the interpolated surface, and overemphasis of isolated observations. The occurrence of the 5830-foot contour line in Figure 3.3-1 of the Report is an example of this problem. Because kriging assumes no trend by default, it is not programmed to contour groundwater elevations, which obviously have a trend i.e., the groundwater flow direction. Hence, kriging and other computer-generated geostatistical interpolation methods must be used with caution and only by a highly experienced hydrogeologist.*

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[8] NMED, May 6, 2020, Approval with Modification Semiannual Progress Report on Chromium Plume Control Interim Measure Performance, July Through December 2019.

[9] NMED, August 31, 2016, Ground Water Discharge Permit, Los Alamos National Laboratory Underground Injection Control Wells Discharge Permit-1835. 37680.

If DOE desires to use kriging to model the water table surface, DOE must provide the following in the revision:

- Gridding resolution (delta x and delta y) to interpolate and to contour the data
- Spatial autocorrelation
- Variogram and its nugget effect, range, and sill
- Drift
- Interpolation error

In the revision, DOE must demonstrate how the above kriging criteria is suitable to model the water table surface configuration for each map presented in the Report. The maps provided in the Report do not represent accurately the IM impacts on the regional aquifer water table. As a result, an accurate assessment of IM effectiveness is not possible.

In addition, use of monthly averages instead of actual synoptic data is not consistent with the industry standard[10], does not comply with permit requirements[9], and does not provide better understanding of the long-term changes in the water table caused by IM activities because averages incorporate water table fluctuations due to other phenomena such as barometric influences and pumping that skew contouring results. Use of synoptic data from continuously recording pressure transducers eliminate such interferences specifically when strategic timeframes such as early morning weekends and holidays are selected. NMED does not concur with DOE’s claim that the low hydraulic gradient requires the use of averages. This statement did not consider NMED’s comment that a series of tenable water table maps using manual triangulation i.e., the three-point problem and synoptic water table elevation data were prepared by NMED (see General Comment No. 2), which demonstrates that use of monthly averages to map the flat water table are not necessary.

The mapping requirements include only 14 wells[9]. This excludes R-28, R-48, R-70, R-35b and R-15. Data from these wells and SIMR-2, one of the 14 wells required by the DP but is typically omitted by DOE from the water table maps, are as instrumental in understanding long-term changes to the water table from IM activities. These data must be incorporated into the mapping for the revision and all future submissions.

Two quarterly water table contour maps are required in each semiannual report as required by the approved work plan: “The maps presented in the semiannual reports will be the same as those presented in quarterly reports provided under discharge permit (DP)-1835”[2]. DOE incorrectly stated in their response that “The language in the Performance Monitoring Work Plan is intended to state that the single water-table map that will be included in each semiannual performance monitoring report will be the map from the most recent DP-1835 quarterly report.” The work plan is clear that multiple maps that correspond to the quarterly maps are to be presented in each semiannual report. DOE must include, at a minimum, the two most recent quarterly water table maps of the regional aquifer in the revision.

***4b <u>Specific Comment No. 4b</u>***

NMED does not concur with DOE’s statement that “subtle depressions in the water table can also be caused by local areas of present-day recharge from the vadose zone resulting in the appearance of water-table “mounding” and an adjacent depression”. NMED contoured the same data for the May 1, 2018, baseline water table map, which is synoptic, but using the three-point problem method



[10] ASTM-D6000-15 Standard Guide for Presentation of Water-Level Information from Groundwater Sites.

*and did not come up with the depression. DOE's position that a subtle, but measurable, depression occurs in the water table around a mound is unlikely. Other factors that also do not support DOE's conceptualization of local areas of recharge from the vadose as the source for mounding in the regional aquifer water table include:*

- *No drilling records corroborate the presence of a perched aquifer or other vadose zone water is present in the area to provide this recharge,*
- *No presence of significant vertical downward hydraulic gradients in the regional aquifer that would result from recharge and the resulting mounding hypothesized by DOE to occur along the water table, and*
- *No mounding is observed from sustained engineered IM injection operations along the regional aquifer water table, or at least not at detectable magnitudes by the existing monitoring well network.*

*It is not plausible that natural recharge in a desert environment such as Los Alamos that must infiltrate through more than 900 feet of vadose zone could provide more flux to the water table than the injection operations of the IM. It is more plausible that there is an irregularity in DOE's wellhead reference survey data and/or that DOE mis-contoured the water table because of its incorrect use of monthly water level averages, errant and anomalous data, and by employing an automated geostatistical contouring method. DOE must select a more representative timeframe for the baseline water table map and recontour the map for inclusion into the revision using the three-point problem. The mapping must be undertaken with NMED involvement and approval before the figure will be accepted for inclusion in the revision.*

**DOE Response**

4a The "Chromium Interim Measures and Characterization Work Plan" describes the use of the three-point method and will be used to generate synoptic water table maps as recommended by NMED (see DOE response to NMED Comment 1). DOE proposes that the requested revisions be provided in the quarterly reports, which can be inclusive of historical data. Any updates will be discussed with NMED technical experts before their publication.

If transient IM operations in the future dictate that more than one point in time is needed for any quarterly time period, then additional synoptic potentiometric surface maps will be generated accordingly.

4b DOE has discontinued its use of automated geostatistical contouring tools. Potentiometric surface maps will be generated using the three-point method for the historical data. The revised maps are to be published in the quarterly/annual reports, which can be inclusive of historical maps.

**NMED Comment**

***5 <u>Specific Comment No. 5</u>***

*NMED does not accept DOE's response to this comment because DOE appears to avoid the need to revise the Report by deferring that "going forward" future reports will address this issue. DOE must revise the Report, regardless of future submittals to address NMED's concern. This requirement is especially significant considering that the monitoring period covered by the Report is inclusive of the effects the COVID shutdown may have had on the vertical gradients at the chromium plume that would be of interest to any serious hydrogeological analysis. Steps to resolution for this comment were discussed during the February 9, 2021, telephone correspondence between NMED and N3B.*

*DOE must use the agreed upon approach in the revision of the Report as well as in all forthcoming semiannual reports.*

**DOE Response**

5. DOE proposes that the revisions be published in upcoming quarterly reporting to consolidate historical analyses, providing consistency in both historical and future reporting.

**NMED Comment**

***6. Specific Comment No. 6***
*NMED's comment did not pertain to CrEX-5, CrIN-1, and CrIN-2 operations, but those along the laboratory's southern boundary at R-50. Based on the various work plans*[1,2]*, DOE must maintain the operations at CrEX-1 as an extraction well and CrIN-5 and possibly CrIN-4 (if it can be shown it is not a cause of the increasing chromium at R-45 S2 through modeling) as injection wells to continue the hydraulic control along the laboratory's boundary until a final remedy is implemented.*

**DOE Comment**

6. DOE appreciates the clarification and proposes that the capture/flood zone analyses and predictive simulations described in the "Chromium Interim Measures and Characterization Work Plan" will provide the technical basis for alternative IM extraction and injection strategies.

   DOE proposes that updates to this semiannual report be consolidated into future quarterly/annual reports. All updates will be discussed with NMED technical experts before publication and submittal.

**NMED Comment**

***7. Specific Comment No. 7***
*NMED requires a system-wide evaluation using capture zone and flood zone analyses and updated model simulations to provide insight to the IM performance. At a minimum, NMED believes the IM injection operations at CrIN-1, CrIN-2 and CrIN-3 are the cause of the unfavorable response at R-45 S2 (see Specific Comment No. 1a).*

**DOE Comment**

7. As stated in the DOE response to Specific Comment No. 6, the capture/flood zone analyses described in the "Chromium Interim Measures and Characterization Work Plan" will provide a quantitative evaluation for alternative IM extraction and injection strategies. A qualitative analysis of the cause for chromium concentration increases at R-45 screen 2 has already been shared with NMED. DOE proposes that both of these analyses be documented in the quarterly/annual performance monitoring reports. All updates will be discussed with NMED technical experts before publication and submittal.

## REFERENCES

LANL (Los Alamos National Laboratory), April 2013. "Interim Measures Work Plan for the Evaluation of Chromium Mass Removal," Los Alamos National Laboratory document LA-UR-13-22534, Los Alamos, New Mexico. (LANL 2013, 241096)

LANL (Los Alamos National Laboratory), May 2015. "Interim Measures Work Plan for Chromium Plume Control," Los Alamos National Laboratory document LA-UR-15-23126, Los Alamos, New Mexico. (LANL 2015, 600458)

**Response to the Notice of Disapproval Comments on the Semiannual Progress Report on Chromium Plume Control Interim Measure Performance, July through December 2020 March 2021 Los Alamos National Laboratory, EPA ID#NM0890010515, HWB-LANL-21-019 Dated August 26, 2021**

## INTRODUCTION

To facilitate review of this response, the New Mexico Environment Department's (NMED's) comments are included verbatim. The U.S. Department of Energy (DOE) Environmental Management Los Alamos Field Office responses follow each NMED comment. These responses are the initial disposition of the comment responses, with final responses to be provided once activities proposed in the "Chromium Interim Measures and Characterization Work Plan" have been completed.

## GENERAL COMMENTS

### NMED Comment

1. ***General Comment No. 1***
   *The April 2018 Chromium Plume Control Interim Measure Performance Monitoring Work Plan (Work Plan)[1] states that a secondary objective of the interim measures (IM) "is to hydraulically control plume migration in the eastern downgradient portion of the plume" and that the "objective of the performance monitoring and associated reporting is to collect, evaluate, and report on the performance of the IM… to guide adjustments in the distribution and rates of extraction and injection." Unlike the IM extraction operation that has demonstrated the rapid development of a sustained cone of depression that serves to control plume migration, the activation of CrIN-3, CrIN-4, and CrIN-5 in 2018 has not produced similar evidence of hydraulic control via injection such as the manifestation of a defined hydraulic mound along the Los Alamos National Laboratory – Pueblo de San Ildefonso boundary.*

   *NMED's potentiometric surface mapping shows that the IM injection and extraction operations do not affect groundwater levels in the deeper screened wells where chromium contaminated groundwater is known to be present at R-28, CrEX-4, and R-70 S2 (see Specific Comments Nos. 7 and 8 below). The fact that the IM is not fulfilling all work plan objectives, and that NMED has identified unfavorable responses at R-45 S2, requires that DOE adjust the distribution and rates of IM extraction and injection. It is essential for DOE to hold technical team meetings with NMED to implement the needed changes to the IM system to achieve all objectives formulated since 2013[2,3]. The following general and specific comments provide substantial insights that support adjustment of the IM operation.*

### DOE Response

1. Alternative extraction and injection strategies will be identified based on the capture and flood zone analyses and predictive simulations that will be performed as part of the "Chromium Interim Measures and Characterization Work Plan." The analysis will address chromium capture at depth. Simulation scenarios will be identified in collaboration with NMED, and results will be documented in

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[1] LANL, April 2018, Chromium Plume Control Interim Measures Performance Monitoring Work Plan (LA-UR-18-23082). 38423.

[2] LANL, April 30, 2013, IM Work Plan for the Evaluation of Chromium Mass Removal. 35819

[3] LANL, May 26, 2015, Interim Measures Work Plan for Chromium Plume Control (LA-UR-15-23126). 37125.

quarterly/annual reports. Results will be discussed with NMED technical experts in technical team meetings.

**NMED Comment**

2. ***General Comment No. 2***

*Section XXIII of the Consent Order requires pre-submittal meetings be held for IM reports for NMED and DOE to review and discuss the content, technical approach, and/or results to be presented in the document. During the pre-submittal review, NMED is to identify issues or concerns with the technical approach and/or results that would preclude NMED approval.*

*Following review of the first IM progress report submitted in 2018, NMED sent DOE a letter with the subject "Approval, Annual Progress Report on Chromium Plume Control Interim Measure Performance" (2019 Letter)[4]. NMED's general comment 1 attached to the 2019 Letter stated, "numerical groundwater model and capture/flooding zone width calculations must be included in future IM performance reports to sufficiently assess the IM performance." DOE's response to this comment was "Applicability and incorporation of numerical modeling for semiannual reporting might be appropriate to guide IM operational strategies if performance monitoring wells are not responding favorably. The use of modeling for the chromium project should be further discussed with NMED in pre-submission meetings for future semiannual progress reports." NMED's approval of DOE's response is for the numerical groundwater modeling requirement only, and the capture/flooding zone width calculations requirement set by NMED must be included in each report. The approval of this statement does not relieve DOE from conducting the modeling requirement, especially considering that NMED has identified an unfavorable response in R-45 S2 (see Specific Comment No. 3 below). This unfavorable response constitutes the type of technical issue both DOE and NMED are required to discuss in pre-submittal meetings. DOE needs to revise the Report to include the required numerical modeling and capture zone and flood zone analyses to better assess the IM performance. This work is to be conducted under the strict technical direction of NMED.*

**DOE Response**

2. The capture/flood zone analyses described in the "Chromium Interim Measures and Characterization Work Plan" support the evaluation of IM influences on flow pathways within the regional aquifer. In addition, predictive simulations that examine alternative injection and extraction strategies will be identified in collaboration with NMED. DOE proposes that these results, as well as any revisions to already published analyses, be consolidated into future quarterly/annual performance monitoring reports. The results of these analyses will be discussed with NMED in pre-submittal meetings before their publication.



[4] NMED, October 3, 2019, Approval Letter to the Semiannual Progress Report on Chromium Plume Control Interim Measure Performance. 39134

**SPECIFIC COMMENTS**

**NMED Comment**

1. ***Section 2.1.3 Chromium Mass Removal, Page 3.***
   ***DOE Statement:*** *"Although specific rates and efficiencies of chromium mass removal from extraction wells are not explicit IM objectives, they may provide insights into observed plume response. Table 2.1-3 presents estimates for chromium mass removal for the IM to date."*

   ***NMED Comment:*** *Table 2.1-3 indicates that the hexavalent chromium concentrations upon which the mass removal estimates have been based are derived from use of a HACH colorimetric field meter. NMED operates two such field meters and has found results from both agree with one another but provide an overestimate of actual hexavalent chromium concentration compared to laboratory analytical results of the same sample. To provide accurate chromium mass removal estimates via sampling, DOE should collect and submit groundwater samples to a NELAP-accredited commercial laboratory that employs defensible U.S. EPA Methods for total dissolved chromium. Details shall be discussed in a technical team meeting prior to the next semi-annual IM progress report is submitted (see General Comment Nos. 1 and 2).*

**DOE Response**

1. DOE will be using analytical methods to estimate mass removal estimates as outlined in the "Chromium Interim Measures and Characterization Work Plan." The frequency of measurement will be established collaboratively with NMED, with results documented in the quarterly/annual reports.

**NMED Comment**

2. ***Section 3.2.1 Water-Quality and Tracer Results, Page 4.***

A. ***DOE Statement:*** *"This timeline is indicated as January 2017, representing the approximate beginning of consistent operations along the southern portion of the plume."*

   ***NMED Comment:*** *Based on previous chromium plume control IM reports, the timeline for actual continuous extraction and injection IM operations at the southern area began in May 2018. In addition, the Work Plan states that the initial operational phase of the IM that involves pumping at CrEX-1, CrEX-2, and CrEX-3 and injection into CrIN-3, CrIN-4, and CrIN-5 was to start in 2018. In the revision, correct this statement to reflect the accurate date when continuous IM injection and extraction operations began (i.e., May 23, 2018).*

B. ***DOE Statement:*** *"The decreasing trend in chromium concentrations in extraction well CrEX-1 shown in Figure 3.2-20 is attributable to mixing with treated water primarily from CrIN-4 which is supported by the tracer results presented later in this section. The decreasing trend in chromium concentrations in CrEX-2 shown in Figure 3.2-21 is likely associated with capture of groundwater with lower chromium concentrations."*

   ***NMED Comment:*** *DOE must support this statement using the required capture zone and flood zone mapping, and numerical groundwater modeling (see General Comment 2 and Specific Comments Nos. 3 and 5).*

*C.* ***DOE Statement:*** *"The decreasing and current chromium concentrations at R-50 S1 provide the basis for the estimated plume extent at the 50 µg/L concentration as depicted in the various plume maps in this report (e.g., Figure 1.0-1)."*

***NMED Comment:*** *While this conforms with the Work Plan, one monitoring point (R-50) does not necessarily constitute the basis to state that the plume has been effectively "pushed" in a favorable direction, i.e., toward the extraction wells. Actual measured recovery of the chromium mass in CrEX-1 is not evident and could suggest that DOE's statement is not supported. DOE must model this scenario to determine where the chromium plume edge likely migrated and/or why the mass has not manifested at CrEX-1 due to the IM injection operations. DOE must support this statement with the required capture zone/flood zone mapping and groundwater modeling (see General Comment 2 and Specific Comments Nos. 3 and 5).*

*D.* ***DOE Statement:*** *"Monitoring well SIMR-2 has consistently shown background chromium concentrations, with no increase in chromium concentrations that might have occurred because of either migration of chromium downgradient of the area affected by the IM or a hydraulic push caused by any of the upgradient injection wells."*

***NMED Comment:*** *The fact that chromium concentrations have not increased in a downgradient well from IM injection operations at CrIN-3, CrIN-4, and CrIN-5 in over a three-year period illustrates that the assertion DOE makes on page 6 is unsupported. As such, the injection operations likely have little, if anything, to do with the chromium plume extent being pushed upgradient. If the injection operations were effective at moving the chromium plume front upgradient to CrEX-1, it would also have moved it in all directions from the point of injection, especially downgradient. Consequently, one would expect to see chromium and tracer concentrations increase at a downgradient monitoring location from an effective injection operation front. This statement suggests it is the extraction operations, not the injection operations, that are the cause of the reversal in the hydraulic gradient and for the movement, if any, of the chromium plume extent at the R-50/SIMR-2 south boundary area (see Specific Comment No. 4). DOE must perform the required capture zone/flood zone mapping and groundwater modeling (see General Comment 2 and Specific Comments Nos. 3 and 5) to provide a more substantial line of evidence than water quality observations.*

**DOE Response**

2A. DOE concurs with NMED that sustained southern area operations were initiated in May of 2018. Given that several NMED comments will be addressed with activities described in the "Chromium Interim Measures and Characterization Work Plan," DOE proposes that future quarterly/annual reports include this correction.

2B. DOE concurs. The capture zone and predictive simulations described in the "Chromium Interim Measures and Characterization Work Plan" will provide the technical basis that either confirms or refutes these statements. DOE proposes that the results, including any corrections to previous semiannual performance monitoring reports, be published in the quarterly/annual performance monitoring reports.

2C. DOE concurs. The capture zone and predictive simulations described in the "Chromium Interim Measures and Characterization Work Plan" will provide the technical basis needed that either confirms or refutes these statements. DOE proposes that the results, including any corrections to previous semiannual performance monitoring reports, be published in the quarterly/annual performance monitoring reports.

2D. DOE concurs that additional analyses are needed to verify these statements. The capture zone and predictive simulations described in the “Chromium Interim Measures and Characterization Work Plan” will provide the technical basis needed that either confirms or refutes these statements. DOE proposes that the results, including any corrections to previous semiannual performance monitoring reports, be published in the quarterly/annual performance monitoring reports.

**NMED Comment**

***3. Section 3.2.1 Water-Quality and Tracer Results, Pages 4 and 5.***

***DOE Statement:*** *“Although the chromium concentrations in R-45 S1 had begun to drop before IM operations began in the eastern area, injection may have already increased the rate of decline in chromium concentrations. R-45 S2 did not show similar responses for the same period; chromium concentrations in this well screen have continued to increase. The increase in chromium concentrations predates eastern area IM operations (CrIN-1, CrIN-2, and CrEX-5) and is therefore likely unrelated to IM operations. Two working hypotheses for the presence of the deeper contamination in the R-45 and R-70 areas are being evaluated. One hypothesis is that the concentrations of chromium and related constituents observed in R-45 S2 reflect a deeper pathway that may originate further upgradient in the plume, possibly as far upgradient as the CrEX-4 area where a very similar geochemical signature is observed. Under that case, the increase in chromium in R-45 S2 simply represents plume variability. Other wells have historically shown similar patterns. A second hypothesis is that localized downward gradients caused by infiltration of young post-Cr-release effluent at locations further downgradient from locations where chromium originally infiltrated are at least partially responsible for the observed trend in R-45 S2.”*

***NMED Comment:*** *The data illustrated in the plot in the Attachment show that the decrease in the chromium concentrations at R-45 S1 correlate exactly with the startup of injection wells CrIN-3, CrIN-4, and CrIN-5 in May 2018 and was later accelerated by the startup of injection wells CrIN-1 and CrIN-2 in November 2019. Conversely, these data also show two distinct and pronounced increases in the chromium concentration at the deeper R-45 S2 that also correlate exactly with the commencement of both IM injection operations. Consequently, DOE’s assertion that the chromium concentration in R-45 began to decrease before IM operations began appears to be incorrect. In that statement, DOE only considers the eastern area IM, not the south area IM, which is the obvious cause of the first response shown in the Attachment. In the revision, DOE must provide a less biased discussion on this topic to include the southern area IM injection operations as the cause of the chromium responses observed at R-45 and to delete the “two working hypotheses” from the Report based on the following.*

*The “two working hypotheses” DOE provided in the Report to explain these responses are unsupported by hydraulic and chemical data. The plot in the Attachment shows a very high goodness of fit in the Excel-generated coefficient of determination R-squared value for the chromium detections measured in R-45 S2 in over 10 years of monitoring before IM began. This trendline represents the natural increase in the chromium concentration and, if extrapolated into the future, the chromium concentration should not have reached a concentration of 50 µg/L until February 2035, not December 2020. This contrasts with DOE’s first hypothesis that it is the result of an upgradient preferential pathway unless DOE can substantiate that a new release of chromium has occurred. The second hypothesis is also unsupported because there are no significant vertical hydraulic gradients in this portion of the regional aquifer as shown by the hydrographs in the Attachment, and infiltration to the regional aquifer at this location has no substantial source to be a factor in the downward movement of the chromium at R-45 (see Specific Comment No. 9).*

*Considering the screened zones of the injection wells and R-45 S1 are similar, it is obvious that injection water from the 2018 southern IM system startup either diluted or pushed the chromium concentration at R-45 S1 away from the point of injection. As a result, the chromium previously detected there can no longer be detected with the limited monitoring well network in this area, nor can it be recovered by the IM extraction wells. Additionally, the pressure exerted on deeper groundwater by the same injection operation appears to be the cause of the sudden increase at R-45 S2 over the same timeframe. Subsequent injection at CrIN-1 and CrIN-2 resulted in chromium now exceeding the New Mexico Water Quality Control Commission (WQCC) groundwater quality standard at R-45 S2. The response at R-45 S2 constitutes an unfavorable response in an interim measure performance monitoring well and indicates chromium is present at depth between R-45 and CrIN-1 through CrIN-4 above regulatory limits. This condition merits adjustments to the IM system[1].*

*In accordance with the Work Plan, NMED's concern of this unfavorable response requires readjustment of the entire IM injection operations. As part of the readjustment to the IM system, NMED requires DOE to conduct the required capture zone and flooding zone analyses and numerical groundwater modeling. This work must be conducted with NMED's input. The plan for the necessary adjustments must be included in the revision of the Report (see General Comment No. 2 above) and/or discussed with NMED in technical meetings. Cessation of all injection operations shall be part of the plan and consist of at least one semi-annual monitoring period to evaluate whether these trends reverse. Technical details must be discussed in a technical team meeting prior to the next semi-annual IM progress report is submitted (see General Comment Nos. 1 and 2).*

**DOE Response**

3. DOE has prepared a white paper that analyzes concentration trends at R-28, R-45, CrIN-1, and CrIN-2, both before IM operations and after IM operations had been initiated. This white paper, which has been shared with NMED, does support the statement that concentration trends at R-45 screen 2 were increasing before IM operations. However, DOE agrees that IM operations have moved chromium mass already located between screens 1 and 2 to the measurement point at screen 2. Based on the analyses presented in the white paper, DOE agrees that concentrations in R-45 screen 1 are due to injection operations, as other analytes (e.g., chloride, sulfate, etc.) show an injection water signature.

   The work proposed in the "Chromium Interim Measures and Characterization Work Plan" (e.g., capture and flood zone analyses, alternative extraction and injection strategies) will provide the technical basis for decision-making associated with IM operations. The results and potential alternative extraction and injection strategies will be discussed with technical experts at NMED in technical team meetings before the submittal of quarterly and annual reports.

**NMED Comment**

***4. Section 3.2.1 Water-Quality and Tracer Results, Page 6.***
***DOE Statement:*** *"Injected water is assumed to be spreading out from CrIN-4 in all directions, but the tracer arrivals at CrEX-1 and R-50 S1 are significant in that they demonstrate that injected water has moved significant distances against the natural gradient in this area of the plume when aided by pumping at CrEX-1."*

***NMED Comment:*** *The reversal of the natural hydraulic gradient and the arrival of injected water and tracers from CrIN-4 to R-50 S1 and CrEX-1 is due solely to the pumping at CrEX-1 and not the injection operation at CrIN-4 (see specific comment no. 2D). Groundwater level data at R-50 indicate*

*CrEX-1 pumping creates observable drawdown at R-50 located 450 feet away, but that no discernable rise in the water level occurs from CrIN-4 injection, also 450 feet away. (NMED's analysis of R-50 groundwater levels can be shared with DOE in technical team meetings). It is a physical impossibility that injection can reverse the natural hydraulic gradient enough to push water and tracers upgradient without the development of a mound sufficient to reverse the natural hydraulic gradient. In over three years of operation, the monitoring well network installed around the injection wells indicate that injection operations create no observable hydraulic mound. In contrast, the same monitoring well network shows that a large cone of depression is evident from IM extraction operations. Consequently, there is no evidence that the IM injection operations have been effective at achieving hydraulic plume control and reversing the hydraulic gradient. In accordance with the Work Plan, the effectiveness of the IM activities should be apparent following a three-year period. Based on the data collected by DOE, NMED concludes that injection operations at CrIN-3 through CrIN-5 do not provide plume control along the southern boundary and that adjustments should be made to the IM system (see General Comment Nos. 1 and 2 above). The revision shall strike out the phrase "when aided by pumping at CrEX-1" and replace it with "due to pumping at CrEX-1".*

**DOE Response**

4. The work proposed in the "Chromium Interim Measures and Characterization Work Plan" (e.g., capture and flood zone analyses), will provide the technical basis to identify the role of injection. DOE proposes that the results of these analyses be documented in quarterly/annual reports, updating historical analyses in future reports.

**NMED Comment**

***5. Section 3.2.1 Water-Quality and Tracer Results, Pages 6 – 8***

***A. DOE Statement (pages 6 and 7):*** *"Additional discussion of tracer and geochemical signature responses associated with IM system performance is presented in the pending Proceedings of the 2021 Waste Management Symposium (Reimus et al. 2021, 701331). This paper also summarizes effective/flowing porosity estimates and flow distribution estimates (i.e., cumulative fractions of flow occurring in cumulative fractions of total porosity) that have been derived from the tracer and geochemical signature responses to date. The relation of the tracer detections at R-50 S1 and R-44 S1, and the corresponding steady decrease in chromium concentrations, indicate that the effective flooding radius from injection at CrIN-4 and CrIN-3 has established the 50 µg/L edge of the plume close to and upgradient of R-50 and upgradient of R-44 (Figure 3.2-30)."*

***NMED Comment:*** *Information from tracer test breakthrough, such as travel times, groundwater flow velocity, and effective porosity should have been provided in the Report in accordance with the Work Plan. It is unacceptable for DOE to not include required data in the Report, and in lieu of this requirement, cite its own published work in the Report. In addition, NMED requires DOE to support this statement through capture/flood zone analyses and numerical groundwater flow modeling to evaluate the IM performance, specifically the alleged effective flooding radius from CrIN-3 and CrIN-4 injection operations to have established the 50 $\mu$g/L chromium plume edge (see General Comment Nos. 1 and 2 above). In the revision DOE must include the tracer test results presented in the referenced paper, specifically the aquifer porosity and flow estimates and the flooding radius. Inclusion of this information is a requirement of the Work Plan and subsequent agreements between NMED and DOE.*

**B. DOE Statement (page 8):** *"Some relatively simple calculations show that it is reasonable to expect that aquifer water would not drift back into the injection wells during the 98 days of the EMCA pause prior to sampling. In these calculations, it is assumed that flow into the injection wells is radial over the thickness of the screened intervals (using a flow porosity less than total porosity to account for preferential flow in more conductive layers), with a superimposed natural gradient flow that serves to limit the upgradient distance that injected water can travel before a stagnation point is encountered. The calculations depend on the assumed flow porosity and the natural gradient flow in the aquifer at the specific locations."*

***NMED Comment:*** *DOE must perform the required capture zone/flood zone calculations and groundwater modeling (see General Comment 2 and Specific Comments Nos. 3 and 5A) to provide a more substantial line of evidence than the "simple calculations" and assumptions provided to support this statement.*

**C. DOE Statement (page 8):** *"If a natural flow velocity of 0.27 m/day—which is consistent with the results of the borehole dilution tracer test in R-50 S1 in 2015 after assuming a flow porosity of 0.15—is superimposed on the radial injection flow, a stagnation point is predicted at about 70 m upgradient of the injection well. During the 135 days of injection, the leading edge of the injection water would therefore have moved approximately 32 m upgradient. In the subsequent 98 days of IM shutdown, the natural flow would move this leading edge about 26 m back downgradient (i.e., 98 × 0.27 m/day) toward the injection wells, leaving the untreated aquifer water about 6 m short of the injection wells at the time they were sampled."*

***NMED Comment:*** *The 0.27 m/day natural flow velocity provided in DOE's calculations is twice the value cited in a previous report concerning this parameter[5] and does not pertain to the flow velocity that would result from the injection operations in the upgradient direction against the natural flow velocity. To conduct a proper analysis of this scenario, DOE must perform the required capture zone/flood zone calculations and groundwater modeling (see General Comment 2 and Specific Comments Nos. 3 and 5A) as it is more likely that the CrIN-1 and CrIN-2 injection operations moved the chromium mass downgradient and vertically downward based on the response at R-45 S2 and that no discernable mound formed to reverse the natural hydraulic gradient prior to the shutdown. In addition, DOE's statement, if true, that chromium rebound was observed at R-50 (discussed on page 8) suggests that the IM performance there has not been as successful as DOE indicates because the IM had been operating much longer at the southern IM area than at the eastern area. The entire IM operation needs to be simulated in a groundwater model to address this issue. If DOE's calculation and narrative cannot be substantiated by the model, the narrative must be removed from the revision.*

**D. DOE Statement (page 8):** *"The relatively quick rebound in chromium concentrations observed in R-50 S1 also provides some indication that the current extent of the injection signal is near the R 50 area, meaning that there is likely a stagnation point not far upgradient of R-50 S1"*

***NMED Comment:*** *Figure 3.2-8 does not support this statement because the chromium concentration that immediately precedes and follows the "EMCA pause" timeline are about the same (specifically 26.4 μg/L on 3/4/2020 11:58 AM and 30.3 μg/L on 6/26/2020 12:44 PM). DOE must perform the required capture zone and flood zone calculations and numerical groundwater modeling (see General*

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[5] LANL, September 2012, Phase II Investigation Report for Sandia Canyon (LA-UR-12-24593). 35521.

*Comment 2 and Specific Comments Nos. 3 and 5A) to support this statement or delete it from the revision.*

**DOE Response**

5A. DOE concurs and proposes that the tracer results be documented in the quarterly/annual reports.

5B. DOE concurs that these statements require a stronger technical basis. The capture/flood zone analyses proposed in the "Chromium Interim Measures and Characterization Work Plan" will provide the technical basis for evaluating the influence of the essential mission critical activities (EMCA) pause. DOE proposes that these analyses be documented in future quarterly/annual reports, with results discussed with technical experts at NMED before publication.

5C. DOE concurs that capture/flood zone analyses and predictive simulations, as well as an assessment of the influence of secondary porosity, are needed to either confirm or refute these statements. Contaminant rebound is commonly observed in pump-and-treat operations because of contaminant diffusion into low-permeability zones. Once pump-and-treat operations are paused, back-diffusion from low-permeability zones often occurs.

DOE proposes that these analyses be documented in future quarterly/annual reports, with results discussed with technical experts at NMED before publication.

5D. As previously stated, the capture/flood zone analyses described in the "Chromium Interim Measures and Characterization Work Plan" will provide a technical basis that will either confirm or refute these statements. DOE proposes that the updates to this semiannual report be consolidated into future quarterly/annual reports. DOE will discuss the results of these analyses with NMED technical experts before their publication.

**NMED Comment**

***6. Section 3.2.2 Water-Level Data, Page 11.***

***A.*** ***DOE Statement:*** *"R-45 S1 and S2 are shown in Figure 3.2-38a. Some of the early data, particularly at R-45 S2 but S1 as well, are unreliable, leading to poor corrections and unclear trends, e.g., beginning in 2012 and persisting until around 2018."*

***NMED Comment:*** *In the revision DOE shall provide multiple lines of evidence that support the claim that the data from 2012 to 2018 are unreliable. The assumption that insufficient barometric compensation employed by DOE on these data does not constitute a valid line of evidence.*

***B.*** ***DOE Statement:*** *"The chromium IM infrastructure wells nearest to R-45 are CrIN-1, CrIN-2, CrEX-5, and CrEX-3 (Figure 1.0-1). Figure 3.2-38b shows the hydrograph for 2018–2020, highlighting the recent effects of the IM. As expected, R-45 is strongly affected by CrIN-1 and -2. Figure 3.2-38c shows a period from March to December 2020. At point A, the IM, which had been operating at most wells (CrEX-1, -2, and -5; CrIN-1, -2, -4, and -5), shutdown and water levels immediately declined at both R-45 S1 and S2 but substantially more at S1. It appears the combined effect of injection and extraction results in a greater water-level rise at S1 than at S2. This is likely due to two effects: (1) the combined effect of injection at CrIN-1 and -2 is greater at R-45 S1 (see Figure 3.2-38d, period C, where CrEX-5 is not operational but CrIN-1 and -2 turn on and off at the end of period C); and (2) the effect of extraction at CrEX-5 is greater on R-45 S2 (see Figure 3.2-38e, point D). Note that period B in Figure 3.2-38c does not have CrIN-2 pumping, suggesting that the dominance of injection over* *extraction at R-45 S1 is driven primarily by CrIN-1, not CrIN-2. Given the distances between R 45 and these wells, this is expected."*

***NMED Comment:*** *DOE discusses each chromium IM infrastructure well near R-45 except CrIN-3 in this narrative. The omission of CrIN-3 from this narrative is unacceptable, especially considering it was a comment made by NMED on the Previous Report. In the revision, DOE must include the influences of CrIN-3 operation on R-45 S1 and S2 and consider its obvious effects on chromium concentrations there as attested by the plot in the Attachment and to the similar and simultaneous hydrograph responses discussed in Specific Comment No. 11 and noted by "period B in Figure 3.2-38c". DOE must include the required capture zone and flood zone and numerical groundwater flow modeling analyses to substantiate this statement.*

**DOE Response**

6A. DOE will provide the lines of evidence needed to support this statement and discuss with NMED technical experts before publication. DOE proposes that the revisions to the semiannual reports be consolidated in future quarterly/annual reports.

6B. The capture/flood zone analyses described in the "Chromium Interim Measures and Characterization Work Plan" will address the influence of all of the injection wells within the regional aquifer. As previously stated, DOE proposes documenting revisions in future quarterly/annual reports. The results of the analyses will be discussed with NMED technical experts before publication.

**NMED Comment**

***7. Section 3.3 Water-Table Map, Page 13.***

***DOE Statement:*** *"Water-table maps are presented as an additional line of evidence in evaluating long-term changes in the water-table structure and associated with IM performance and interpreting potential changes in concentrations of key constituents in performance monitoring wells and piezometers. Long-term pumping and injection at IM infrastructure wells may affect the structure of the water table over time in the form of drawdown around extraction wells and mounding around injection wells. The changes in the water table, chromium concentrations, and tracer breakthrough provide insights into overall IM performance."*

***NMED Comment:*** *The water table maps presented in the Report are not sufficient to evaluate the changes in the water table from the IM extraction and injection operations because of the use of the automated kriging computer algorithm, incomplete dataset, and use of monthly averages in lieu of synoptic data (see Specific Comment Nos. 8, 9 and 10 below). Consequently, the mapping shown as Figures 3.3-1 and 4.0-2 in the Report are not representative of the IM performance and do not provide an accurate assessment of the effectiveness of the IM or impact to the structure of the water table. Using the three-point problem (see Specific Comment No. 8) and synoptic data of all the chromium group wells, NMED easily produced much more robust results that reveal the IM extraction operations impact on the water table configuration but not the IM injection operations. NMED's mapping also indicates that none of the IM operations affect the deeper heads recorded in the "S2" screened interval. Hence, DOE's IM does not affect the deeper portions of the chromium groundwater contamination (NMED's maps and the three-point problem triangulation technique can be shared with DOE in technical team meetings).*

*Section 3.2 (page 11) of the Report indicates that the screen 2 heads are affected by pumping differently than the screen 1 heads at some locations. Mapping the deeper heads in the chromium plume provides insights into IM effects, preferential pathways, the occurrence of contamination, and contamination migration at depth. NMED's mapping of the deeper heads show the IM operations do not impact the deeper heads and that a clear plume-scale preferential pathway is identifiable. DOE must revise Figures 3.3-1 and 4.0-2 to also show the potentiometric surface contours of the heads measured at depth as recorded from screen 2 wells superimposed with the water table contours recorded by screen 1 wells and include them in the revision. DOE must use the three-point problem using synoptic data of all wells in the chromium group and recontour Figures 3.3-1 and 4.0-2 and include them in the revision. The mapping shall be undertaken with NMED involvement and approval before both figures are included in the revision.*

**DOE Response**

7. The "Chromium Interim Measures and Characterization Work Plan" describes the use of the three-point method and will be used to generate synoptic water table maps as recommended by NMED. DOE proposes that the requested revisions be provided in the quarterly reports, which can be inclusive of historical data. DOE will publish potentiometric surface map updates based on NMED guidance. DOE will discuss results with NMED technical experts before submittal.

**NMED Comment**

8. ***Section 3.3 Water-Table Map, Page 13.***
***DOE Statement:*** *"The method used for water table mapping utilizes kriging and provides a degree of automation that allows for consistency in the maps over time. The use of monthly averages of water-level data ensures that any given water-table depiction is not driven by one or more anomalous values in any given well."*

*The extremely low gradient in the plume area supports use of periodic monthly averages to represent long-term changes specifically associated with the IM. Various short-duration perturbations, such as monthly groundwater monitoring for the Interim Facility-Wide Groundwater Monitoring Plan and daily and longer variations in pumping rates from nearby Los Alamos County water-supply wells, could have a local effect at one or more locations, resulting in non-representative water-table depictions if a more synoptic approach were to be used."*

***NMED Comment:*** *DOE's assertions in this section are incorrect, specifically DOE's justifications for the use of kriging and the use of monthly averages in lieu of actual water level data. Kriging does not necessarily align with industry standards. Kriging does not provide any more consistency over time than other method of interpolation and is prone to misrepresent surfaces if improperly used. Use of synoptic data does not result in non-representative water table depictions but constitutes the only information upon which a representative water table configuration can be based. Additionally, use of synoptic data is the industry standard[6].*

*While kriging honors the data at the measurement locations and is commonly used in industry for interpolating datasets, by default it is a poor choice to provide a representative groundwater flow interpolation because it assumes the dataset has a normal distribution, has no trend, and has no significant data gaps. Kriging is highly prone to interpolation artifacts that cause overemphasis of*

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[6] ASTM-D6000-15 Standard Guide for Presentation of Water-Level Information from Groundwater Sites.

*isolated observations, excessive smoothing and/or abrupt changes in the interpolated surface and data gaps. The gridding resolution, drift and the semivariogram model must be appropriately applied to each dataset, otherwise kriging is prone to misrepresent the groundwater flow system. Hence, kriging and other automated geostatistical interpolation methods must be used with caution. The flat hydraulic gradient requires a very low interpolation error to provide a representative water table map. However, DOE did not provide the error in the predicted surface for each map in the Report to validate their application of kriging. DOE's reason for using kriging shows a lack of understanding in what constitutes formulation of tenable representative maps because automation should not be an overriding factor when choosing a method of interpolation. The commonly accepted, unbiased, and tenable method in mapping the water table surface is triangulation of the three-point problem. The three-point problem is a mathematically based method used in geology and hydrogeology to determine the true dip and hydraulic gradient. NMED's application of the three-point problem using synoptic data produced a series of tenable potentiometric surface maps that provide a far more representative water table configurations that contrasts with DOE's interpretation during periods of IM operations and during periods without IM operations.*

*DOE's statement that the low hydraulic gradient requires the use of monthly averages is unsupported by hydraulic data and information. DOE's use of monthly averages instead of actual synoptic data is not consistent with the industry standard[6], does not comply with discharge permit requirements[7], and does not provide better understanding of the long-term changes in the water table caused by the IM activities. The use of monthly average water levels to map the water table incorporates undesirable water table fluctuations caused by barometric pressure changes, drawdown from sampling purges and earth tides, which all skew the interpolating and contouring results. Conversely, use of synoptic data obtained from continuously recording pressure transducers at low activity times (e.g., early mornings, weekends, and holidays) negates these undesired effects on groundwater levels because all measurements are from the same time and under the same influence. Consequently, compensation of barometric and tidal influences are not required; unlike monthly averages, which incorporate such influence, and thus result in a nonrepresentative potentiometric surface. DOE must provide multiple standards (e.g., U.S. EPA, ASTM) and studies in peer reviewed journals or textbooks to support the use of monthly averages over synoptic data when synoptic data are available for mapping the water table surface. In addition, detecting effects from pumping from the IM extraction wells and County production wells is a prime objective in preparing these maps in the semi-annual reports and should not be circumvented by using monthly averages.*

**DOE Response**

8. DOE has already initiated the use of the three-point method for generating synoptic water table maps per NMED guidance. DOE proposes that the requested revisions be provided in the quarterly reports, which can be inclusive of historical data. DOE will publish potentiometric surface map updates based on NMED guidance. DOE will discuss results with NMED technical experts before submittal.

[7] NMED, August 31, 2016, Ground Water Discharge Permit, Los Alamos National Laboratory Underground Injection Control Wells Discharge Permit-1835. 37680.

**NMED Comment**

9. ***Section 3.3 Water-Table Map, Page 13 and 14.***
***DOE Statement:*** *"In addition to being potentially caused by pumping, subtle mounds and adjacent apparent depressions in the water table can also be caused by local areas of present-day recharge from the vadose zone. For example, although the water table generally dips gently from west to east across the chromium plume area, a suspected recharge window causing slight mounding in the water table to the east of CrPZ-2 could cause the appearance of a lower point to the west, even in the May 2018 baseline map."*

***NMED Comment:*** *NMED does not concur that "subtle mounds and adjacent apparent depressions in the water table can also be caused by local areas of present-day recharge from the vadose zone." The suggestion that a subtle, but measurable, depression or low point in the water table can occur from a mound is unlikely. The prevailing cause for a depression in a water table surface is pumping. However, the use of monthly averages, conflicting reference well surveys, data gaps, and incorporation of different zones (i.e., deeper, or shallower) can create errant closed contours when automated computer algorithms like kriging are used.*

*NMED contoured the same data (which is synoptic) for the May 1, 2018, baseline water table map presented by DOE in Figure 3.3-2 of the Report, but using the three-point problem, and was not able to reproduce the depression. DOE must recontour the baseline water table map using the three-point problem for inclusion into the revision. Figures 3.3-1 and 4.0-2 in the Report also show a closed contour at an equal elevation of 5830 feet that forms an apparent depression in the water table in the same area. However, no data support these closed contours, and the closed contours are not centered around an operating extraction well. These errant closed contours are a recurring problem in many previous semi-annual reports and it is obvious they are due to artifacts that result from the application of automated software, data gaps, questionable reference surveys, and use of monthly averages in lieu of actual synoptic data. Piezometers paired adjacent to CrEX-1, CrEX-3 and CrEX-4, like CrPZ-1 is paired with CrEX-2, will be required to help fill in the data gaps if DOE continues to use computer algorithms in formulating water table maps in future submittals. In addition, DOE states in Section 3.3 of the Report that "slight mounding in the water table to the east CrPZ-2 could cause the appearance of a lower point to the west, even in the May 2018 baseline map." This "mound" east of CrPZ-2a/b may be attributed to a false high at R-28 in the baseline map that is due to the loss of hydraulic connectivity in R-28 with the aquifer due to the August 2017 molasses amendment injection. Conversely, it could be due to survey issues among the piezometer and the monitoring well. DOE must investigate this as a possibility, as well as the pressure transducer settings and the wellhead reference surveys, as potential underlying causes of the apparent water level anomalies in this area that affect mapping of the water table. DOE should perform a well resurvey, if necessary, at each chromium group installation due to the high sensitivity the flat hydraulic gradient is to aberrations in reference data. Results of such investigations (e.g., well resurvey, R-28 water level representativeness…) should be included in the revision.*

*Another potential source of error in mapping of the water table is DOE not including all data points available in the chromium group when preparing these maps. While the mapping requirements include only 14 wells[7], it excludes key wells such as R-28, R-48, R-70, R-35b and R-15 from formulation these maps. Data from these wells and SIMR-2 (one of the 14 required wells that DOE typically omits from the water table maps) are as instrumental in understanding long-term changes to the water table from IM activities as the locations listed in the discharge permit[7]. NMED does not understand why DOE omits groundwater level data from several local chromium group monitoring wells but includes the statement that "Monitoring wells within and surrounding the plume are used,* *including wells not presented on the map (i.e., R-21, R-31, R-32, R-37, and R-40). Water levels in wells surrounding the plume provide useful control points for contouring along the edges of the area of interest for this report."[8] The use of data closest to the subject matter is especially important when using automated computer algorithms to interpolate data because the algorithm stresses reliance on the nearest data over more distant data. Accurate representation of the water table requires inclusion of all chromium group well data regardless of the permit requirements. DOE must include synoptic data from each chromium group installation and revise Figures 3.3-1 and 4.0-2 in the revision and in all future submittals using three-point problem manual interpolation method to minimize the impacts the existing data gaps have on automated computer interpolation methods.*

*Drilling records demonstrate that no perched aquifer or other vadose saturation is present in the area to provide the "present-day recharge" to the water table as surmised by DOE. Additionally, the documented decline in the perched water levels at the upgradient chromium group area counters DOE's statement (e.g., MCOI-4, MCOI-5, SCI-1). Sustained engineered injection operations from the plume control IM have shown that mounding does not occur along the water table, or at least not at detectable magnitudes by the existing monitoring well network. It is implausible that the natural recharge in a desert environment such as Los Alamos would provide more flux to the water table than the IM injection operations. DOE must remove this narrative in the revision or support it by identifying the source with recent drilling data, quantifying the recharge flux to the water table from the source, and comparing the "present-day recharge" flux to the IM injection operation flux through calculations and groundwater modeling. More realistic scenarios that explain the errant closed contours include well survey issues, mis-contouring of the water table due to errant use of monthly water level averages, inclusion of R-28 and R-42 and different hydrostratigraphic zones, data gaps and use of the automated kriging interpolation method.*

**DOE Response**

9. DOE has already initiated the use of the three-point method for generating synoptic water table maps, including wells based on NMED guidance. DOE proposes that the requested revisions be provided in the quarterly reports, which can be inclusive of historical data. DOE will publish potentiometric surface map updates based on NMED guidance. DOE will discuss results with NMED technical experts before submittal.

**NMED Comment**

***10. Section 3.3 Water-Table Map, Page 14.***
***DOE Statement:*** *"The water table in the chromium area is relatively flat. Therefore, even relatively small localized variations in hydraulic conductivity may be linked to discernible changes in pressure measurements."*

***NMED's Comment:*** *On page 13 of the Report DOE states, "The use of monthly averages of water-level data ensures that any given water-table depiction is not driven by one or more anomalous values at any given well." If this statement is true, explain in the revision how the anomalous low at CrPZ-2 is consistently an issue in mapping the water table. Knowing that hydraulic conductivity is a tensor, explain how "…relatively small localized variations in hydraulic conductivity may be linked to discernible changes in pressure measurements." If true, one would expect it to be a common problem in mapping of potentiometric surface elsewhere in the chromium site, and in hydrogeology in general,*

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[8] Newport News Nuclear BWXT-Los Alamos, LLC, March 2021, Quarterly Report for the Discharge of Treated Groundwater to the Regional Aquifer under Discharge Permit 1835, Calendar Year 2020 Quarter 4. EM2021-0056.

*considering the stated geologic conditions at CrPZ-2 are not unique. In the revision, provide peer-reviewed literature (e.g., journal articles, university textbooks…) and a numerical groundwater model run that simulates the mechanics of the flow field in such hydrogeologic conditions (e.g., flat water table and small localized variations in hydraulic conductivity) to support this statement. Otherwise, remove the statement from the revision and pursue a different approach to solve the cause of this anomaly (Specific Comment No. 9).*

**DOE Response**

10. Numerical simulations will be executed to address any anomalies generated from synoptic water table mapping using the three-point method. The update will be documented in future quarterly/annual reports, inclusive of historical data.

**NMED Comment**

***11. Figure 2.1-2 - Injection well flow rates and water levels for CrIN-1, CrIN-2, CrIN-3, CrIN-4, and CrIN-5 from July 1 through December 31, 2020, page 23.***

***NMED Comment:*** *In this figure, there is a unique pattern to the sudden near 80-foot water level rise recorded in CrIN-3 during October 2020 as it contrasts with concurrent patterns of water level changes recorded in the other injection wells. Figure 3.2-38c on page 65 of the Report shows a very similar pattern recorded in the hydrograph for R-45 S1 during the timeframe denoted by "period B", also in October 2020 (see specific comment 6B). In Section 3.2.2 on page 11 of the Report, the 1-foot rise noted by "period B" is attributed to CrIN-1 because CrIN-2 was not operating. However, there was little increase in the CrIN-1 water level rise in October compared to that shown in CrIN-3 and the pattern resembles that of the near 80-foot water level rise in CrIN-3 not CrIN-1. In the revision, explain these unique patterns and comment on whether the large injection recorded in CrIN-3 is the cause of the similar pattern recorded in R-45 S1 and how DOE will include this response in the pending groundwater model as this cause and response indicates a definite hydraulic connection between CrIN-3 and R-45 S1 (see Specific Comment No. 6B). This hydraulic connection is also noted by the groundwater chemistry trend changes shown in the Attachment.*

*The Work Plan requires DOE to provide key data that support its evaluation of IM performance including water level data[1]. DOE has not provided the water level data from the 10 IM infrastructure wells in the Report. Within five business days of the date of this Notice of Disapproval, DOE must submit the raw pressure transducer data from the 10 IM infrastructure wells shown in Figure 2.1-1 and 2.1-2, and barometric pressure changes used to compensate the raw water levels, if performed. E-mail these data directly to Christopher.krambis@state.nm.us.*

**DOE Response**

11. As previously stated, the data- and model-based capture/flood zone analyses will address the influence of injection within the regional aquifer. DOE proposes that updates to the potentiometric surfaces be consolidated in future reports. Results will be discussed with NMED technical experts before publication.

    Given changes in personnel, DOE requests that NMED clarify if the pressure transducer data are still required and provide directions for transmittal, if needed.

**NMED Comment**

***12. Figures 3.2-37a through 3.2-42, pages 60 through 77.***

***NMED Comment:*** *Many of these figures are too busy, specifically Figures 3.2-37a, -38a, -38b, -38c, -39a, -39d, -40a, - 40c, -41a, and -42, due to the excessively long timeframes shown by the x-axis scale compared to the less busy figures that have much more concise timeframes. In the revision, provide a second set of figures for each well that show only the timeframe of concern by the Report (i.e., July 2020 through December 2020).*

**DOE Response**

12. DOE will provide the additional set of figures, which can be consolidated into a historical presentation of data in future quarterly/annual reports, if needed.