IEc

Los Alamos National Laboratory Natural Resource Damage Assessment

Groundwater Contaminant Data Characterization

DOE Contract DE-EM0003939

DOE Task Order DE-DT0011621

FINAL | December 2021

Prepared for:

Los Alamos National Laboratory Natural Resource Damage Assessment Trustee Council

Prepared by:

Dr. Rita Cabral, Dr. Arnulfo Aguirre, Isabelle Weisman, Dr. Christopher Lewis, Nadia Martin, and Robert Unsworth

Industrial Economics, Incorporated
2067 Massachusetts Avenue
Cambridge, MA 02140
617/354-0074

and

Dr. Lee Wilson and Casey Gierke

Lee Wilson & Associates
105 Cienega Street
Santa Fe, NM 87501

INDUSTRIAL ECONOMICS, INCORPORATED

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LIST OF ACRONYMS

µg/L	micrograms per liter
2-D	two-dimensional
3-D	three-dimensional
AFFF	aqueous film forming foams
C.F.R.	Code of Federal Regulations
CDV	Cañon de Valle
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
Ci	curie
CME	corrective measures evaluation
COC	contaminant of concern
Cr(III)	trivalent chromium
Cr(VI)	hexavalent chromium
CSM	conceptual site model
DAP	Damage Assessment Plan
DNE	does not exceed
DNX	hexahydro-1,3-dinitroso-5-nitro-1,3,5-triazine
DOE	Department of Energy
DOI	Department of the Interior
DP	Delta Prime
EIM	Environmental Information Management
EPA	Environmental Protection Agency
ft msl	feet above mean sea level
ft	feet
GIS	geospatial information system
HE	high explosives
HMX	High Melting eXplosive
IEc	Industrial Economics, Incorporated
IFGMP	Interim Facility-Wide Groundwater Monitoring Plan
K_{OC}	organic carbon-water coefficient
LANL	Los Alamos National Laboratory
LAO	Los Alamos Observation
LAUZ	Los Alamos Alluvial Upper Zone
lb	pound
mCi	millicurie
MCL	Maximum Contaminant Level
MCO	Mortandad Canyon Observation
MDA	Material Disposal Area
mg/L	milligrams per liter
MNX	hexahydro-1-nitroso-3,5-dinitro68 1,3,5-triazine

MTBE	methyl tert butyl ether
NAS	National Academy of Sciences
ND	non-detect
NMAC	New Mexico Administrative Code
NMED	New Mexico Environment Department
NOD	Notice of Deficiency
NPDES	National Pollutant Discharge Elimination System
NQ	not qualified
NRDA	Natural Resource Damage Assessment
PAO	Pueblo Alluvial Observational
pCi/L	picocuries per liter
PFAS	perfluoroalkyl substances
PFHxS	perfluorohexanesulfonic acid
PFOA	perfluorooctanoic acid
PFOS	perfluorooctanesulfonic acid
PM	Pajarito Mesa
PRSs	Potential Release Sites
RDX	Royal Demolition eXplosive
RLWTF	Radioactive Liquid Waste Treatment Facility
SCA	Sandia Canyon Alluvial
SERF	Sanitary Effluent Reclamation Facility
SLVs	screening level values
SOP	Standard Operating Procedure
SWMU	solid waste management unit
SWSC	sanitary wastewater systems consolidation
SWWS	sanitary wastewater system
TAs	Technical Areas
TCE	trichloroethylene
TNT	2,4,6-trinitrotoluene
TNX	hexahydro-1,3,5-trinitroso-1,3,5-triazine
U.S.	United States
U.S.C.	United States Code
USGS	United States Geological Survey
UU	universal use
VOCs	volatile organic compounds
WQCC	Water Quality Control Commission
WWTP	wastewater treatment plant
yd^3	cubic yards
yr	year

EXECUTIVE SUMMARY

The Los Alamos National Laboratory (LANL) Natural Resource Trustee Council (collectively, the "Trustees") [1] is conducting a natural resource damage assessment (NRDA) following the United States Department of the Interior's (DOI) NRDA regulations (43 Code of Federal Regulations [C.F.R.] Part 11) under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA; 42 United States Code [U.S.C.] Chapter 103). As part of assessment planning, the Trustees finalized a Damage Assessment Plan (DAP) (LANLTC 2014) that describes the assessment activities necessary to complete the NRDA. As stated in the DAP, the Trustees intend to evaluate the nature and extent of natural resource injuries resulting from releases of hazardous substances from operations at LANL. To facilitate this evaluation, this report compiles and summarizes available information on current and past groundwater contamination as part of the first objective of the *Groundwater Data, Baseline, and Services Review* assessment activity.[2]

This report concludes that existing data and information are sufficient to proceed with groundwater injury quantification. A review of LANL hydrogeologic investigation reports and comparisons of groundwater sampling data against screening level values (SLVs) were used to evaluate contaminants of concern (COCs) relevant to the NRDA. These analyses determined that the chromium and Royal Demolition eXplosive (RDX) groundwater plumes are the primary areas of groundwater contamination at LANL. The chromium plume, which is located below Sandia and Mortandad Canyons, contains elevated levels of chromium relative to baseline and SLVs in both perched-intermediate groundwater and the regional aquifer.[3] In some cases, concentrations exceed the New Mexico Water Quality Control Commission (WQCC) groundwater standard of 50 micrograms per liter (µg/L). The RDX plume consists of elevated levels of RDX relative to baseline and SLVs underlying Cañon de Valle in alluvial, perched-intermediate, and regional groundwater. Likewise, groundwater concentrations in some areas exceed the United States Environmental Protection Agency (EPA) tap water screening level of 6.1 µg/L.

Both plumes are reasonably well-characterized, although some uncertainty remains regarding their spatial and vertical extents and future migration. This uncertainty is primarily because incompletely characterized masses of both contaminants remain in perched-intermediate groundwater in the vadose zone that provides recharge to the regional aquifer. While elevated levels of other COCs (such as radionuclides and perchlorate) occur at LANL, these tend to be co-located with the chromium and RDX plumes. As such, most of the groundwater injury would likely be captured by quantifying the injured volume of the chromium and RDX plumes.[4]

[1] The LANL NRDA Trustee Council includes representatives from the United States (U.S.) Department of Energy, U.S. Department of Agriculture (acting through the Forest Service), Pueblo of Jemez, Pueblo de San Ildefonso, Santa Clara Pueblo, Pueblo de Cochiti, and State of New Mexico (acting through the Office of the Natural Resources Trustee).

[2] This report has been prepared in accordance with the work plan supporting this assessment activity (IEc 2017a).

[3] Baseline is "the condition or conditions that would have existed at the assessment area had the discharge of oil or release of the hazardous substance under investigation not occurred" (43 C.F.R. § 11.14(e)).

[4] Recent discussions with the Trustees have raised the issue of whether perfluoroalkyl substances (PFAS) were released from LANL operations. The Trustees are currently investigating the potential for groundwater contamination with these substances, and thus may incorporate these substances during injury quantification.

CHAPTER 1 | INTRODUCTION

The Los Alamos National Laboratory (LANL) Natural Resource Trustee Council (herein referred to as the "Trustees") are conducting a natural resource damage assessment (NRDA) to evaluate natural resource injuries and damages associated with the releases of hazardous substances from LANL.[5] The goal of the assessment is to replace, restore, rehabilitate, or acquire the equivalent of injured natural resources and resource services lost due to such releases. The Trustees finalized a Damage Assessment Plan (DAP) in February 2014, which presents the Trustees' understanding of the assessment work necessary to complete the NRDA (LANLTC 2014). This includes activities to identify and quantify injuries to natural resources and the services they provide, and to identify, scale, estimate the cost of, and implement restoration to compensate the public for these injuries and lost services. In accordance with the DAP, the Trustees have undertaken the *Groundwater Data, Baseline, and Services* assessment activity. Under U.S. Department of Energy (DOE) Contract DE-EM0003939, Task Order DE-DT0011312, Industrial Economics, Incorporated (IEc) prepared a comprehensive work plan for its implementation (IEc 2017a). This report presents findings related to the first objective of the work plan: "*Summarize available, existing information on groundwater in and around LANL, including information on current and past groundwater hydrological and chemical conditions*" (IEc 2017a).

1.1 GOALS AND OBJECTIVES OF THE ASSESSMENT ACTIVITY

As described in the work plan, the goal of this activity is to compile and summarize available data and information on groundwater conditions in and around LANL, including current and past groundwater conditions, baseline services, and potential impacts to groundwater services to support injury and damages determination.[6] This report focuses on the first part of the goal, "*current and past groundwater conditions*"; the baseline condition of groundwater and consideration of groundwater services will be covered in two separate reports. This report describes sources of contamination, contaminant pathways, nature and extent of contaminants, and contaminant trends. Available data and information related to key NRDA parameters needed for groundwater injury quantification are summarized, and data gaps and next steps identified. Within the context of NRDA, groundwater at LANL can be viewed as both a pathway and a receptor. Although groundwater can discharge to surface water at springs and subsequently be used by biological resources (e.g., plants, mammals, birds, etc.), for purposes of this report, groundwater resources are the sole focus. Other natural resources that may be exposed via groundwater as a pathway are addressed in the NRDA under separate assessment activities.

[5] The LANL NRDA Trustee Council includes representatives from the United States (U.S.) Department of Energy, U.S. Department of Agriculture (acting through the Forest Service), Pueblo of Jemez, Pueblo de San Ildefonso, Santa Clara Pueblo, Pueblo de Cochiti, and State of New Mexico (acting through the Office of the Natural Resources Trustee). The NRDA is being implemented following the United States Department of the Interior's (DOI) NRDA regulations (43 Code of Federal Regulations [C.F.R.] Part 11) under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA; 42 United States Code [U.S.C.] Chapter 103).

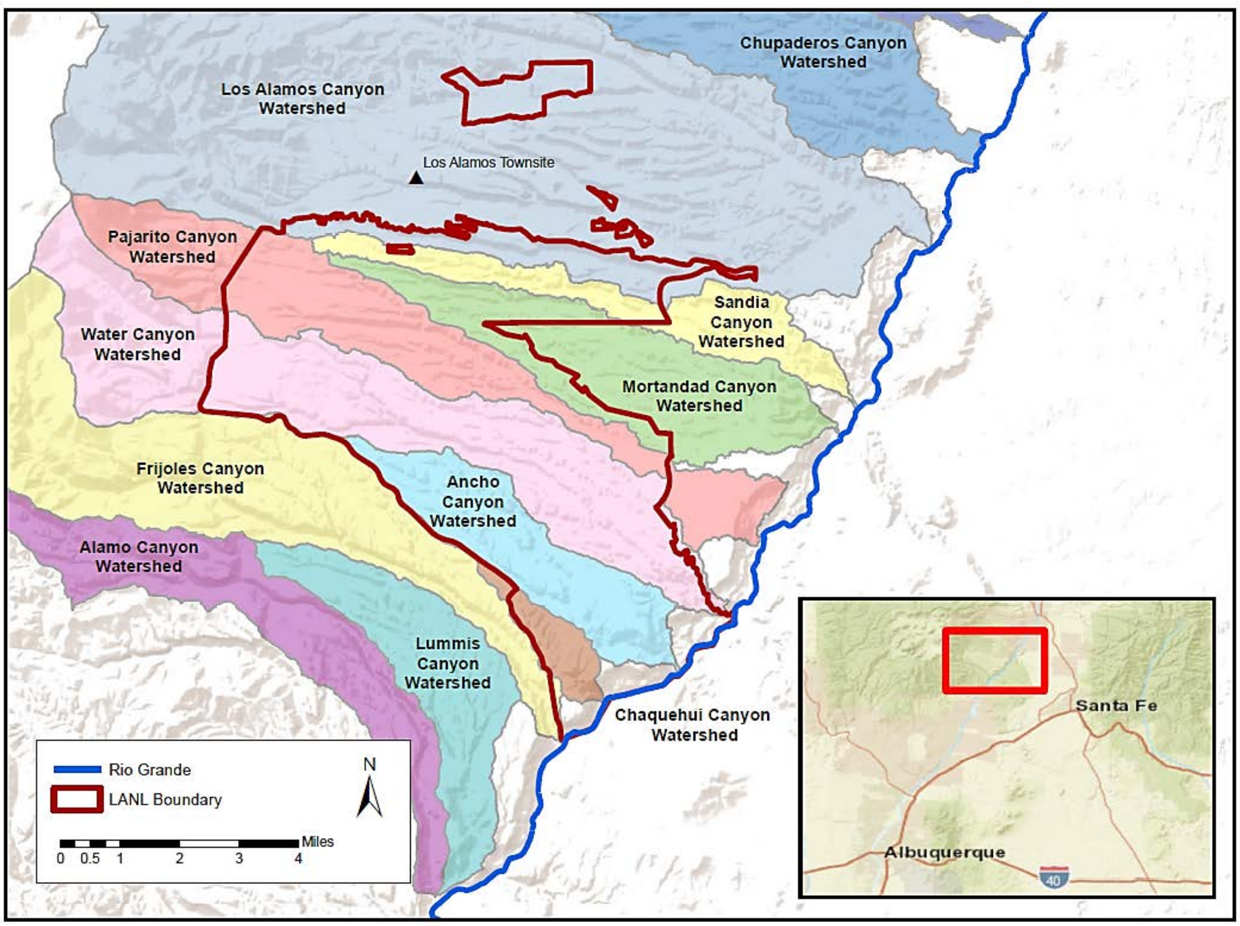
[6] In Exhibit 6-1 of the DAP, one assessment activity is an "initial priority" titled "*Quantification of injured groundwater, volume and time dimensions*." Another assessment activity is a "nearer-term priority" titled "*Determination of baseline services provided by groundwater and service losses attributable to hazardous substance contamination*." Finally, a "longer-term priority" assessment activity is titled "*Determination and monetization of groundwater damages*" (LANLTC 2014).

1.2 GROUNDWATER AT LOS ALAMOS NATIONAL LABORATORY

LANL is situated on approximately 27,500 acres (40 square miles) in north-central New Mexico, 60 miles north of Albuquerque and 25 miles northwest of Santa Fe (Exhibit 1-1). Scientific research began at LANL in March of 1943 with the inception of Project Y of the Manhattan Project, the U.S. government's effort to develop and test nuclear weapons. Nuclear weapons research included the handling of, use of, and experimentation with a variety of radioactive and explosive materials. These practices and related research led to the release of hazardous substances into the surrounding environment. In recent decades, operations at LANL have broadened beyond nuclear weapons development and its mission is now to "*solve national security challenges through scientific excellence*" (LANL 2020).

Water supply has been an important concern since the establishment of LANL and the town of Los Alamos in the early 1940s (Griggs and Hem 1964). By 1949, the Atomic Energy Commission requested that the United States Geological Survey (USGS) study the groundwater of the Valles Caldera and surrounding areas in detail for the purposes of determining the availability of water. A second project studying the underground movement of waste products discharged from LANL began simultaneously (Griggs and Hem 1964). Following these initial efforts, studies to protect and monitor groundwater quality were initiated by LANL in 1949 (LA-14263-MS). Since the late 1960s, a large volume of data has been collected at LANL and numerous reports published, including a series of "Historical Investigation" and "Canyon Investigation" reports.

EXHIBIT 1-1. LANL LOCATION MAP



1.3 GEOGRAPHIC SCOPE OF STUDY

The geographic scope of this assessment activity consists of areas within LANL property and vicinity, including where LANL-related hazardous substances have come to be located per section 101(9) of CERCLA (42 U.S.C. § 9601 et seq.) and as described in the LANL DAP (LANLTC 2014).

1.4 CONTAMINANTS OF CONCERN

LANL-related contaminants of concern (COCs) that appear to be primary injury drivers based on existing information include: radionuclides (e.g., uranium isotopes, iodine isotopes, tritium, americium-241, cesium-137, plutonium-238, plutonium-239/240, strontium-90, and technetium-99), hexavalent chromium (and total chromium, which is composed of both trivalent and hexavalent forms of chromium), high explosives (RDX, TNT, HMX), perchlorate, and nitrate (IEc 2017a).[7]

With the exception of the three high explosives compounds (i.e., RDX, TNT, HMX), perchlorate, and nitrate, all of the contaminants listed above are considered listed hazardous substances under CERCLA. Under the New Mexico Water Quality Control Commission (WQCC) Ground and Surface Water Protection regulations, nitrate has maximum allowable human health-based numerical standards, but RDX, TNT, HMX, and perchlorate are defined as "toxic pollutants" (New Mexico Administrative Code [NMAC] 20.6.2.7.T.(2), NMAC 20.6.2.3103.A). Toxic pollutants should not be present in groundwater at concentrations that may injure "human health, or the health of animals or plants which are commonly hatched, bred, cultivated or protected for use by man for food or economic benefit" (NMAC 20.6.2.3103.A). Since regulation of toxic pollutants in New Mexico is pertinent to the protection of natural resources from hazardous substances, all CERCLA hazardous substances, as well as RDX, HMX, TNT, and perchlorate are considered in detail in this report. Although nitrate releases and groundwater contamination with nitrate are discussed qualitatively, nitrate is not evaluated to the same level of detail as the remaining COCs.

To the extent new information becomes available, additional LANL-related contaminants may be identified and included in the NRDA. For example, the Trustees are investigating whether perfluoroalkyl substances (PFAS) were released from LANL operations and the potential for groundwater contamination with these substances.[8] As such, these substances may be incorporated into the NRDA during injury quantification.

[7] RDX is the acronym for Royal Demolition eXplosive or cyclotrimethylenetrinitramine. HMX is the acronym for High Melting eXplosive or octogen. TNT is the acronym for 2,4,6-trinitrotoluene.

[8] PFAS are a group of constituents including perfluorooctanesulfonic acid (PFOS), perfluorooctanoic acid (PFOA), perfluorohexanesulfonic acid (PFHxS), and numerous other PFAS compounds contained in aqueous film forming foams (AFFF), waterproof clothing, waste drums, and pipe coatings.

1.5 OUTLINE FOR THE REMAINDER OF THE REPORT

The remainder of this report is organized as follows:

- **Chapter 2** provides a summary of available groundwater data and information related to LANL, the approach for reviewing this information, and the key sources relied on for this report.
- **Chapter 3** describes the findings from the information review and data evaluation. Topics include the hydrogeology of the area, groundwater monitoring efforts, and sources of contamination and pathways for those contaminants to reach groundwater.
- **Chapter 4** presents the results of the data review, including an evaluation of spatial and temporal trends for LANL-related COCs (see Section 1.4).
- **Chapter 5** presents evaluations of chromium and RDX contaminant plumes, including assessments of spatial and temporal trends and an evaluation of NRDA-relevant plume parameters.
- **Chapter 6** summarizes the findings, potential next steps, and uncertainties inherent to data characterization.

CHAPTER 2 | METHODS AND APPROACH

LANL's history of environmental investigation and monitoring has generated many documents and data relevant to groundwater resources. In addition, investigations have been completed by other federal, state, tribal, and public organizations. This chapter provides an overview of the types of information that are available, the methodology and approach used to review this information, and the key sources identified as pertinent to understanding and characterizing groundwater contamination.

2.1 INFORMATION AND DATA SOURCES

For this assessment activity, contaminant chemistry data, written documents, and presentations from state, federal, and other sources were identified. Available information sources include results from primary data collection and field observation efforts, as well as secondary reports that interpret, reinterpret, or rework such data. The summaries and evaluations provided in this report rely primarily on LANL data and reports that have been reviewed and approved by the New Mexico Environment Department (NMED).[9]

LANL maintains an Environmental Information Management (EIM) Intellus New Mexico database with a public interface (hereafter, "Intellus") for reviewing and downloading environmental data, which was the primary source of quantitative data considered as part of this task. The database includes LANL- and NMED-collected environmental surveillance and compliance sampling data from in and around LANL. These data include target matrices beyond groundwater, such as vegetation, soil, sediment, and animal tissue. Additionally, LANL maintains geospatial information about various Technical Areas (TAs) and Potential Release Sites (PRSs) that can be combined with the Intellus data for mapping the spatial distributions of the COCs in the various matrices.

In addition to groundwater contaminant chemistry data contained in Intellus, relevant and available LANL documents include site-wide and TA-specific information about groundwater, contaminant releases, and transport pathways. Many such documents are available through the LANL Electronic Public Reading Room[10], which houses over 800 groundwater-related documents dating back to 2001. These include abstracts; comment documents; correspondence regarding permits, permit modifications, plans, and reports; evaluations; fact sheets; papers; maps; posters; presentation slides; procedures; work plans; and documents related to the Consent Order (Consent Order 2005, 2016).[11] The Consent Order of 2016 superseded the Consent Order of 2005 and outlined a framework for effective cleanup actions and cooperation among parties. Additional groundwater information from other sources was identified, such as reports published by the USGS or the New Mexico Bureau of Geology and Mineral Resources, as well as documents in the peer-reviewed literature and other public repositories (e.g., Española Basin Technical Advisory Group website).

[9] For example, for details on NMED approved activities related to chromium contamination see: https://www.env.nm.gov/hazardous-waste/chromium-groundwater-contamination/.

[10] LANL Electronic Public Reading Room is available at: https://www.lanl.gov/environment/public-reading-room.php.

[11] The Compliance Order on Consent is more widely referred to as the Consent Order, and that convention is maintained herein.

Finally, in-person and phone interviews were conducted with staff from relevant entities (NMED, LANL, Los Alamos County, Pueblo de San Ildefonso, and Utton Transboundary Resources Center) to discuss available data, information about LANL releases and area groundwater, the hydrology and stratigraphy at the site, upcoming reports, and preliminary thoughts regarding COCs in groundwater.

2.2 APPROACH FOR INFORMATION AND DATA REVIEW

With such a large volume of information available, it was important to establish an approach for review, which varied by information type (i.e., quantitative data versus qualitative reports):

- **Data**. IEc received a backup copy of the Intellus database from the DOE on August 22, 2017. This file contained tables identified by IEc as potentially relevant to the NRDA. Separately, NMED data from 1990 to the date of download (July 6, 2017) were obtained and combined with the Intellus data into a single database. Groundwater data were extracted and processed in accordance with the Standard Operating Procedure (SOP) presented in Appendix A. This approach (Appendix A) can be replicated in the future when new backup database files are received, assuming few changes are made to the overall structure of the database. These data contain geospatial information so may be investigated in the context of other spatial data, such as information on contamination sources.
- **Written Reports.** Written reports were used primarily for historic source and pathway information, hydrologic and structural geology descriptions, and contemporary data interpretation. Initial review followed recommendations from the LANL Natural Resource Trustee Council as well as staff from NMED, LANL, Pueblo de San Ildefonso, the Utton Transboundary Resources Center, and Los Alamos County. This included targeting “Historical Investigation” and “Canyon Investigation” reports, which detail LANL’s understanding of contamination within the covered areas as of the date of publication.[12] These reports provide descriptions of site-specific activities, releases, and potential pathways to groundwater. The New Mexico Bureau of Geology and Mineral Resources website includes lithologic and structural geologic maps of the area.[13] Reports published by the USGS, LANL, and others also contain information regarding these topics. Other documents produced by USGS focus on groundwater modeling; early evaluations of monitoring; records of wells, test holes, springs, and surface-water stations; aquifer and well characteristics; and post-fire characterization. The Española Basin Technical Advisory Group webpage includes a compiled list of technical publications that are relevant to the Española Basin that include annual workshop proceedings as well as relevant publication lists from federal, state, and other groups.

[12] These are categorized as “Remediation” rather than “Groundwater” in the LANL Electronic Public Reading Room.

[13] New Mexico Bureau of Geology and Mineral Resources website can be accessed via https://geoinfo.nmt.edu/

2.3 KEY INFORMATION AND DATA RELIED UPON

As a result of the information review, the following set of documents were identified as key to informing this assessment activity (in addition to groundwater sampling data in Intellus):

- ***Los Alamos National Laboratory's Hydrogeologic Studies of the Pajarito Plateau*** (LA-14263-MS, 2005) – Provides detailed discussion of the hydrogeology of the Pajarito Plateau, along with information from the 1998 to 2004 drilling of twenty-five regional aquifer and six intermediate zone wells. The conceptual model presented in the report identifies wet canyons in the LANL area as a primary source of local recharge through the intermediate zone to the regional aquifer and surface effluents as the sources of LANL-related contamination at depth.
- ***Selected Key Contaminant Sources from Los Alamos National Laboratory including Liquid Outfalls and Material Disposal Areas*** (Birdsell et al. 2006) – Identifies six LANL outfalls that had significant past discharges of mobile contaminants to canyons, which are considered the most significant sources of groundwater contamination. The report includes estimates of release quantities (contaminant mass, liquid volumes) and maps of release locations. One of the six locations is associated with chromium contamination, another with RDX contamination, and the remaining outfalls with radionuclides (e.g., tritium) and perchlorate contamination.
- ***Interim Facility-Wide Groundwater Monitoring Plan for the 2018 Monitoring Year, October 2017-September 2018*** (IFGMP 2017).[14] This report summarizes LANL's approach for the collection and analysis of groundwater and surface water samples and water level data in fulfillment of requirements imposed by the 2016 Consent Order. Monitoring is conducted in several defined areas, including TA-21, the chromium plume, Material Disposal Area (MDA) C, TA-54, TA-15, and MDA AB; as well as the general surveillance monitoring group.
- ***Geology and Groundwater Resources of the Los Alamos Area New Mexico*** (Griggs and Hem 1964). This report provides one of the earliest descriptions of LANL groundwater investigations. It demonstrates the importance of water supply in this area and LANL's early concerns regarding groundwater contamination due to hazardous substance releases from LANL facilities. The report also provides a description of the geology and groundwater availability in the area.
- ***Compendium of Technical Reports Conducted Under the Work Plan for Chromium Plume Center Characterization*** (LA-UR-18-21450). This is a 2018 compilation of nine studies of the hydrology, geology, and geochemistry of Sandia and Mortandad Canyons. These studies appear to have been conducted between 2013 and 2017, though some are not dated (LA-UR-18-21450). Detailed attachments address local geology, tracer and pump tests, hydrologic and hydrogeochemical modeling, natural attenuation of chromium, and bench-scale studies of bioremediation and chemical remediation.
- ***Compendium of Technical Reports Related to the Deep Groundwater Investigation for the RDX Project at Los Alamos National Laboratory*** (LA-UR-18-21326). This is a 2018 compilation of nine studies of the hydrology, geology, and geochemistry of TA-16. These studies appear to have been conducted between 2015 and 2018, though not all are dated (LA-UR-18-21326). Detailed

[14] For in-text citations either author and data or LANL's document numbering system were utilized, where relevant, except in cases where a report is widely known by another name or by the authors, as is the case with IFGMP (2017).

attachments in the report address topics such as the RDX inventory in the subsurface; local geology; hydrologic and hydrogeochemical modeling; RDX fate and transport; microbial and chemical degradation of RDX; and tracer tests.

- ***Investigation Report for Royal Demolition Explosive in Deep Groundwater*** (EM2019-0235). This is an August 2019 summary of published information on TA-16. Its publication was one of the milestones established in the 2016 Consent Order. It provides details on the regulatory context of the RDX investigations; site conditions; geology and hydrogeology; site and release history, investigations, and remediation; and various geophysical and laboratory studies. An informative aspect of this report is its description of a conceptual site model (CSM) that considers geochemical and hydrogeologic conditions.

CHAPTER 3 | GROUNDWATER AND CONTAMINATION

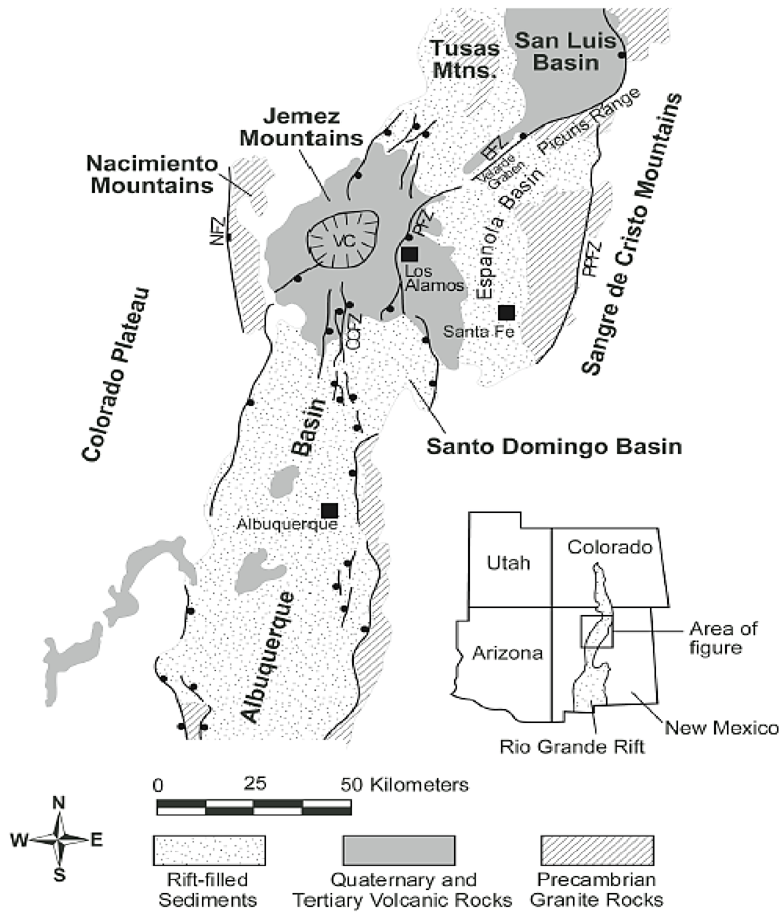
3.1 HYDROGEOLOGY

The complex geology of the Pajarito Plateau affects infiltration and groundwater flow. As a precursor to characterizing groundwater contamination, this section describes the regional geological setting and the three zones of groundwater within it.

3.1.1 REGIONAL HYDROGEOLOGICAL SETTING

The Pajarito Plateau lies on the eastern side of the Jemez Mountains volcanic pile (within the dark gray shaded area in Exhibit 3-1), which sits at the volcanically and seismically active boundary between the Colorado Plateau and the Rio Grande Rift (Griggs and Hem 1964, LA-14263-MS). The Rio Grande Rift is characterized by north-trending, fault-bounded basins extending from central Colorado to northern Mexico with local areas of subsidence (e.g., the Española Basin). The basement rock in this area is Eocene (approximately 34 to 56 million years old) to Precambrian age (approximately 541 to 4,600 million years old) and was uplifted during the Laramide orogeny (mountain building event), which occurred approximately 65 million years ago. On top of this basement rock, geologic units include basin-fill deposits and interfingering volcanic rocks from the Jemez and Cerros del Rio volcanic fields (LA-14263-MS). At LANL, these units are covered by ash-flow tuffs (e.g., the Bandelier Tuff), which give rise to the Pajarito Plateau's characteristic mesa tops.

EXHIBIT 3-1. LOCATIONS OF MAJOR STRUCTURAL AND GEOLOGIC ELEMENTS (FROM LA-14263-MS)



The semiarid climate of the Pajarito Plateau receives average annual precipitation ranging from more than 20 inches (0.5 meters) along the western boundary near the Jemez mountains to less than 14 inches (0.36 meters) to the east at the Rio Grande (Birdsell et al. 2005 and references therein). Groundwater from the Pajarito Plateau flows eastward towards the Rio Grande.

3.1.2 ALLUVIAL GROUNDWATER

The canyon bottoms contain Holocene (present geologic epoch, began approximately 12 thousand years ago) and late Pleistocene (between 12 thousand and 2.58 million years ago) alluvium comprised of stratified, lenticular deposits of unconsolidated fluvial sands, gravels, and cobbles (LA-14263-MS and references therein). Depending upon the canyon and the outcrops within it, a different proportion of detritus can be found in the alluvial deposits, ranging from tuff to dacite. The sediments form cross-cutting deposits due to geomorphic actions of stream channels in the floodplains. The sediments interfinger laterally with the colluvium of the canyon walls. Typically, the canyon-floor alluvium also varies in thickness by canyon. For example, alluvium in Pueblo Canyon ranges from 11 feet (3.4 meters) thick on the west side of the Pajarito Plateau to approximately 18 feet (5.5 meters) thick near the confluence with Los Alamos Canyon (LA-14263-MS). Similarly, Mortandad Canyon has one to two feet (0.3 to 0.6 meters) of alluvium near its headwaters and more than 100 feet (30 meters) of alluvium plus colluvium near the eastern LANL boundary (LA-14263-MS).

Groundwater occurs in limited and variable extents in the alluvium, but can accumulate below springs or effluent discharge points or from infiltration during stormwater runoff and snowmelt. Most surface water flow within the vicinity of LANL is ephemeral or intermittent, but a few canyons have short stretches with perennial surface flow. In some cases, the perennial flow may be attributed to anthropogenic discharges from water treatment outfalls (LA-14263-MS). Surface water infiltrates to form near-surface perched alluvial groundwater systems in many of the canyons (LA-14263-MS). The volume of water in these systems is insufficient for domestic use but may transport LANL-derived contamination significant lateral distances before infiltrating to greater depths.

3.1.3 PERCHED-INTERMEDIATE GROUNDWATER

Intermediate zone groundwater exists in discontinuous, perched lenses within the vadose zone of the Pajarito Plateau.[15] The thickness of the vadose zone can range from approximately 600 feet to over 1,200 feet (183 meters to over 366 meters) (LA-14263-MS). Unsaturated flow through the Bandelier Tuff near the land surface occurs predominantly through the porous matrix of the rock (mean porosity of 0.49), whereas flow through basalt units is fracture-dominated (LA-12968-MS). Within this zone, perched water can occur for a number of reasons, including capillary barriers and low permeability barriers coupled with complex stratigraphic subsurface structures (Bagtzoglou 2003a and 2003b, as cited in LA-14263-MS).[16] The geologic structures giving rise to perched-intermediate groundwater vary by canyon and are discussed in more detail in subsequent chapters of the report.

Similar to alluvial groundwater, bodies of perched intermediate groundwater are also generally too small for municipal supplies, but are of significant interest for understating the data summarized in this report because they may divert, slow, or stop the vertical migration of groundwater or alternatively may suggest the existence of a fast, subsurface pathway (e.g., a fault). Perched intermediate groundwater also provides recharge to the regional aquifer, and thus can be used to monitor contaminants migrating downward to the

[15] In the vicinity of LANL, the vadose zone is considered the soil and rock between the alluvial groundwater (or the ground surface if alluvial groundwater is not present) and the regional aquifer water table (LA-14263-MS).

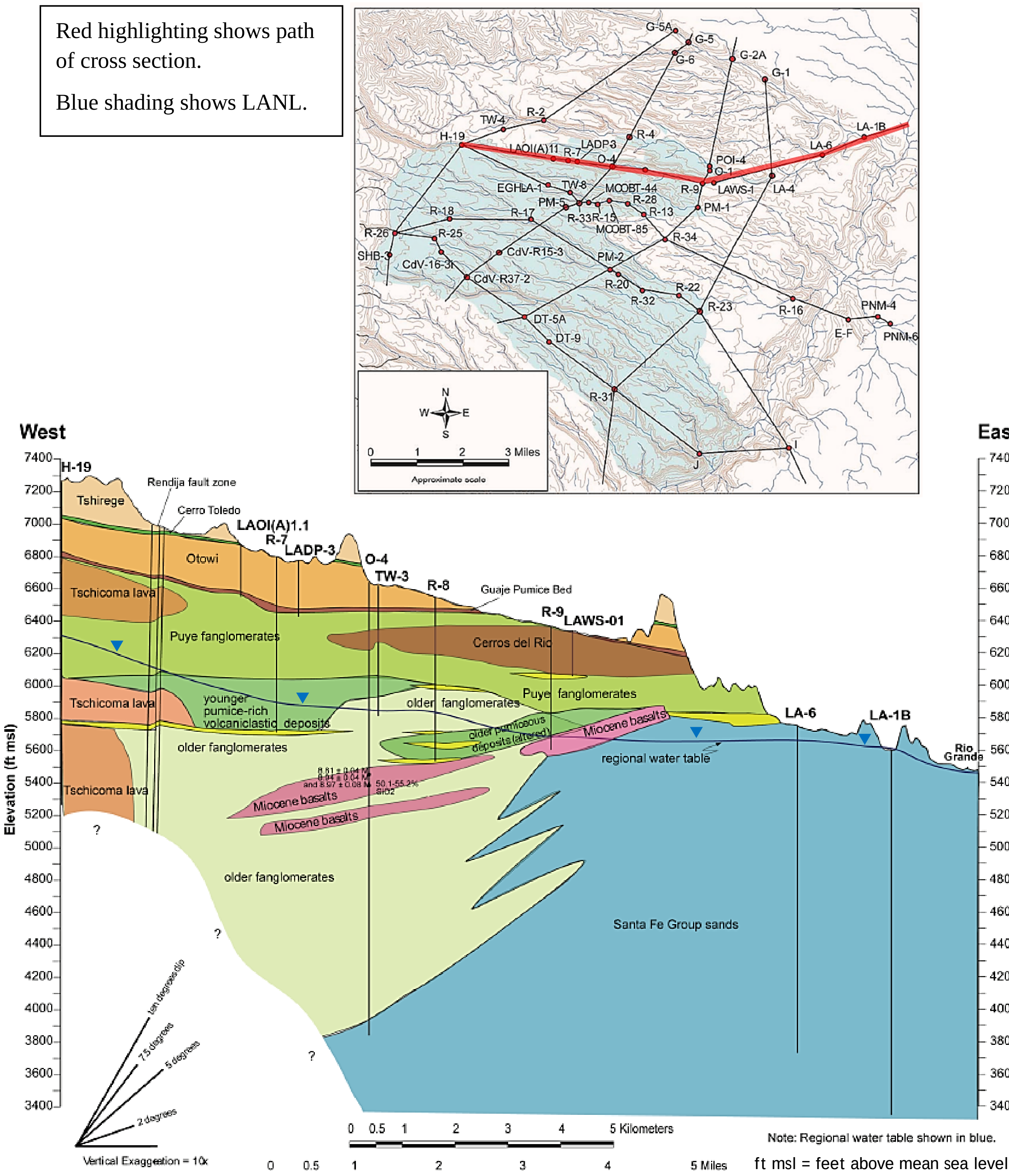
[16] A capillary barrier is a contact in the unsaturated zone between an overlying geologic unit containing relatively small-diameter openings and an underlying unit containing relatively large-diameter openings across which water does not flow (Neuendorf et al. 2005).

regional aquifer; and it has chemical and radioisotopic signatures that inform vadose zone groundwater transport rates.

3.1.4 REGIONAL AQUIFER

The regional aquifer beneath the Pajarito Plateau is in the Santa Fe Group, which extends throughout the Española Basin and is the primary source of potable water for LANL, Santa Fe, Española, Los Alamos, and numerous Pueblos. The Santa Fe Group includes the following rock units, in ascending order: the Tesuque Formation; older fanglomerate (ancient alluvial fan sediments that have lithified) deposits of the Jemez volcanic field; the Totavi Lentil and older river gravels; pumice-rich volcaniclastic rocks; and the Puye Formation (Exhibit 3-2). These deposits interfinger with or are overlain by volcanic rocks from the nearby volcanic fields (e.g., Jemez and Cerros del Rio) (LA-14263-MS). The Santa Fe Group is thick, totaling 4,800 feet (1,463 meters) in the eastern and northern part of the Española Basin (LA-14263-MS). However, the thickest deposits are thought to occur in the western Española Basin, beneath the Pajarito Plateau (LA-14263-MS and references therein). This has not yet been confirmed, as the deepest wells on the Pajarito Plateau (i.e., 3,110 feet or 948 meters) do not fully penetrate the basin-fill sediments. In the eastern part of the Pajarito Plateau, water in the Tesuque Formation provides a significant proportion of groundwater for local communities and LANL (LA-14263-MS and references therein). This formation is made up of thick fluvial deposits of partially lithified, arkosic (potassium feldspar-rich) sediments derived from Precambrian granite, pegmatite, and sedimentary rocks. Individual bedding planes are typically less than 10 feet (3 meters) thick with cross-bedded, light pink to buff siltstone and sandstone, with minor lenses of pebbly conglomerate (LA-14263-MS). Natural discharge from the regional aquifer is primarily into the Rio Grande or to springs that flow into the Rio Grande (LA-14263-MS).

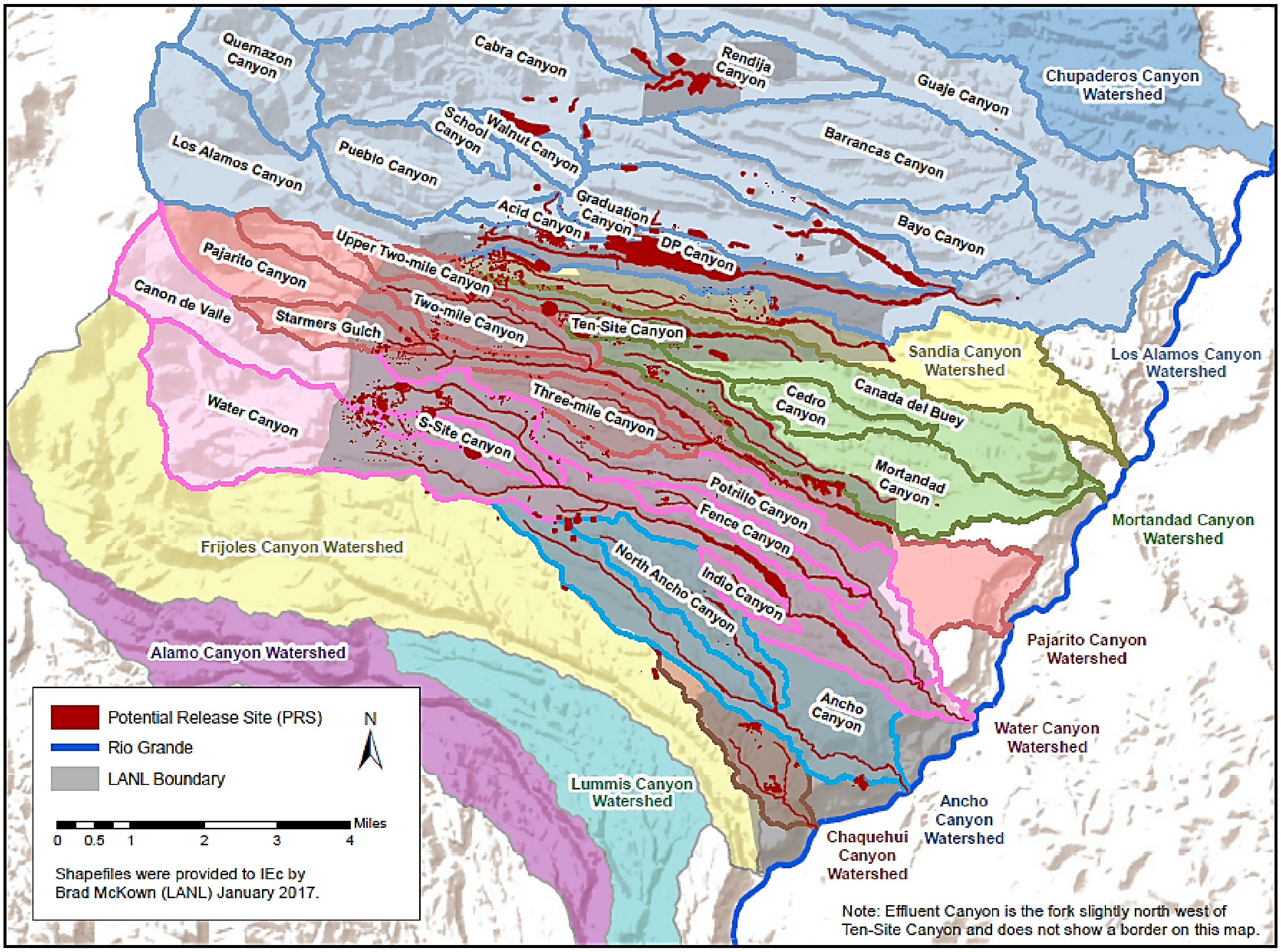
EXHIBIT 3-2. CONCEPTUAL GEOLOGIC CROSS SECTION FOR LOS ALAMOS CANYON (MODIFIED FROM LA-14263-MS)



3.2 OVERVIEW OF GROUNDWATER MONITORING

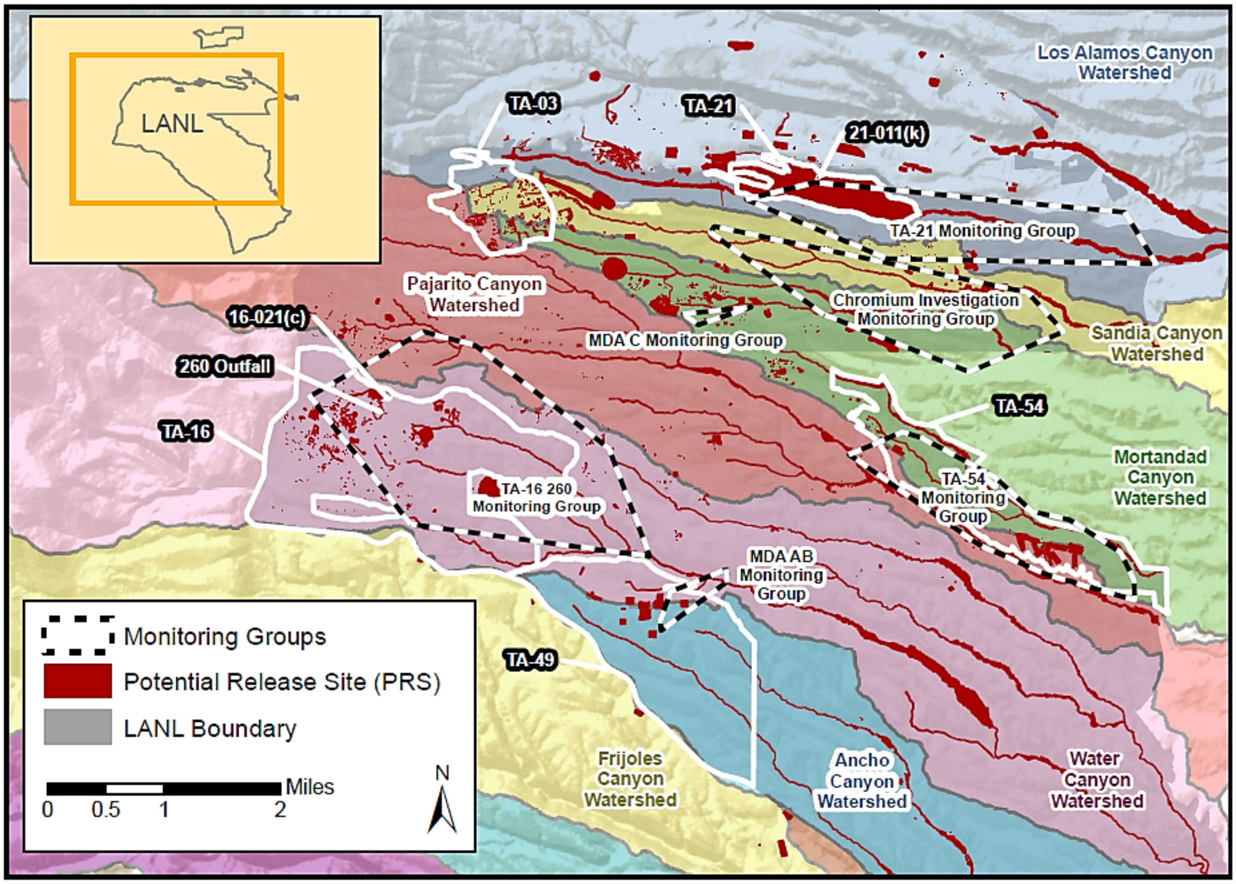
As described above, groundwater occurs within three depth zones beneath the Pajarito Plateau; in the alluvium, as perched-intermediate groundwater, and in the regional aquifer. LANL monitoring wells are completed in each of these zones within seven major watersheds: Los Alamos/Pueblo, Sandia, Mortandad, Pajarito, Water/Cañon de Valle, Ancho/Chaquehui/Frijoles, and White Rock/Rio Grande (Exhibit 3-3). Monitoring also occurs outside of LANL boundaries, including in areas where operations have occurred in the past (e.g., Guaje and Rendija Canyons). Surface water monitoring outside LANL boundaries also occurs (e.g., the Rio Grande and springs in White Rock Canyon) (IFGMP 2017).

EXHIBIT 3-3. MAJOR CANYONS AT LANL AND POTENTIAL RELEASE SITES



LANL has grouped some monitoring wells and surface water monitoring stations where there is base flow (persistent surface water), into six area-specific contaminant monitoring groups: TA-21, Chromium Investigation, MDA C, TA-54, TA-16 260, and MDA AB (IFGMP 2017) (Exhibit 3-4). Monitoring wells that do not fall into these six monitoring groups are assigned to the "General Surveillance" monitoring group. These groups were created because project areas and contaminant plumes can cross several watersheds through groundwater underflow. Groundwater monitoring frequency ranges from quarterly to every five years depending on the contaminant. An Interim Facility-Wide Groundwater Monitoring Plan (IFGMP) is updated annually to incorporate information collected during the previous year, with refinements based on characterization efforts, aquifer test results, water-level monitoring, network assessments, and water-quality data. Each of the monitoring groups are described in greater detail below. Most recently collected groundwater data (available in Intellus) are from these monitoring groups.

EXHIBIT 3-4. LANL AREA-SPECIFIC MONITORING GROUPS



Note: This map highlights technical areas (TAs) and other features of interest relevant to the in-text discussion. Additional TAs and features exist in and around LANL.

- **TA-21:** This monitoring group is primarily located in upper Los Alamos Canyon, in and around TA-21. The monitoring wells in this group are completed in perched-intermediate groundwater and the regional aquifer. Tritium, nitrate, and perchlorate released via the solid waste management unit (SWMU) 21-011(k) outfall have dispersed down Delta Prime (DP) and Los Alamos Canyons through surface water and alluvial groundwater. These contaminants are present in perched-intermediate groundwater near the northern boundary of TA-21 and DP Canyon, near the confluence of DP and Los Alamos Canyons, farther down Los Alamos Canyon, and beneath Mesita de Los Alamos. Additional sources of contaminants near the TA-21 monitoring group include the adsorption beds and disposal shafts at MDA T, the adsorption beds at MDA U, the former TA-02 Omega West Reactor cooling tower and outfall, DP West, and waste lines and sumps. DP East, leakage from an underground diesel fuel line, and past releases from the former Omega West Reactor may also be potential sources of contaminants in the area (IFGMP 2017). Available data and information suggest that contamination does not reach the regional aquifer in this area but contamination farther down Los Alamos Canyon may have originated at SWMU 21-011(k) (IFGMP 2017).

- **Chromium Investigation:** The primary contaminants of concern in this monitoring group include chromium, nitrate, sulfate, perchlorate, 1,4-dioxane, and tritium (IFGMP 2017). The focus of this monitoring group has been in the perched-intermediate and regional aquifer zones of Sandia and Mortandad Canyons. An interim measure is underway to control contaminant migration along the downgradient periphery of the chromium plume in the regional aquifer and to characterize the plume center. Sanitary wastewater and cooling tower effluent releases have been the dominant source of surface water in Sandia Canyon since the early 1950s and continue to support a seven-acre wetland near the head of the canyon prior to infiltrating. Historical effluent releases also were a source of surface water in middle Mortandad Canyon, adjacent to Sandia Canyon, but no effluent has been released since 2010 (IFGMP 2017). The primary source of chromium was blowdown water discharged from the TA-3 power plant cooling tower from 1956 to 1972. However, nitrate and tritium are also above background levels in this monitoring group. The most recent conceptual model hypothesizes that groundwater contaminants originate from historical effluent releases to Sandia Canyon that infiltrated locally but then have migrated laterally in groundwater to areas underlying Mortandad Canyon. Historical releases from the Radioactive Liquid Waste Treatment Facility (RLWTF) outfall in Mortandad Canyon also contributed contamination to groundwater in this area. Furthermore, lateral migration of contaminants from Los Alamos Canyon sources (e.g., Outfall 21-011[k], which discharged to DP Canyon) also appear to be detected.
- **MDA C:** Located on Mesita del Buey in TA-50 at the head of Ten Site Canyon, MDA C is an inactive 11.8-acre landfill. It includes seven disposal pits and 108 shafts, ranging from 10 feet to 25 feet (3 meters to 7.6 meters) below the original ground surface, containing solid low-level radioactive and chemical wastes. The groundwater monitoring group includes wells on the mesa top in addition to those in Mortandad Canyon. Groundwater has not been detected in the vadose zone beneath MDA C, because it is located on the mesa top. Further, regional groundwater monitoring wells downgradient of MDA C show no signs of contamination. However, vapor-phase COCs (trichloroethylene and tritium) and tritium are present in the upper 500 feet of the unsaturated zone beneath MDA C, but LANL considers aqueous-phase transport to be minimal because MDA C is above thick, unsaturated units of Bandelier Tuff (IFGMP 2017). No evidence has been found of groundwater contamination in the regional aquifer (IFGMP 2017).
- **TA-54:** This monitoring group was established to support monitoring requirements for TA-54 and includes perched-intermediate and regional wells. TA-54 is on Mesita del Buey in the east-central portion of the LANL facility, but the monitoring group is located across the Pajarito and Mortandad Canyon watersheds. Vapor-phase contaminants (primarily 1,1,1-trichloroethane, trichloroethylene, and tritium) are present in the unsaturated zone beneath MDA G and MDA L. Historical data indicate sporadic detections of the organic compounds in groundwater, with consistent detections only at two wells, but concentrations are reportedly below Consent Order groundwater cleanup levels. Corrective measure evaluations provide further information and descriptions of organic and inorganic contaminants detected in the perched-intermediate and regional groundwater (IFGMP 2017).

- **TA-16 260:** TA-16 was established to develop explosives formulations, cast and machine explosives charges, and assemble and test explosives components for the nuclear weapons program. Located in the southwest portion of the LANL facility, it is bordered by both Bandelier National Monument and the Santa Fe National Forest. The monitoring group was established in the upper Water Canyon/Cañon de Valle watershed to detect releases from Consolidated Unit 16-021(c)-99, the TA-16 260 Outfall (i.e., the 260 Outfall), and other sites at TA-16. The 260 Outfall discharged effluent carrying high explosives (HE) and inorganic compounds related to the explosives machining process to Cañon de Valle from 1951 to 1996. This is the primary source of contaminants detected in groundwater in this area although historical releases of HE, including RDX from TA-09, may have also contributed to the contamination detected in this monitoring group. Monitoring activities for this group are thus focused on HE, but also target volatile organic compounds (VOCs) in the upper Cañon de Valle watershed (IFGMP 2017). The monitoring group includes springs as well as alluvial, perched-intermediate, and regional groundwater wells. Contaminants in the drainage channel below the TA-16 260 outfall, the canyon bottom, surface water, alluvial groundwater, and intermediate groundwater include RDX, HMX, TNT, and barium. VOCs (tetrachloroethene, trichloroethylene [TCE], methyl tert butyl ether [MTBE], and toluene) have been detected in perched-intermediate and regional groundwater. RDX has been detected in regional groundwater wells.
- **MDA AB:** The MDA AB monitoring group is contained within TA-49 and includes perched-intermediate and regional groundwater wells. This TA was used for underground hydronuclear testing in the early 1960s. Associated experiments produced large inventories of uranium and plutonium isotopes, lead, beryllium, and barium nitrate, as well as explosives such as TNT, RDX, and HMX. Much of this material remains in shafts on the mesa top (IFGMP 2017). Radionuclides have not been detected in groundwater despite having been detected in canyon sediments. Perchlorate has been detected slightly above background in one intermediate well, but otherwise the three decades of data from regional wells in this area do not show substantial changes in water chemistry (IFGMP 2017).[17]
- **General Surveillance Monitoring:** As described previously, this monitoring group captures locations that are not associated with the area-specific monitoring groups. This includes perennial (base-flow) surface water monitoring locations, alluvial monitoring wells, and springs (except for those assigned to the TA-16 260 monitoring group). Some perched-intermediate and regional aquifer wells are also included in this group. These monitoring locations exist across the Pajarito Plateau in all the major watersheds. Some locations show little or no contamination, whereas others show residual contamination due to past operations or effluent releases. This residual contamination appears to be most common in surface water, alluvial groundwater, and occasionally in perched-intermediate groundwater. The regional aquifer has also been affected (see results from plume evaluations in Chapter 4). Concentrations detected at these locations are steady over time or decreasing due to reduced source contributions. The objectives of this monitoring are four-fold: 1) to continue monitoring long-term water-quality trends; 2) to continue

[17] The specific background value for perchlorate was not reported in the IFGMP (2017). However, it is assumed to be 0.414 micrograms per liter (µg/L) based on 1) the publication year of LANL's Groundwater Background Investigation Report (2016) (LA-UR-16-27907) and 2) a mention of the Groundwater Background Investigation Report in Appendix E of the IFGMP (2017).

verifying decreasing contaminant trends at these locations in some watersheds (Los Alamos, Sandia, and Mortandad Canyons); 3) to monitor for potential impacts from ongoing operations under DOE requirements for environmental surveillance; and 4) to continue surveillance for potential LANL-related impacts to groundwater, as shown in White Rock Canyon springs (IFGMP 2017).

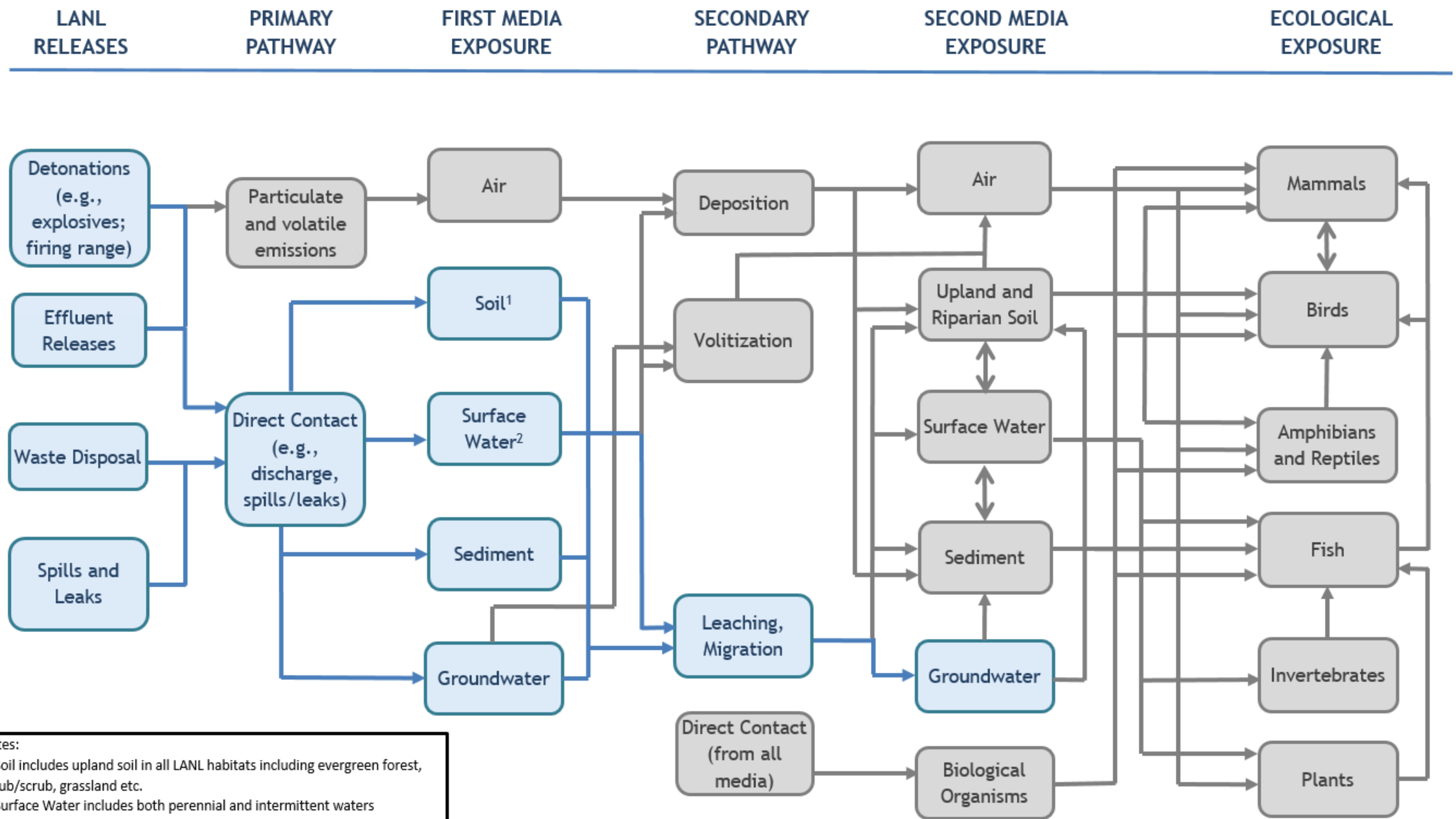
3.3 PATHWAYS OF CONTAMINATION

Exhibit 3-5 presents a CSM for groundwater contamination at LANL. A CSM identifies contaminant sources; illustrates potential contaminant fate and transport and exposure pathways; and is helpful for identifying receptors and resources of potential concern. CSMs may evolve as more data are collected and site-specific understanding refined. The pathways relevant to this report are highlighted in blue in Exhibit 3-5.

Although LANL operations historically were centered around what is now the Town of Los Alamos (Exhibit 1-1), as of 1997, activities at LANL were spread across 47 active TAs occupying 43 square miles (111 square kilometers) of land (LA-UR-97-4275).[18] TA-03 is the main technical area where nearly half of LANL's personnel are located; TA-0 includes the town of Los Alamos, which contains leased facilities located on County land; and one TA, TA-57, is noncontiguous and lies approximately 28 miles (45 kilometers) to the west of LANL (the Fenton Hill Site). Operations are conducted within approximately 2,043 structures, which include 1,835 buildings that contain 7.3 million square feet (678,192 square meters) of space. Other structures include meteorological towers, water tanks, manholes, small storage sheds, and electrical transformers, among others (LA-UR-97-4275). Given the extent of these operations across multiple TAs and over LANL's nearly 80-year history, LANL operations – and particularly effluents from these operations (Exhibit 3-6) – present numerous pathways for contaminants that could potentially reach groundwater.

[18] TA boundaries have been updated over time, including the consolidation of some individual TAs into larger areas. As such, the TA numbering system may now appear to skip numbers and has a maximum value of 74.

EXHIBIT 3-5. CONCEPTUAL SITE MODEL DEMONSTRATING POTENTIAL ROUTES OF EXPOSURE OF NATURAL RESOURCES TO HAZARDOUS SUBSTANCES FROM LANL OPERATIONS (MODIFIED FROM LANLTC 2014)



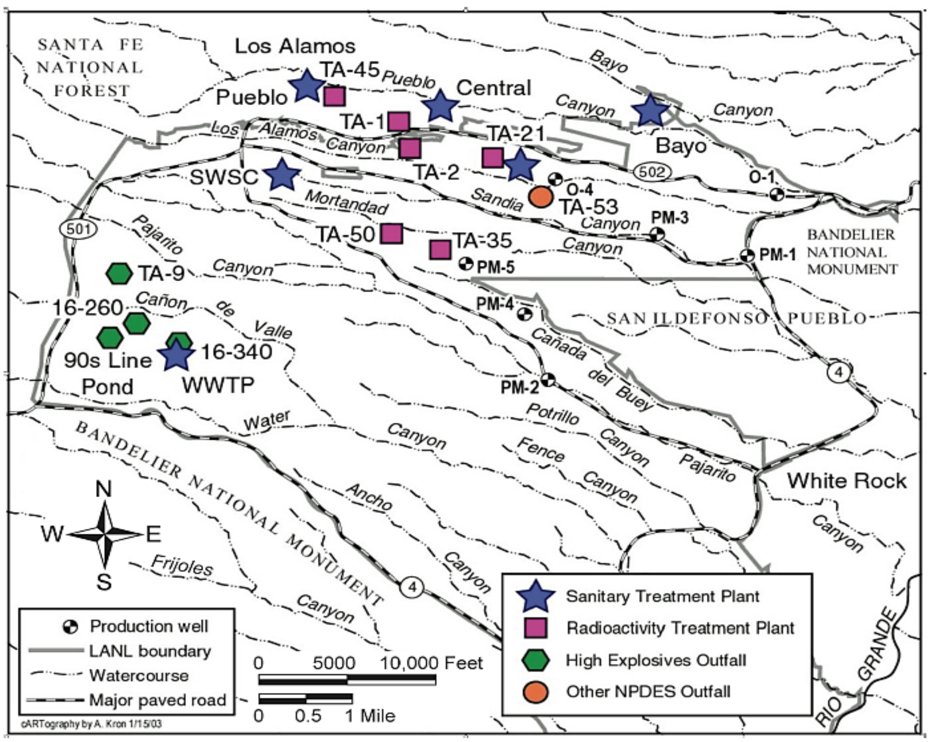
Notes:
1. Soil includes upland soil in all LANL habitats including evergreen forest, shrub/scrub, grassland etc.
2. Surface Water includes both perennial and intermittent waters throughout LANL Property.
3. Intake routes from media to ecological receptors include absorption, inhalation, and ingestion.

Note: The blue coloration highlights the potential routes of exposure to hazardous substances that are relevant to groundwater.

Contaminants originating from the TAs vary in their mobility and, therefore, have a range of travel times from the surface to alluvial, perched-intermediate, and regional groundwater. Physical and chemical characteristics that affect contaminant transport over time and distance include:

- Adsorption, including cation exchange, precipitation or dissolution, oxidation/reduction, or radioactive decay can slow contaminant movement or decrease contaminant concentrations (e.g., uranium, strontium-90, barium, some HEs, and solvents).
    - Some constituents are nearly immobile because they strongly adsorb to sediment particles (e.g., americium-241, plutonium-238 -239, and 240, and cesium-137).
    - Oxidation state can strongly influence mobility as well. For example, chromium (III) can be reactive (i.e., adsorb and precipitate) to mineral surfaces, while chromium (VI) is soluble in water and very mobile (LA-UR-07-6018).[19]
- Dilution and dispersion govern the movement of non-reactive species (e.g., RDX, tritium [which also undergoes radioactive decay], perchlorate, and nitrate).

EXHIBIT 3-6. LOCATIONS OF MAJOR LIQUID RELEASE SOURCES THAT HAVE POTENTIALLY AFFECTED GROUNDWATER (FROM LA-14263-MS)



Note: Additional sources may have been identified since the publication of LA-14263-MS.
WWTP = wastewater treatment plant
SWSC = sanitary wastewater systems consolidation

[19] Hexavalent chromium (chromium (VI), valence state +6) is highly toxic, while trivalent chromium (chromium (III), valence state +3) is a micronutrient and is not considered a health hazard. However, both trivalent and hexavalent chromium pose a risk to natural resources because, depending on the oxidation state and whether there are reducing electrochemical conditions in the subsurface, the valence state of chromium can change between hexavalent and trivalent, especially in the presence of reactive manganese (II, IV).

3.3.1 LIQUID WASTE EFFLUENTS

Due to the dry climate at LANL, the primary pathway for contamination of groundwater is via liquid effluent, rather than solid waste disposal or other activities, though other less-dominant pathways from surface contamination sites to groundwater can exist (LA-14263-MS). This is because most solid waste disposal sites at LANL are located on mesa tops where surface water infiltration is low (Kwicklis et al. 2005). By contrast, as early as the 1940s liquid discharges from LANL effluents had degraded water quality in the alluvial and intermediate zones.

Discharges from LANL outfalls that could potentially impact groundwater were evaluated for the National Academy of Sciences (NAS) review committee in support of the *Technical Assessment of Environmental Programs at the Los Alamos National Laboratory* (Birdsell et al. 2006). Six of the most significant historic and (then) current liquid outfalls, in terms of water volume or contaminant mass released, were summarized in the NAS review. The outfalls evaluated were in Acid Canyon (Pueblo Canyon), Upper Los Alamos Canyon, DP Canyon (Los Alamos Canyon), Sandia Canyon, Cañon de Valle (Water Canyon), and Effluent Canyon (Mortandad Canyon). A variety of contaminants were released through these outfalls, including tritium, perchlorate, strontium-90, plutonium, nitrate, cesium-137, americium-241, chromium, RDX, plutonium-239, -240, and -238. The results of this report are summarized in Exhibit 3-7 (Birdsell et al. 2006). Mortandad Canyon and Pueblo Canyon received radioactive effluent discharges through the Acid Canyon tributary whereas Water Canyon, its tributary Cañon de Valle, and Pajarito Canyon received effluents produced by HE processing and experimentation (LA-14263-MS).

LANL has also historically operated sanitary wastewater treatment plants (Exhibit 3-6). These plants have contributed large volumes of water to the canyons over time, though most are now inactive. In at least one instance, LANL operated a wastewater treatment plant that is now a sanitary wastewater system (Exhibit 3-7). In addition to LANL's wastewater treatment activities, Los Alamos County has operated several sanitary treatment plants over time, but only the Los Alamos and White Rock wastewater treatment plants are currently operational (Los Alamos County 2021).

As a result of these extensive liquid discharges, LANL contaminants can be found in alluvial and intermediate groundwater zones in multiple canyons and, in some cases, the regional aquifer (LA-14263-MS).

EXHIBIT 3-7. SIX KEY LANL OUTFALLS AND APPROXIMATE CONTAMINANT QUANTITIES RELEASED (MODIFIED FROM BIRDSELL ET AL. 2006)

SOURCE	LOCATION CANYON (WATERSHED)	OPERATION	PERIOD OF OPERATION	KEY MOBILE CONSTITUENTS DETECTED IN DEEP GROUNDWATER	APPROXIMATE WATER VOLUMES RELEASED (FT^3)	APPROXIMATE CONTAMINANT QUANTITY RELEASED[1]	APPROXIMATE KEY RADIONUCLIDE RELEASED
Combined TA-01 & TA-45 Outfalls (SWMUs 01-002 and 45-001)	Acid Canyon (Pueblo Canyon)	Radioactive waste treatment	1944 - 1964	Tritium, perchlorate	21,188,800	Perchlorate – unknown Nitrate –220,462 lbs	Tritium: ~58 Ci Strontium-90: ~27 mCi Plutonium: ~170 mCi
Omega West Reactor (SWMU 02-004[a])	Upper Los Alamos Canyon	Research and Molybdenum production	mid 1956 – 1993*	Tritium, chromium†	70,629 to 141,258		Tritium: 70 Ci (maximum)
SWMU 21-011(k)	DP Canyon (Los Alamos Canyon)	Industrial wastewater outfall	1952 – 1986	Tritium, perchlorate, nitrate	7,062,933	Perchlorate – unkown Nitrate > 44 lbs	Tritium: > 55 Ci Plutonium: ~36 mCi Strontium-90: ~5 mCi Cesium-137: ~250 mCi Americium-241: ?
TA-03 Power Plant (SWMU 03-045[h]-00). Former TA-03 Wastewater Treatment Plant (legacy waste site 03-014(a)-99) and current sanitary wastewater system (SWWS).	Sandia Canyon	Cooling towers and sanitary wastewater treatment	1950 – present	Chromium (ca. 1956 – 1972); accidental tritium release with sanitary waste (ca. 1969 – 1986)	> 10,000,000 (~150,000 to 400,000 m^3/yr continuously since 1951)	Chromium – 57,320 to 231,485 lbs	Tritium: ~30 Ci
260 Outfall (SWMU 16-021[c]-99)	Cañon de Valle (Water Canyon)	High explosives machining	1951 – 1996	High explosives (RDX)	2,006,986 to 52,972,000	RDX 33,069 to 141,096 lbs	None
TA-50 Outfall (National Pollutant Discharge Elimination System [NPDES] Outfall 051)	Effluent Canyon (Mortandad Canyon)	Radioactive wastewater treatment	1963 – present	Tritium, nitrate, perchlorate	49,440,533	Perchlorate – 1,764 to 2,646 lbs Nitrate – 440,925 lbs	Tritium: ~800 Ci Strontium-90: ~470 mCi Plutonium-239,-240: ~0.2 Ci Plutonium-238: ~0.1 Ci Cesium-137: ~2.1 Ci Americium-241: ~0.2 Ci

Quantification in this table may have been modified through more recent investigations.
[1] Note that tritium releases here are reported as original releases rather than decay-corrected current masses. See Rogers 1998 (as cited in Birdsell et al. 2006) for tritium releases decay-corrected to 1997.
*LA-UR-04-2714
†LA-UR-07-6018
Ci = curie; ft = feet; lb = pound; mCi = millicurie; yr = year

3.3.2 INFILTRATION FROM SURFACE SOURCES

Groundwater contamination can also be attributed to infiltration or leaching from surface disposal in trenches and pits. Over 2,000 PRSs exist in and around LANL, some of which may have contaminated groundwater. Effluent and outfalls aside, PRS categories include, but are not limited to, sediment trap and disposal sites within canyons, soil contamination sites, impoundments, surface disposal, firing sites and explosives storage, transformers, and other non-intentional release sites.

CHAPTER 4 | INITIAL DATA CHARACTERIZATION

4.1 EVALUATION FRAMEWORK

In this chapter, the LANL-related COCs are evaluated by comparing observed contaminant concentration data to identified screening level values (SLVs) and assessing spatial and temporal trends. As noted in Section 1.4, COCs include radionuclides (e.g., uranium isotopes, iodine isotopes, tritium, americium-241, cesium-137, plutonium-238, plutonium-239/240, strontium-90, and technetium-99), hexavalent chromium (and total chromium, which is composed of both trivalent and hexavalent forms of chromium), high explosives (RDX, TNT, HMX), perchlorate, and nitrate (IEc 2017a).

4.2 SCREENING LEVEL VALUE ANALYSIS APPROACH

To understand the potential scope of groundwater contamination and prioritize COCs for further analysis, groundwater contaminant sampling data (after data processing and cleanup described in Chapter 2) are compared to SLVs. The SLVs were compiled from federal, state, and LANL sources and include promulgated criteria (e.g., U.S. Environmental Protection Agency [EPA] Maximum Contaminant Levels [MCLs]), screening levels, and ecological and human risk-based thresholds. Details regarding the preparation of raw data are provided in Appendix A, while the SLV analysis methodology and sources are described in Appendix B. The results summarized in this chapter are based on the processed dataset (i.e., post-implementation of the Appendix A SOP). Therefore, counts of sampling locations and samples may differ from those calculated using original, raw data tables.

Analysis of groundwater COCs reveals 2,938 samples with exceedances of SLVs, 89 percent of which are for seven contaminants (contaminants bolded and highlighted in the "Parameter" column of Exhibit 4-1). Contaminants exhibiting the highest number of exceedances in groundwater samples are RDX and chromium (both total and hexavalent), comprising 42 percent of all exceedances. Other contaminants with large numbers of exceedances are strontium-90, perchlorate, tritium, cesium-137, and americium-241, which account for 47 percent of all exceedances.

Sixty-five percent of exceedances are for COCs in samples for which affirmative detectable concentrations were measured above their respective analytical limits of detection. Conversely, 45 percent of the noted exceedances are identified as non-detects.[20] The true concentration of such samples, and whether they truly exceeded SLVs, is thus unknown (but may be able to be estimated); the concentrations are just known to be less than the analytical detection limit. Detection limits for the analytical methods used during the initial groundwater monitoring programs at LANL were higher (less sensitive) relative to methods used more recently. In the context of NRDA, these results still carry valuable information, but may require the use of analytical treatments to draw conclusions (e.g., perform statistical comparisons) (see IEc 2017b for more information).[21] For many radionuclides (e.g., cesium-137, strontium-90, tritium), most exceedances are from measures where the detection limit was greater than the SLV (i.e., non-detect

[20] Non-detects arise in environmental datasets because methods used to measure contaminants are limited in their sensitivity (i.e., the constituent concentration is below the limit of detection of the analytical instrument).

[21] This report utilizes the reported result values as they are (i.e., a non-detect treatment was not applied). Non-detects will be treated in accordance with LANL NRTC 2017 in the course of injury quantification analyses, as appropriate.

exceedances). Sixty-one percent of all non-detect exceedances are associated with legacy analytical methods, for which there is incomplete information about the instruments or methodology used.

While SLV exceedances indicate the potential scope of contamination, such contamination does not necessarily constitute mappable plumes in groundwater. For example, the counts in Exhibit 4-1 are inclusive of samples collected from sampling locations where the aquifer was "none" or "unknown" in the Intellus database (i.e., counts include all data, regardless of aquifer). The lack of this information precludes accurate depth mapping of concentrations. Therefore, the subsequent sections of this chapter further evaluate the spatial and temporal trends in the identified COC exceedances for those that have aquifer information (i.e., alluvial, intermediate, regional).

EXHIBIT 4-1. SUMMARY COUNTS OF SCREENING LEVEL VALUES ANALYSIS

PARAMETER[1]	ND AND DNE SLV	ND AND EXCEEDS SLV	DETECTED BUT DNE SLV	DETECTED AND EXCEEDS SLV	TOTAL ND	TOTAL DETECTED	TOTAL DNE SLV	TOTAL EXCEEDS SLV	GRAND TOTAL
Americium-241	4,995	136	299	17	5,131	316	5,294	153	5,447
Cesium-137	6,305	185	36	-	6,490	36	6,341	185	6,526
Chromium (total)	4,856	2	7,109	618	4,858	7,727	11,965	620	12,585
Chromium (VI)	57	-	190	17	57	207	247	17	264
HMX	2,956	-	792	-	2,956	792	3,748	-	3,748
Perchlorate	2,128	102	4,371	298	2,230	4,669	6,499	400	6,899
Plutonium-238	6,879	45	216	6	6,924	222	7,095	51	7,146
Plutonium-239/240	6,799	65	285	11	6,864	296	7,084	76	7,160
RDX	2,918	20	385	583	2,938	968	3,303	603	3,906
Strontium-90	5,103	115	280	294	5,218	574	5,383	409	5,792
Technetium-99	297	-	31	-	297	31	328	-	328
Trinitrotoluene	3,606	12	115	3	3,618	118	3,721	15	3,736
Tritium	5,348	240	2,349	2	5,588	2,351	7,697	242	7,939
Uranium	1,374	63	8,815	33	1,437	8,848	10,189	96	10,285
Uranium-234	620	-	3,981	17	620	3,998	4,601	17	4,618
Uranium-235	849	36	2	3	885	5	851	39	890
Uranium-238	743	3	3,863	12	746	3,875	4,606	15	4,621
Total	55,833	1,024	33,119	1,914	56,857	35,033	88,952	2,938	91,890

All values presented correspond to the total number of measurements (i.e., counts) that are not detected (non-detect, ND), detected, does not exceed (DNE), or exceed.
SLVs were compiled from federal, state, and LANL sources and include promulgated criteria (e.g., U.S. EPA MCLs), screening levels, and risk-based thresholds. Details regarding the preparation of raw data are provided in Appendix A, while the SLV analysis methodology and sources are described in Appendix B.
[1] Analysis of groundwater COCs reveals 89 percent of SLV exceedances are for seven contaminants, which are bolded and highlighted.
ND = Non-detect
DNE = Does not exceed SLV

4.3 SPATIAL DISTRIBUTION AND TEMPORAL TRENDS

Spatial evaluation of exceedance patterns by watershed reveals that Los Alamos, Mortandad, Water, and Sandia watersheds contain the largest numbers of groundwater exceedances at LANL (Exhibit 4-2). The spatial distribution of exceedances is consistent with the location of the contaminant monitoring groups (see Section 3.2 and Exhibit 3-4). Exceedances in these watersheds appear to be related to laboratory activities and outfall locations. For example, in Los Alamos watershed, strontium-90, cesium-137, americium-241, and perchlorate are derived primarily from releases from outfall SWMU 21-011(k) discharging to DP Canyon. In Mortandad watershed, cooling tower effluent has caused significant chromium contamination in groundwater. Additionally, effluent from the TA-50 RLWTF are major sources of tritium, cesium-137, nitrate, and strontium-90 to middle Mortandad watershed. Sandia watershed contains significant chromium contamination from the TA-03 power plant and is part of the Chromium Investigation Monitoring Group that spans portions of Mortandad and Sandia watersheds (described in more detail in Chapter 5). Lastly, Cañon de Valle in Water watershed is the location of the RDX groundwater plume. Chromium contamination is also present in Water watershed, derived from effluent from the TA-16 260 Outfall (LA-UR-11-5478). The following subsections explore the patterns observed in COC data from the alluvial, perched-intermediate, and regional groundwaters in these primary watersheds and their hydrologic connection to PRSs.

EXHIBIT 4-2. SUMMARY COUNTS OF GROUNDWATER EXCEEDANCES OF SCREENING LEVEL VALUES BY WATERSHED

PARAMETER	ANCHO	FRIJOLES	LOS ALAMOS	MORTANDAD	PAJARITO	SANDIA	WATER	OTHER AREAS†
Americium-241	2	-	44	44	10	6	1	2
Cesium-137	3	-	75	71	4	1	-	5
Chromium (total)	1	-	11	380	4	118	62	-
Chromium (VI)	-	-	-	14	-	3	-	-
HMX‡	-	-	-	-	-	-	-	-
Perchlorate	2	-	31	266	2	-	8	-
Plutonium-238	-	-	-	48	-	-	-	-
Plutonium-239/240	-	-	11	58	-	-	-	1
RDX	-	2	-	-	2	-	292	-
Strontium-90	-	-	126	154	-	-	-	1
Technetium-99‡	-	-	-	-	-	-	-	-
Trinitrotoluene	-	-	-	-	2	-	5	-
Tritium	2	-	47	190	-	-	-	-
Uranium	-	-	18	2	-	-	22	10
Uranium-234	-	-	2	1	2	-	-	9
Uranium-235	2	-	13	2	5	-	2	5
Uranium-238	-	-	3	-	3	1	-	5
Total	12	2	381	1230	34	129	392	38

Non-detect results are included in these counts.
† The "Other Areas" category includes locations along the Rio Grande and outside of watersheds with sampling data or PRSs.
‡ No exceedances were identified for these contaminants.

4.3.1 LOS ALAMOS WATERSHED

A total of 38 alluvial sampling locations are within Los Alamos watershed (Exhibit 4-3).[22] Most alluvial sampling locations are in Pueblo, DP, and upper Los Alamos Canyons. Upper Los Alamos watershed contains numerous alluvial sampling locations comprising the Los Alamos Observation (LAO), LAUZ (presumably Los Alamos Upper Zone), and PAO (presumably Pueblo Alluvial Observation) networks. There are a total of 22 perched-intermediate sampling locations with a similar spatial distribution as the alluvial sampling locations. Finally, 38 regional aquifer sampling locations are distributed throughout Los Alamos, DP, Pueblo, and Guaje Canyons.

The SLV analysis in Los Alamos watershed determined that alluvial groundwater had the most SLV exceedances with 292, followed by groundwater in the regional aquifer with 59, and intermediate groundwater zone with 30. The COCs with the most exceedances in alluvial groundwater are strontium-90, cesium-137, and tritium. In intermediate groundwater, the COCs with the most exceedances include uranium-235 with fewer exceedances of plutonium-239/240 and americium-241. Whereas, in regional aquifer groundwater, americium-241, cesium-137, and uranium had the most exceedances of SLVs. Perchlorate exceedances are found primarily in the alluvial and intermediate groundwater zones, while uranium exceedances are widespread across all groundwater zones. Lastly, the regional aquifer well R-9 had chromium exceedances in several groundwater samples that surpassed the MCL by orders of magnitude.

4.3.1.1 Alluvial Groundwater

The analysis of alluvial groundwater of Los Alamos watershed identified a total of 5,343 observations from 38 sampling locations. The COCs with most exceedances are strontium-90, cesium-137, tritium, perchlorate, and americium-241 (Exhibit 4-4). COCs like plutonium-239/240, uranium, uranium-235, and chromium are less common with fewer than ten exceedances. A total of 292 exceedances were observed and most observations were non-detect (Exhibit 4-4).

Groundwater observations of the alluvial aquifer span from 1967 to 2016 (Exhibit 4-5). Between 1967 and 1994, all COCs measurements were non-detect. Nonetheless, the percentage of observations with exceedances of the SLVs were highest during this time because detection limits for the analytical methods used were higher (less sensitive) relative to methods used more recently. During the late 1960s and early 1970s, exceedances of the SLVs ranged between 20 and 40 percent. In 1972, the percentage of exceedances of the SLVs peaked at 40 percent. Starting in 1995, alluvial groundwater detections were observed for the first time, constituting approximately two percent of all observations. The emergence of observed detections in the mid-1990s is more likely a result of more sensitive analytical methods (lower detection limits) than increasing concentrations. This notion is further supported by an overall decreasing trend in the percentage of exceedances of the SLVs between 1998 and 2016 from a high of nine percent. Since 2004, the annual percentages of exceedances of the SLVs have remained below five percent.

[22] In many instances, but perhaps not all, the location table includes location_ids for individual wells in addition to their well screens. Therefore, this report considers sampling locations to be defined as the x, y, z location of groundwater sample collection (the well and screen depth interval), as opposed to the x, y location of an individual well (i.e., reported counts of sampling locations will likely be higher than counts of individual wells). The “sampling location” terminology is used except when a unique well can be reasonably identified or a site report description uses the term “well.”

EXHIBIT 4-3. SAMPLING LOCATIONS IN LOS ALAMOS WATERSHED

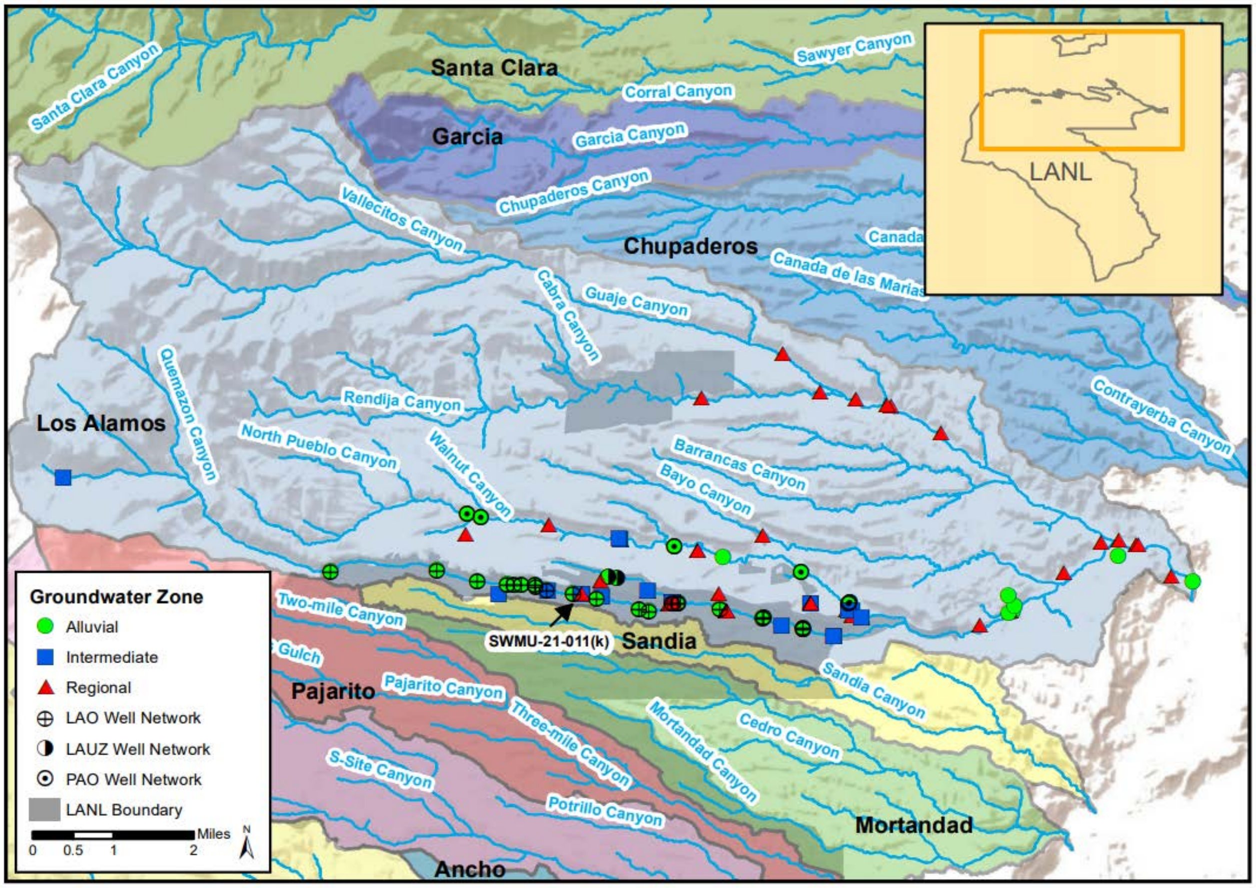
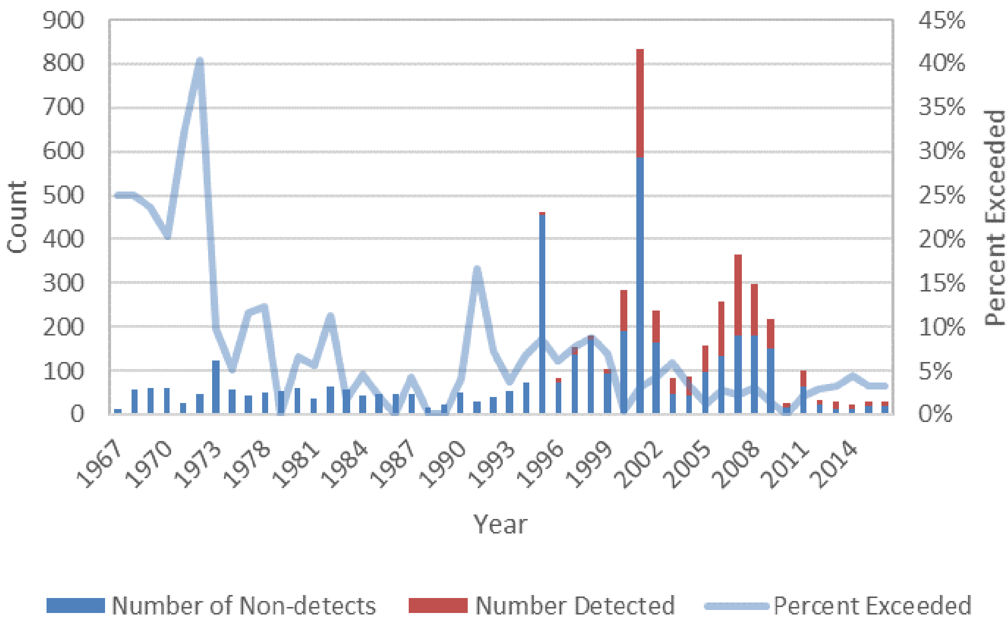


EXHIBIT 4-4. EXCEEDANCES OF SCREENING LEVEL VALUES FOR CONTAMINANTS OF CONCERN IN ALLUVIAL GROUNDWATER IN LOS ALAMOS WATERSHED

PARAMETER†	DETECTED	EXCEEDS SLV	DETECTED AND EXCEEDS SLV	DETECTED BUT DNE SLV	ND BUT EXCEEDS SLV	ND AND DNE SLV
Americium-241	45	19	1	44	18	411
Cesium-137	-	59	-	-	59	546
Chromium (total)	153	1	-	153	1	381
Chromium (VI)‡	-	-	-	-	-	-
HMX	-	-	-	-	-	5
Perchlorate	112	27	3	109	24	111
Plutonium-238	12	-	-	12	-	685
Plutonium-239/240	72	7	3	69	4	620
RDX	-	-	-	-	-	5
Strontium-90	155	124	75	80	49	267
Technetium-99	2	-	-	2	-	48
Trinitrotoluene	-	-	-	-	-	5
Tritium	116	45	-	116	45	399
Uranium	161	7	-	161	7	76
Uranium-234	202	-	-	202	-	104
Uranium-235	-	3	-	-	3	136
Uranium-238	167	-	-	167	-	137
Total	1,197	292	82	1,115	210	3,936

† SLV sources are presented in Exhibit B-1 of Appendix B.
‡ This contaminant was not measured in the groundwater samples collected from sampling locations in the area of interest.
SLV = Screening level value
DNE = Does not exceed SLV
ND = Non-detect

EXHIBIT 4-5. NUMBER OF OBSERVATIONS AND EXCEEDANCES OF SCREENING LEVEL VALUES IN ALLUVIAL GROUNDWATER IN LOS ALAMOS WATERSHED



COC concentrations in the alluvial groundwater of Los Alamos watershed range considerably (Exhibit 4-6). Average concentrations of strontium-90 and perchlorate, and maximum concentrations of americium-241, perchlorate, strontium-90, and tritium all exceed their respective SLVs (Exhibit 4-6).

EXHIBIT 4-6. SUMMARY STATISTICS OF THE MAJOR CONTAMINANTS OF CONCERN IN ALLUVIAL GROUNDWATER IN LOS ALAMOS WATERSHED

PARAMETER	UNIT	AVERAGE	STANDARD DEVIATION	MAXIMUM	MINIMUM	SLV
Americium-241	pCi/L	1	20	300	-33	1.2
Cesium-137	pCi/L	33	88	370	-85	120
Perchlorate	µg/L	60	216	2,530	0	13.8
Strontium-90	pCi/L	14	36	368	-3	8
Tritium	pCi/L	159,362	3,633,963	86,000,000	-2,030	20,000
pCi/L = picocuries per liter						

The LAO alluvial sampling locations in mid to upper Los Alamos watershed are the primary locations of strontium-90, cesium-137, and tritium exceedances. These exceedances are attributed to radioactive waste discharged starting in the 1940s. Former TA-02 and TA-41 contain SWMUs with leach fields that have released cesium-137 and strontium-90 to the alluvial groundwater and the Omega West Reactor in TA-02 is a known source of tritium to alluvial groundwater (LA-UR-04-2714). The alluvial sampling locations of LAO-1, LAO-3, and LAO-2 are downstream from these two TAs. More importantly, the sampling locations are near outfall SWMU 21-011(k), which discharged to DP canyon and is the most important source of cesium-137, strontium-90, and americium-241 in upper Los Alamos watershed. The wells LAO-2, LAUZ-1, and LAUZ-2, in DP Canyon are dominated by strontium-90, tritium, and cesium-137 exceedances of the SLVs with only minor americium-241, plutonium-239/240, and uranium exceedances of the SLVs.

Effluent from SWMU 21-011(k) was also a source of perchlorate to DP Canyon (LA-UR-04-2714). Perchlorate exceedances are present in the neighboring LAO alluvial sampling locations in Los Alamos watershed and well PAO-4 in Pueblo watershed, resulting from historical discharges to Acid Canyon from former TA-45. Translation of radionuclides and perchlorate across canyons in alluvial groundwater occurs primarily from streambed infiltration. Spring snowmelt in the upper canyon creates seasonal recharge that increases groundwater water levels down the canyon.

4.3.1.2 Intermediate Groundwater

A total of 3,324 observations from 22 sampling locations were identified in intermediate groundwater of Los Alamos watershed. Uranium-235 has the most exceedances of SLVs (Exhibit 4-7). Other COCs, including plutonium-239/240, perchlorate, americium-241, cesium-137, chromium, uranium-234, uranium-235, uranium-238, strontium-90, and tritium have fewer than five exceedances of their respective SLVs each. A total of 26 SLV exceedances are observed overall for these other COCs, but most observations are non-detects (Exhibit 4-7).

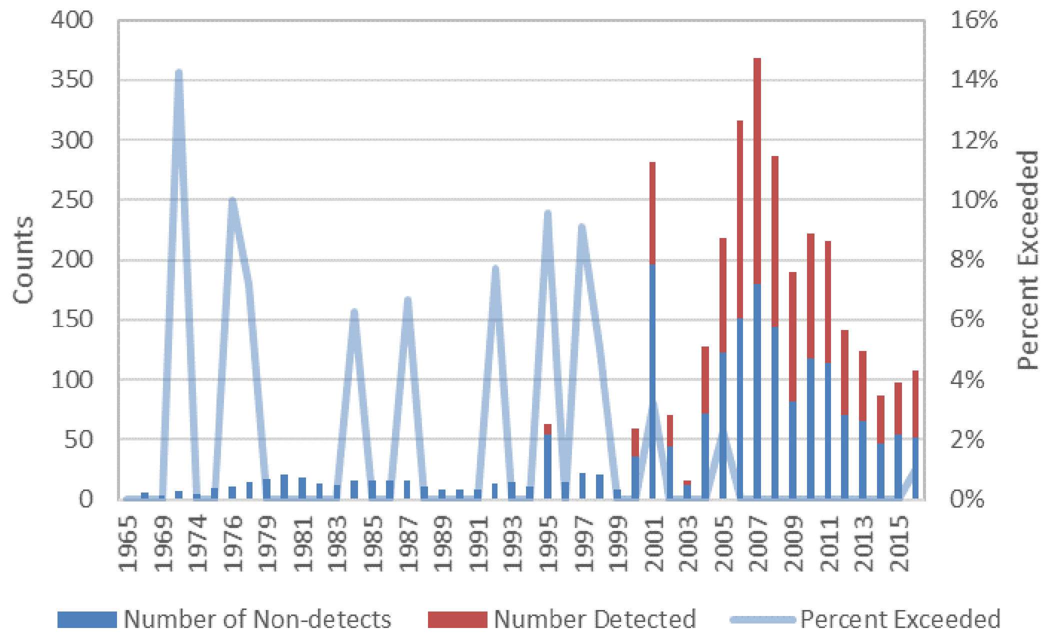
Chemical observations of the intermediate groundwater span from 1965 to 2016 (Exhibit 4-8). Between 1965 and 1995, all analytical results of COCs were non-detects. During this time there are numerous peaks in exceedances of SLVs, between six and 14 percent per year. The highest percentage of exceedances of SLVs occurs in 1971 at 14 percent. Starting in 1995, intermediate groundwater detections are observed for the first time, constituting approximately 14 percent of all observations. Additionally, the percentage of exceedances of the SLVs in 1995, 1998, and 2001 gradually decrease to 10, five, and three percent, respectively. In the period between 2002 and 2015, there were no intermediate groundwater exceedances. The decrease in the percentage of samples with exceedances of the SLVs in the intermediate groundwater coincides with a decrease of exceedances in the alluvial groundwater of Los Alamos watershed.

EXHIBIT 4-7. EXCEEDANCES OF SCREENING LEVEL VALUES FOR CONTAMINANTS OF CONCERN IN INTERMEDIATE GROUNDWATER IN LOS ALAMOS WATERSHED

PARAMETER †	DETECTED	EXCEEDS SLV	DETECTED AND EXCEEDS SLV	DETECTED BUT DNE SLV	ND BUT EXCEEDS SLV	ND AND DNE SLV
Americium-241	9	4	1	8	3	229
Cesium-137	1	3	-	1	3	266
Chromium (total)	224	3	3	221	-	187
Chromium (VI)	6	-	-	6	-	-
HMX	-	-	-	-	-	45
Perchlorate	192	4	2	190	2	67
Plutonium-238	5	-	-	5	-	287
Plutonium-239/240	5	4	-	5	4	283
RDX	2	-	-	2	-	42
Strontium-90	5	1	1	4	-	239
Technetium-99	-	-	-	-	-	25
Trinitrotoluene	1	-	-	1	-	44
Tritium	161	1	-	161	1	121
Uranium	357	-	-	357	-	21
Uranium-234	209	2	2	207	-	12
Uranium-235	2	6	1	1	5	36
Uranium-238	203	2	2	201	-	20
Total	1,382	30	12	1,370	18	1,924

† SLV sources are presented in Exhibit B-1 of Appendix B.
SLV = Screening level value
DNE = Does not exceed SLV
ND = Non-detect

EXHIBIT 4-8. NUMBER OF OBSERVATIONS AND EXCEEDANCES OF SCREENING LEVEL VALUES IN INTERMEDIATE GROUNDWATER IN LOS ALAMOS WATERSHED



The 30 exceedances noted in Exhibit 4-7 above are in nine sampling locations in Los Alamos and Pueblo Canyons. Los Alamos sampling locations LAOI(a)-1.1, R-5 OB, and R-7 OB show exceedances for constituents like perchlorate and chromium. Additionally, radionuclide exceedances in these nine sampling locations include americium-241, cesium-137, plutonium-239/240, strontium-90, and uranium isotopes like uranium-234, -235, and -238. Uranium-235 has the highest number of exceedances with six across LAOI(a)-1.1, LAO1-3.2 OB, R-7 S1, and Test Well 2a. Maximum concentrations of uranium-235 and perchlorate for LAOI(a)-1.1 are orders of magnitude higher than their corresponding SLVs. In Pueblo Canyon, Test Well 1A and 2A primarily show exceedances of cesium-137 and plutonium-239/240. Test Well 2A has an anomalous tritium exceedance of 24,200 pCi/L in 1978 that exceeds the EPA MCL of 20,000 pCi/L (Exhibit 4-9).

EXHIBIT 4-9. MAXIMUM CONCENTRATIONS OF CONTAMINANTS OF CONCERN IN INTERMEDIATE GROUNDWATER IN LOS ALAMOS WATERSHED

WELL	CANYON	PARAMETER	YEAR	MAXIMUM CONCENTRATION	SLV	UNITS
LAOI(a)-1.1	Los Alamos	Perchlorate	1995	1,290	13.8	µg/L
		Uranium-235	1995	339	20	pCi/L
Test Well 2A	Pueblo Canyon	Tritium	1978	24,200	20,000	pCi/L

Compared to alluvial groundwater, there are fewer exceedances of strontium-90 and tritium SLVs in the intermediate zone. However, perched-intermediate groundwater has more SLV exceedances of chromium and uranium radionuclides, such as uranium-234, -235, and -238.

4.3.1.3 Regional Aquifer

A total of 7,680 observations from 38 sampling locations are identified in regional groundwater of Los Alamos watershed. The COCs with the most SLV exceedances in the regional aquifer of Los Alamos watershed are americium-241, cesium-137, uranium, and chromium (Exhibit 4-10). Other COCs, including uranium-235, uranium-238, strontium-90, and tritium are less common with fewer than five exceedances each. A total of 59 exceedances are observed and most of those observations were non-detect measurements (Exhibit 4-10).

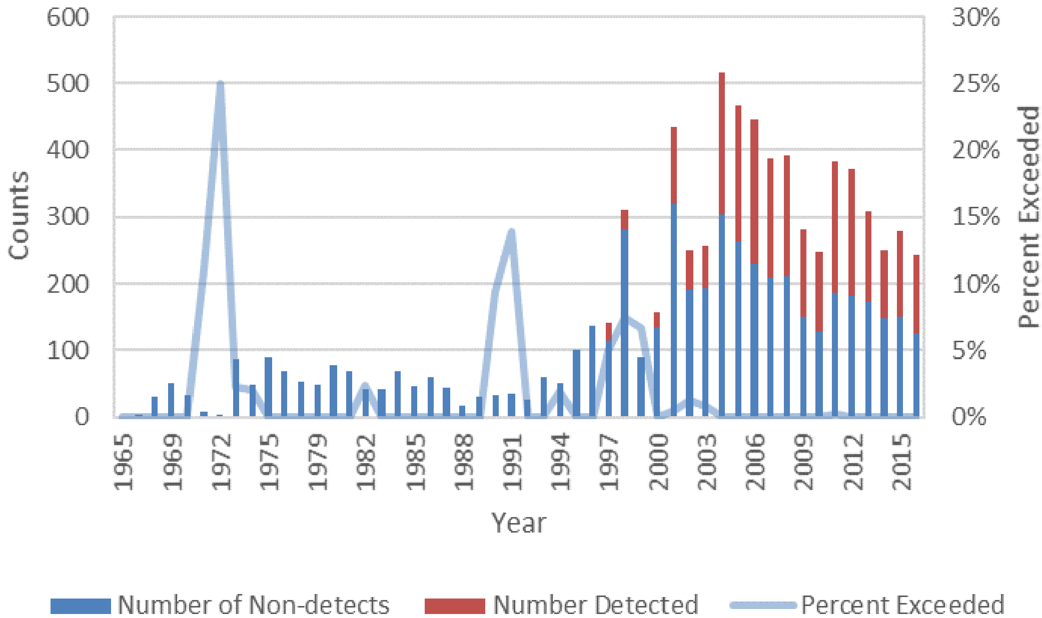
Groundwater observations of the regional aquifer span from 1965 to 2016 (Exhibit 4-11). Between 1965 and 1996, all COC measurements were non-detect. In contrast to alluvial and perched-intermediate groundwater, the regional aquifer has had three peaks of elevated COC concentrations, during the early 1970s, early 1990s, and late 1990s. The highest percentage of SLV exceedances was observed in 1972 at 25 percent, though all of these were in samples flagged as non-detects. Starting in 1997, with improvements in detection limits, detections are observed for the first time constituting approximately 20 percent of all observations. In 1998, the percentage of SLV exceedances peaks at seven percent, but begins a decreasing trend, ultimately reaching one percent in 2003. Since 2004, no samples in the regional aquifer in Los Alamos watershed have exceeded their respective SLVs.

EXHIBIT 4-10. EXCEEDANCES OF SCREENING LEVEL VALUES FOR CONTAMINANTS OF CONCERN IN REGIONAL GROUNDWATER IN LOS ALAMOS WATERSHED

PARAMETER†	DETECTED	EXCEEDS SLV	DETECTED AND EXCEEDS SLV	DETECTED BUT DNE SLV	ND BUT EXCEEDS SLV	ND AND DNE SLV
Americium-241	15	21	1	14	20	478
Cesium-137	2	13	-	2	13	656
Chromium (total)	572	7	7	565	-	180
Chromium (VI)	25	-	-	25	-	-
HMX	-	-	-	-	-	209
Perchlorate	408	-	-	408	-	229
Plutonium-238	9	-	-	9	-	740
Plutonium-239/240	4	-	-	4	-	750
RDX	-	-	-	-	-	208
Strontium-90	6	1	-	6	1	629
Technetium-99	-	-	-	-	-	33
Trinitrotoluene	-	-	-	-	-	209
Tritium	142	1	-	142	1	716
Uranium	526	11	8	518	3	43
Uranium-234	356	-	-	356	-	15
Uranium-235	3	4	1	2	3	102
Uranium-238	355	1	-	355	1	18
Total	2,423	59	17	2,406	42	5,215

† SLV sources are presented in Exhibit B-1 of Appendix B.
SLV = Screening level value
DNE = Does not exceed SLV
ND = Non-detect

EXHIBIT 4-11. NUMBER OF OBSERVATIONS AND EXCEEDANCES OF SCREENING LEVEL VALUES IN THE REGIONAL AQUIFER IN LOS ALAMOS WATERSHED



Regional aquifer SLV exceedances in Los Alamos watershed groundwater are distributed primarily among three canyons: Los Alamos, Gauje, and Pueblo Canyons. Strontium-90 only exceeds SLVs once in the regional groundwater despite multiple americium-241 and cesium-137 exceedances. As previously discussed, COCs discharged by SWMU 21-011(k) into DP Canyon include strontium-90, cesium-137, and americium-241. Despite each exhibiting strong adsorption behavior, these radionuclides differ in the mechanisms through which they adsorb to soils. Strontium-90 adsorption is dominated by associations with organic matter and cation-exchange with mineral surfaces whereas cesium-137 and americium-241 adsorption is dominated by cation-exchange (LA-13108-MS, Nyhan et al. 1985). As a result, organic-rich alluvial sediments may limit the mobility of strontium-90 beyond alluvial groundwater.[23]

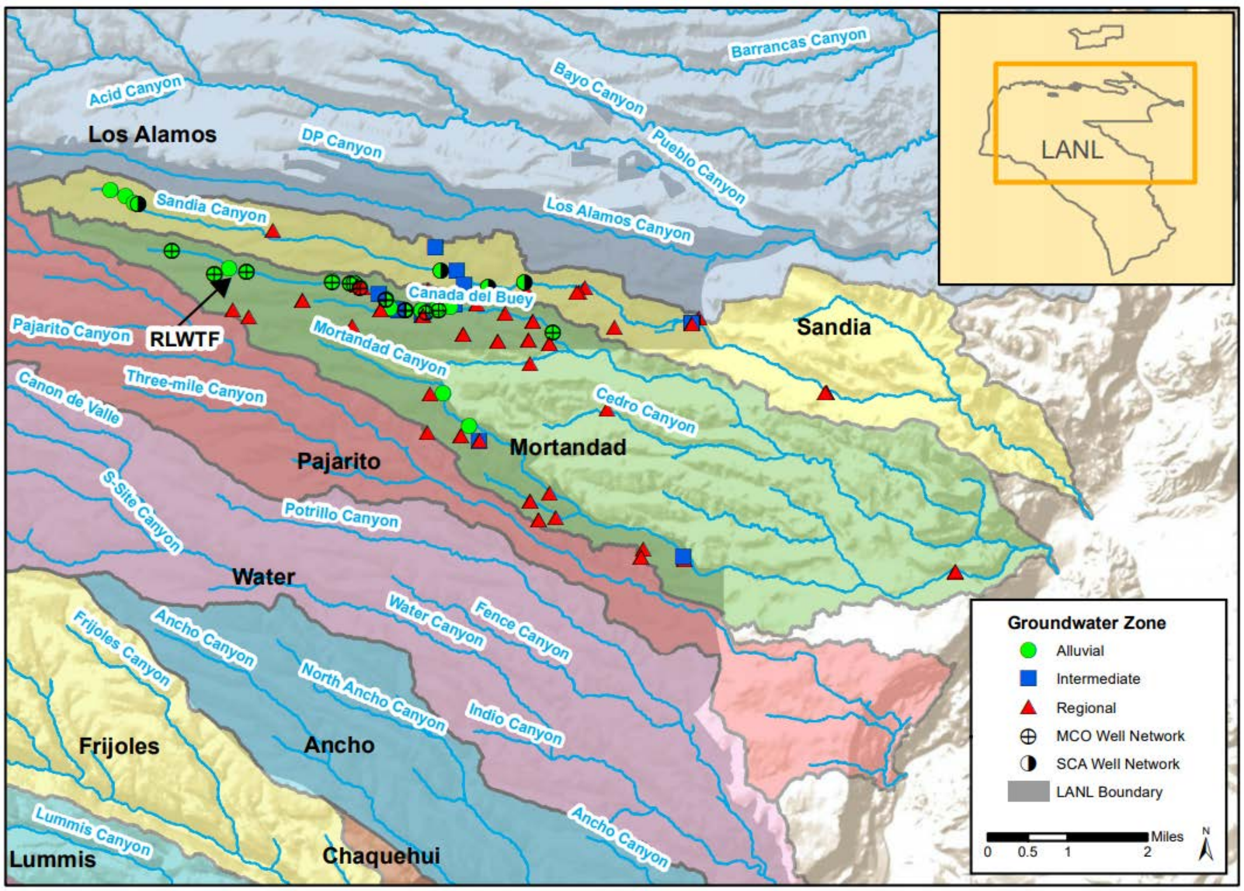
Chromium exceedances in the regional aquifer of Los Alamos watershed are found only in the R-9 well. R-9 is in Upper Los Alamos Canyon downstream from the TA-01 and TA-21 outfalls. The TA-01 and TA-21 outfalls are known sources of chromium contamination, although other sources of chromium contamination in Upper Los Alamos Canyon may exist (LA-UR-04-2714). Measurements of chromium in the regional aquifer started in 1980, and detections are reported starting in the late 1990s. Four exceedances are reported in 1997 with a maximum concentration of 1,060 µg/L at well R-9. In 1998, there were three exceedances and a maximum concentration of 2,980 µg/L. These maximum concentrations exceed the SLV of 50 µg/L.

[23] Americium-241 SLV exceedances in the regional aquifer are primarily non-detects (20 non-detect SLV exceedances out of a total of 21, see Exhibit 4-10). It is unlikely that americium-241 will be elevated in deeper groundwater zones because of its tendency to strongly adsorb to mineral surfaces. This is an unexpected observation and the results are presented for transparency.

4.3.2 MORTANDAD AND SANDIA WATERSHEDS

A total of 126 sampling locations are located within Mortandad and Sandia watersheds (Exhibit 4-12). The majority are in upper Mortandad and Sandia watersheds within Cañada del Buey and Sandia Canyon. This area contains 50 alluvial sampling locations and two primary sampling location networks: the Mortandad Canyon Observation (MCO) network with alluvial and intermediate sampling locations, and Sandia Canyon Alluvial (SCA) network with alluvial sampling locations. There are also 15 intermediate sampling locations in Mortandad and Sandia watersheds with a similar spatial distribution as the alluvial sampling locations. Finally, 61 regional sampling locations are distributed throughout Cañada del Buey, Mortandad, and Sandia Canyons.

EXHIBIT 4-12. SAMPLING LOCATIONS IN MORTANDAD AND SANDIA WATERSHEDS



Mortandad and Sandia watersheds are grouped in this section because of their strong hydrogeologic connection and the contamination that extends across both watersheds. In particular, the chromium plume is distributed between these two watersheds (discussed in more detail in Section 5.3). The following sub-sections characterize COCs, sources, and exceedances of SLVs in the three groundwater zones.

The SLV analysis for Mortandad and Sandia watersheds demonstrates that chromium exceedances are present throughout all three groundwater zones. However, there are clear distinctions in the group of COCs present within alluvial, intermediate and regional groundwater. Alluvial groundwater is characterized by exceedances of radionuclides, chromium, and perchlorate, while chromium and perchlorate are the primary COCs in perched-intermediate groundwater. The regional aquifer has the largest occurrence of chromium exceedances with 351, and only minor (i.e., less than 15) radionuclide exceedances.

4.3.2.1 Alluvial Groundwater

A total of 4,678 observations from 50 unique sampling locations were identified in alluvial groundwater of Mortandad and Sandia watersheds. There are 732 exceedances of the SLVs (out of the total 4,678 observations) and most are non-detect for tritium, strontium-90, perchlorate, and cesium-137 in alluvial groundwater (Exhibit 4-13). COCs like plutonium-239/240, plutonium-238, americium-241, and chromium are less common, with respective exceedance counts of the SLVs ranging from 23 (3 percent) to 58 (or three and eight percent of total exceedances, respectively).

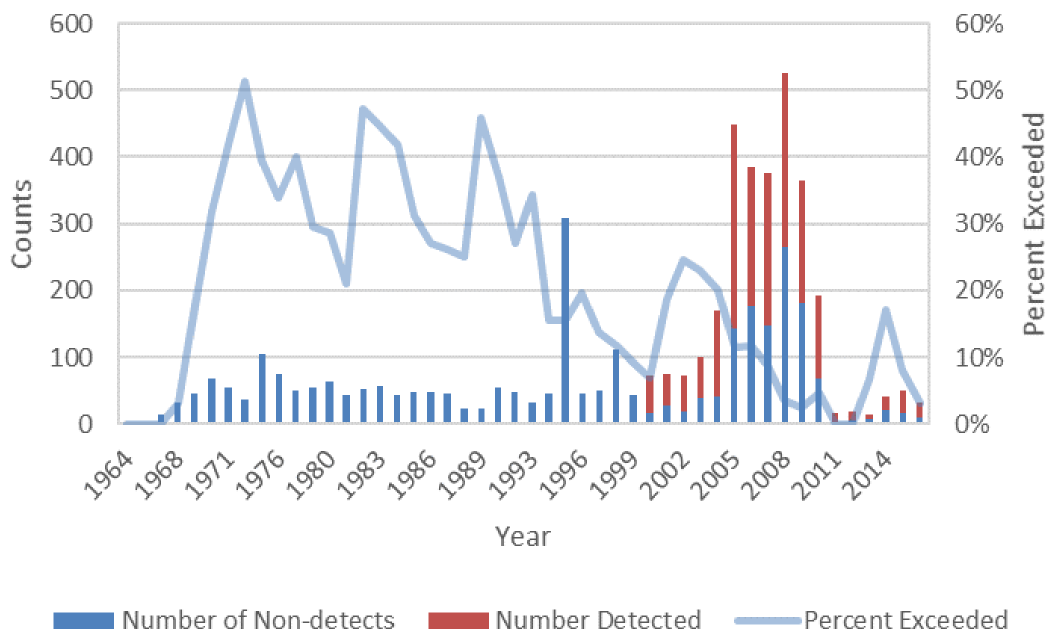
EXHIBIT 4-13. EXCEEDANCES OF SCREENING LEVEL VALUES FOR CONTAMINANTS OF CONCERN IN ALLUVIAL GROUNDWATER IN MORTANDAD AND SANDIA WATERSHEDS

PARAMETER†	DETECTED	EXCEEDS SLV	DETECTED AND EXCEEDS SLV	DETECTED BUT DNE SLV	ND BUT EXCEEDS SLV	ND AND DNE SLV
Americium-241	116	43	5	111	38	183
Cesium-137	4	69	-	4	69	406
Chromium (total)	274	23	23	251	-	289
Chromium (VI)	3	-	-	3	-	8
HMX	-	-	-	-	-	52
Perchlorate	325	149	138	187	11	44
Plutonium-238	60	48	4	56	44	460
Plutonium-239/240	55	58	5	50	53	462
RDX	-	-	-	-	-	52
Strontium-90	140	153	97	43	56	158
Technetium-99	17	-	-	17	-	3
Trinitrotoluene	-	-	-	-	-	52
Tritium	131	189	-	131	189	101
Uranium	323	-	-	323	-	81
Uranium-234	157	-	-	157	-	37
Uranium-235	-	-	-	-	-	29
Uranium-238	165	-	-	165	-	31
Total	1,770	732	272	1,498	460	2,448

† SLV sources are presented in Exhibit B-1 of Appendix B.
SLV = Screening level value
DNE = Does not exceed SLV
ND = Non-detect

Analyzed groundwater data span from 1964 to 2016 (Exhibit 4-14). Between 1964 and 1999, all COC measurements are non-detect despite the highest percentage of SLV exceedances occurring during this time. During the late 1960s and early 1970s, exceedances ranged between three to 51 percent annually. Starting in 2000, with improvements in detection limits, COCs are detected in alluvial groundwater for the first time, constituting approximately 76 percent of all observations. Between 2002 and 2016, SLV exceedances show a decreasing trend from 25 percent. Starting in 2007, SLV exceedances generally remained below 10 percent except in 2014 when exceedances spiked to 17 percent.

EXHIBIT 4-14. NUMBER OF OBSERVATIONS AND EXCEEDANCES OF SCREENING LEVEL VALUES IN ALLUVIAL GROUNDWATER IN MORTANDAD AND SANDIA WATERSHEDS

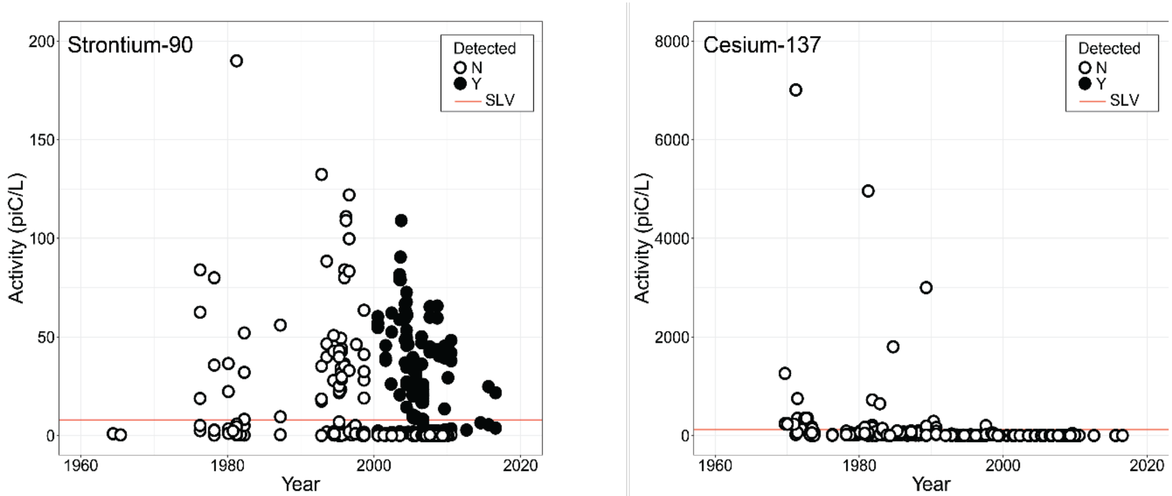


Observations from alluvial groundwater sampling locations represent 50 percent of all exceedances within Mortandad and Sandia watersheds. The cluster of alluvial sampling locations with exceedances are in upper Cañada del Buey within TA-05, -60, -35, -55, and -48, most of which are sampling locations in the MCO sampling location network. Most alluvial groundwater exceedances are for tritium, which comprises 26 percent of all exceedances. The sampling locations with tritium exceedances are downstream of the TA-50 RLWTF outfall. This outfall discharges to Effluent Canyon and has been the primary source of radioactive contamination in middle Cañada del Buey since the 1960s.

Records of discharge through the TA-50 RLWTF outfall suggest that between 1963 and 2004, 823 curies of tritium, two curies of cesium-137, and 1.5 curies of strontium-89/90 were released (LA-UR-06-6752). However, most of the cesium-137 and strontium-90 was released prior to the 1980s. Therefore, radioactive decay from these short-lived radionuclides (half-life of less than or equal to 30 years) has likely reduced the activities of these COCs in groundwater. This analysis shows that strontium-90 and cesium-137 activities in alluvial sampling locations begin decreasing in the 1970s (Exhibit 4-15). The decreasing pattern may be caused by a combination of reduced discharge and radioactive decay.

Perchlorate SLV exceedances are prevalent in alluvial groundwater and represent 20 percent of all exceedances (Exhibit 4-13). The relevant sampling locations are similarly downstream from the RLWTF, but SLV exceedances are primarily observed after the year 2000, which may coincide with the start of measurement of liquid effluent releases of perchlorate from RLWTF in 2000 (LA-UR-06-6752).

EXHIBIT 4-15. STRONTIUM-90 AND CESIUM-137 EXCEEDANCES IN ALLUVIAL SAMPLING LOCATIONS IN MORTANDAD AND SANDIA WATERSHEDS



Outfall flow through Effluent Canyon is the primary source of surface water for middle Cañada del Buey down to the confluence with Ten Site Canyon. Alluvium thickness along this segment generally increases from west to east (i.e., with increasing distance downstream).[24]

The observed co-location of tritium, strontium-90, cesium-90 and perchlorate in the alluvial groundwater of Mortandad watershed is likely due to the location of the common source, TA-50 outfall RWLTF. The differences in chemical behavior between these COCs generally results in the partitioning between groundwater zones; radionuclides strongly adsorb to fine-grained sediments near the surface and tritium and perchlorate typically remain in the aqueous phase and migrate to deeper zones of the groundwater system.[25]

4.3.2.2 Intermediate Groundwater

A total of 3,117 observations from 15 unique sampling locations are identified in intermediate groundwater of Mortandad and Sandia watershed. The primary COCs with SLV exceedances are chromium and perchlorate (Exhibit 4-16). Tritium is a minor COC with only one exceedance. A total of 258 exceedances (eight percent) are observed and all exceedances are detected (Exhibit 4-16).

[24] The western portion of the segment overlies welded tuffs that progressively become older and more porous to the east. Therefore, the western reach near the confluence with Effluent Canyon consists of thinner saturated alluvium compared to the thicker alluvium near the confluence with Ten Site Canyon (LA-UR-06-6752).

[25] Concentrations of radionuclides such as cesium-137 and strontium-90 in alluvial groundwater are driven by their association (cation exchange) with sediment particles. These radionuclides bind strongly to mineral surfaces and are less mobile than tritium and perchlorate. Upon release, these radionuclides are more likely to adsorb to sediment and be mobilized in surface water through resuspension following increased discharge from snowmelt, summer storms, and post-fire runoff events. Though once deposited in streambeds, they can infiltrate to the alluvial groundwater.

EXHIBIT 4-16. EXCEEDANCES OF SCREENING LEVEL VALUES FOR CONTAMINANTS OF CONCERN IN INTERMEDIATE GROUNDWATER IN MORTANDAD AND SANDIA WATERSHEDS

PARAMETER†	DETECTED	EXCEEDS SLV	DETECTED AND EXCEEDS SLV	DETECTED BUT DNE SLV	ND BUT EXCEEDS SLV	ND AND DNE SLV
Americium-241	4	-	-	4	-	179
Cesium-137	-	-	-	-	-	177
Chromium (total)	408	136	136	272	-	139
Chromium (VI)	14	5	5	9	-	4
HMX	-	-	-	-	-	68
Perchlorate	241	116	116	125	-	25
Plutonium-238	2	-	-	2	-	182
Plutonium-239/240	2	-	-	2	-	182
RDX	-	-	-	-	-	68
Strontium-90	2	-	-	2	-	182
Technetium-99	4	-	-	4	-	2
Trinitrotoluene	-	-	-	-	-	68
Tritium	203	1	1	202	-	44
Uranium	466	-	-	466	-	53
Uranium-234	171	-	-	171	-	13
Uranium-235	-	-	-	-	-	30
Uranium-238	153	-	-	153	-	31
Total	1,670	258	258	1,412	-	1,447

† SLV sources are presented in Exhibit B-1 of Appendix B.
SLV = Screening level value
DNE = Does not exceed SLV
ND = Non-detect

Perched-intermediate groundwater data are more recent than alluvial zone groundwater observations, spanning between 1998 to 2017 (Exhibit 4-17). SLV exceedances range between one and 16 percent annually. Beginning in 2009, the percentage of exceedances exhibit an increasing trend, reaching 17 percent in 2016. In 2017, the counts and percentage of SLV exceedances drop dramatically because of only two observations during this year.

Perchlorate SLV exceedances are observed in upper and middle Mortandad watershed, downstream from the TA-50 RLWTF outfall, a known source of perchlorate and radionuclides. The chromium plume in the regional aquifer is adjacent to and overlapping with the eastern portion of the perchlorate plume, as shown by recent environmental assessments performed by LANL (Exhibit 4-18) (DOE 2015).[26] Most remedial activity in these watersheds is focused on the chromium plume under the Chromium

[26] The perchlorate plume in Exhibit 4-18 includes perched-intermediate wells MCOI-5 and MCOI-6, and regional aquifer wells R-15 and R-61. Detected SLV exceedances were identified for sampling locations MCOI-5 (total of 41), MCOI-6 (total of 48), and R-16 S4 (total of 1) but none for R-15. This inconsistency will be further evaluated during groundwater injury quantification.

Investigation Monitoring Group. However, chromium remediation efforts are believed to also address perchlorate contamination (DOE 2015).

EXHIBIT 4-17. NUMBER OF OBSERVATIONS AND EXCEEDANCES OF SCREENING LEVEL VALUES IN INTERMEDIATE GROUNDWATER IN MORTANDAD AND SANDIA WATERSHEDS

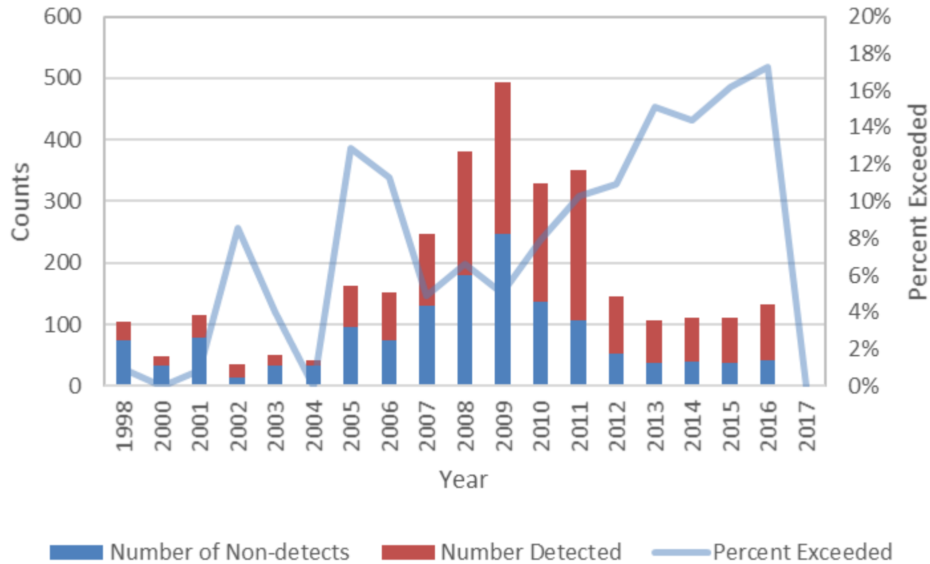
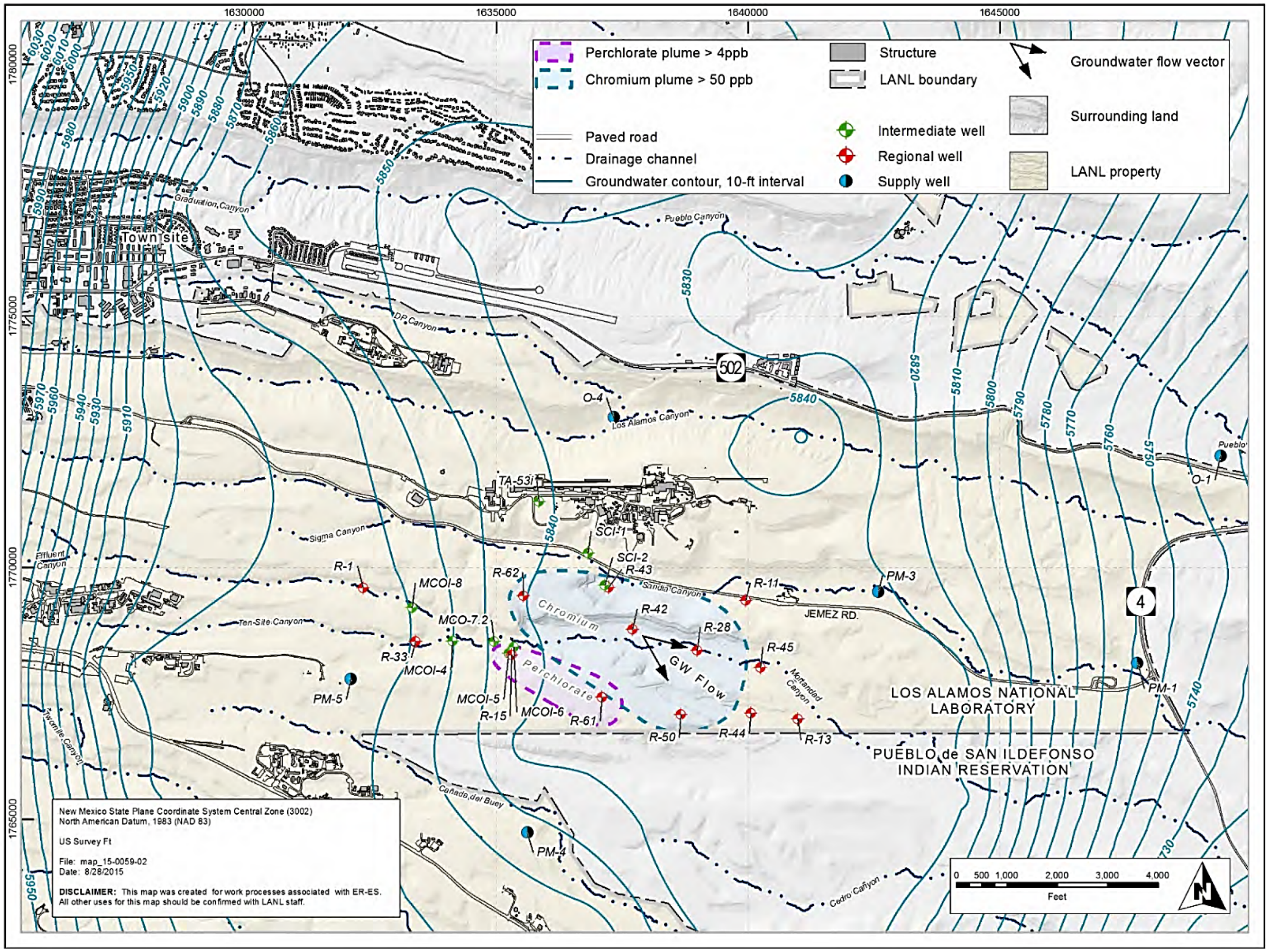


EXHIBIT 4-18. CHROMIUM AND PERCHLORATE PLUMES IN MORTANDAD AND SANDIA WATERSHEDS (FIGURE 1-4 FROM DOE 2015)



Note: This exhibit shows the chromium plume in the regional aquifer and the perchlorate plume that is defined by perched-intermediate and regional groundwater wells.

4.3.2.3 Regional Groundwater

A total of 17,510 observations from 61 sampling locations are identified in regional groundwater of Mortandad and Sandia watershed. Chromium has the most SLV exceedances in the regional aquifer in Mortandad and Sandia watersheds (Exhibit 4-19). Other COCs, including americium-241, cesium-137, strontium-90, total uranium, and uranium isotopes such as uranium-234, -235, and -238 are less common with fewer than 10 exceedances (0.04 percent). A total of 369 SLV exceedances are observed and most are detected (Exhibit 4-19).

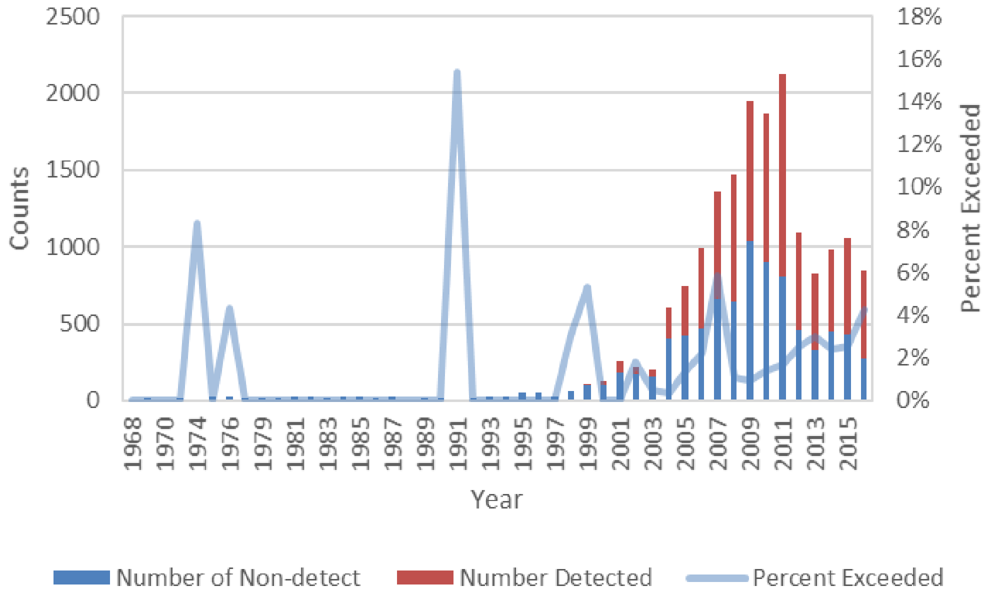
Regional aquifer groundwater observations in Mortandad and Sandia watersheds span from 1968 to 2016 (Exhibit 4-20). Between 1968 and 1998, all COC measurements were non-detects. There are some SLV exceedances during this time, with exceedance peaks in 1974, 1976, 1991, and 1999. Fewer than 100 groundwater observations are available annually between 1968 and 1998. Starting in 1999, detections are observed for the first time with improvements in detection limits, and the number of observations increased by a factor of two. Additionally, annual percent SLV exceedances start to gradually increase in 2004 but have remained below five percent.

EXHIBIT 4-19. EXCEEDANCES OF SCREENING LEVEL VALUES FOR CONTAMINANTS OF CONCERN IN REGIONAL GROUNDWATER IN MORTANDAD AND SANDIA WATERSHEDS

PARAMETER†	DETECTED	EXCEEDS SLV	DETECTED AND EXCEEDS SLV	DETECTED BUT DNE SLV	ND BUT EXCEEDS SLV	ND AND DNE SLV
Americium-241	5	7	-	5	7	891
Cesium-137	-	3	-	-	3	958
Chromium (total)	2,696	339	339	2,357	-	411
Chromium (VI)	104	12	12	92	-	4
HMX	-	-	-	-	-	520
Perchlorate	1,319	1	1	1,318	-	431
Plutonium-238	3	-	-	3	-	986
Plutonium-239/240	1	-	-	1	-	989
RDX	1	-	-	1	-	518
Strontium-90	9	1	-	9	1	955
Technetium-99	1	-	-	1	-	59
Trinitrotoluene	-	-	-	-	-	520
Tritium	296	-	-	296	-	1,156
Uranium	2,732	2	2	2,730	-	108
Uranium-234	842	1	1	841	-	12
Uranium-235	-	2	-	-	2	113
Uranium-238	822	1	-	822	1	34
Total	8,831	369	355	8,476	14	8,665

† SLV sources are presented in Exhibit B-1 of Appendix B.
SLV = Screening level value
DNE = Does not exceed SLV
ND = Non-detect

EXHIBIT 4-20. NUMBER OF OBSERVATIONS AND EXCEEDANCES OF SCREENING LEVEL VALUES IN THE REGIONAL AQUIFER IN MORTANDAD AND SANDIA WATERSHEDS



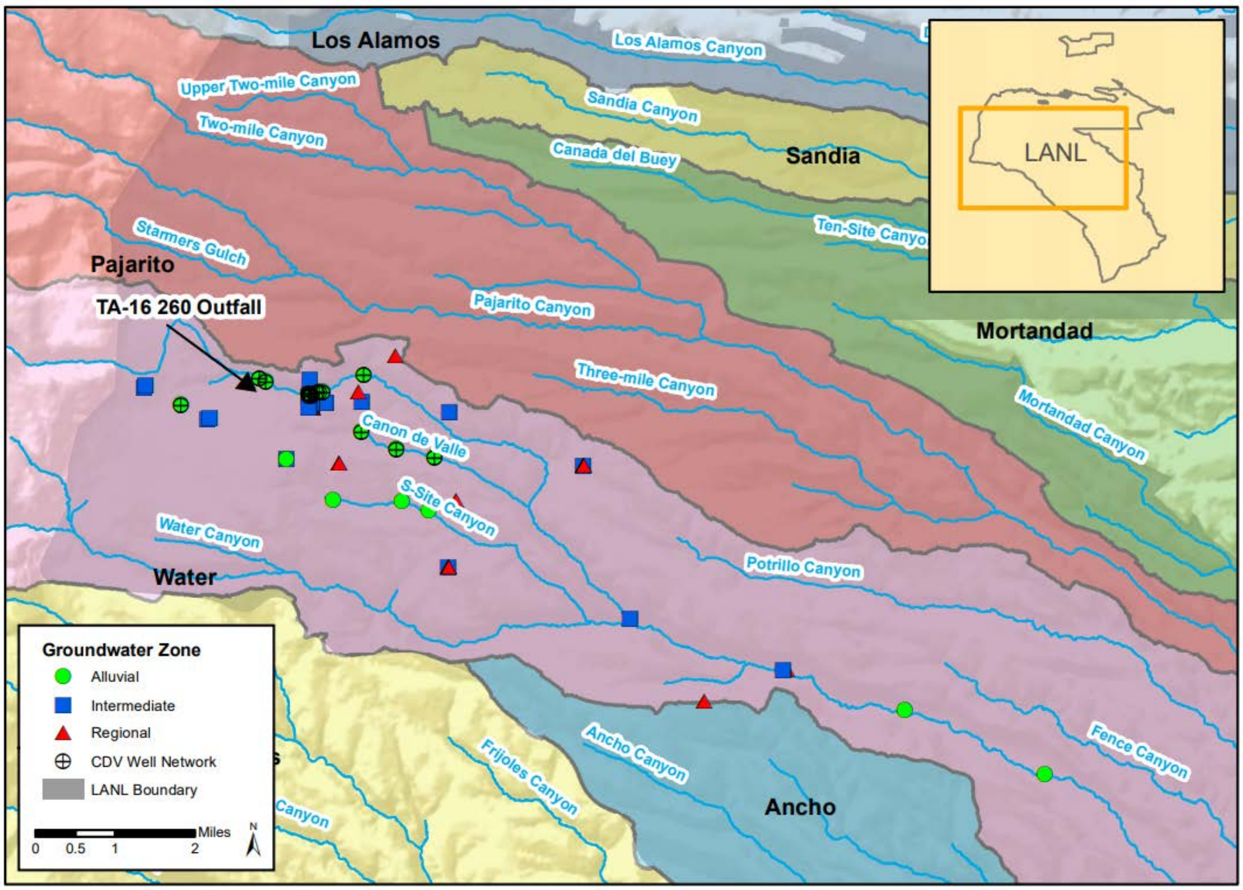
Chromium exceedances in the regional aquifer are the focus of extensive research under the Chromium Investigation Monitoring Group. Additional information on the chromium plume is provided in Section 5.3. Americium-241 SLV exceedances are co-located with chromium exceedances in Pajarito Mesa (PM) PM-1 and PM-3 in Sandia watershed, which are both water supply wells. Maximum concentrations for PM-1 and PM-3 are 64 and 136 pCi/L, respectively. With an SLV of 1.2 pCi/L, the PM wells of Sandia watershed exceed the SLV for americium-241 by more than two orders of magnitude. In Mortandad watershed, PM-4 and R-14 S1 have exceedances of cesium-137 and uranium-235, respectively. However, Test Well 8 has exceedances of multiple COCs like americium-241, cesium-137, strontium-90, and uranium-235. The RWLTF in Mortandad watershed has been a source of multiple radionuclides to groundwater and most likely explains the greater suite of contaminants found in the groundwater of Mortandad watershed. Sandia watershed has fewer exceedances of radionuclides and is dominated by chromium exceedances derived from releases of the TA-03 power plant. The suite of COCs with elevated levels in the regional aquifer of Mortandad and Sandia watershed demonstrate that the regional aquifer is the ultimate repository for surface contamination from the RLWTF and TA-03 power plant. Released radionuclides and chromium have infiltrated through the unsaturated zone and ultimately concentrated in the area monitored by the Chromium Investigation Monitoring Group.

4.3.3 WATER WATERSHED

A total of 60 alluvial, perched, and regional aquifer sampling locations can be found within Water watershed, of which 26 are part of the Cañon de Valle (CDV) sampling location network (Exhibit 4-21). There are 21 alluvial sampling locations, 22 perched-intermediate sampling locations, and 17 regional aquifer sampling locations. Most sampling locations are located in Cañon de Valle with fewer locations in Potrillo, S-site, and Water sub-canyons. The following sections discuss COCs exceedances throughout Water watershed within the alluvial, perched-intermediate, and regional groundwater.

Water watershed is dominated by RDX exceedances throughout the three groundwater zones; though most are found in alluvial and intermediate groundwater. Chromium also exceeds its SLV throughout the three zones of groundwater. In alluvial groundwater, COCs associated with the production of explosives like TNT and perchlorate have exceedances. Total uranium and uranium-235 are observed in all the groundwater zones but are minor COCs, with the exception of alluvial groundwater. The earliest year of observation is 1997, and effluent discharge into Water watershed preceded the start of monitoring and sample collection. Additionally, in all groundwater zones, the highest percentage of exceedances are in the late 1990s and early 2000s. Therefore, incomplete data preceding 1997 limits understanding of the historical extent and distribution of contamination in Water watershed.

EXHIBIT 4-21. SAMPLING LOCATIONS IN WATER WATERSHED



4.3.3.1 Alluvial Groundwater

A total of 2,851 observations from 21 sampling locations are available in the alluvial groundwater of Water watershed. Out of these observations, there are 152 SLV exceedances and the majority of those observations are detected results (Exhibit 4-22). Most SLV exceedances are RDX and uranium in alluvial groundwater, and chromium, TNT, and perchlorate have fewer than 15 exceedances each (Exhibit 4-22).

Groundwater observations of the alluvial aquifer span from 1997 to 2016 (Exhibit 4-23). Throughout the observation period, annual detected observations ranged between 33 and 71 percent. The SLV exceedances were highest during 1998 at 26 percent. After 1998, percent exceedances began a decreasing trend and have been less than five percent since 2003.

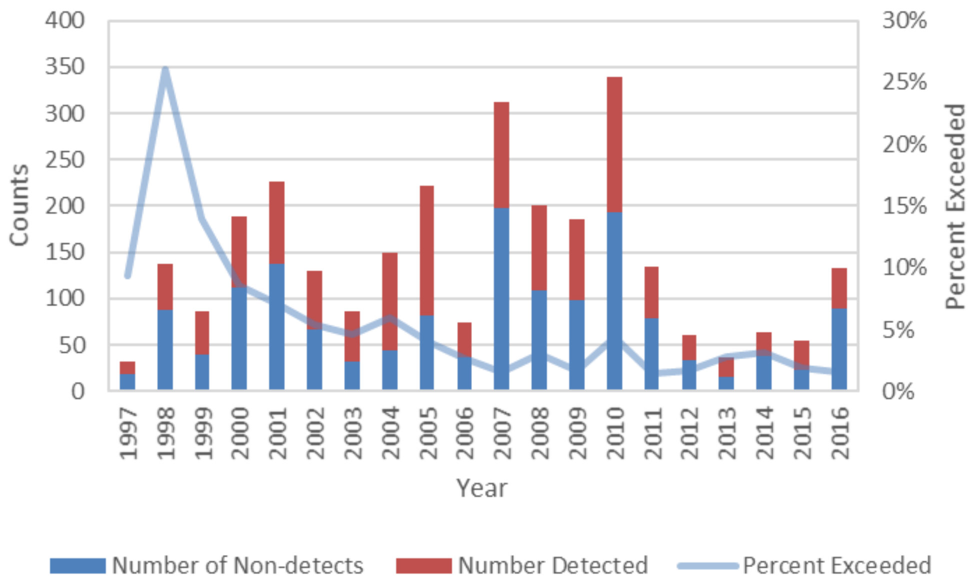
EXHIBIT 4-22. EXCEEDANCES OF SCREENING LEVEL VALUES FOR CONTAMINANTS OF CONCERN IN ALLUVIAL GROUNDWATER IN WATER WATERSHED

PARAMETER†	DETECTED	EXCEEDS SLV	DETECTED AND EXCEEDS SLV	DETECTED BUT DNE SLV	ND BUT EXCEEDS SLV	ND AND DNE SLV
Americium-241	-	-	-	-	-	66
Cesium-137	-	-	-	-	-	65
Chromium (total)	245	15	15	230	-	364
Chromium (VI)‡	-	-	-	-	-	-
HMX	265	-	-	265	-	84
Perchlorate	98	7	3	95	4	129
Plutonium-238	-	-	-	-	-	66
Plutonium-239/240	3	-	-	3	-	63
RDX	242	104	103	139	1	107
Strontium-90	2	-	-	2	-	64
Technetium-99‡	-	-	-	-	-	-
Trinitrotoluene	15	4	2	13	2	324
Tritium	174	-	-	174	-	8
Uranium	208	22	-	208	22	98
Uranium-234	32	-	-	32	-	34
Uranium-235‡	-	-	-	-	-	-
Uranium-238	37	-	-	37	-	29
Total	1,321	152	123	1,198	29	1,501

† SLV sources are presented in Exhibit B-1 of Appendix B.
‡ This contaminant was not measured in the groundwater samples collected from sampling locations in the area of interest.
SLV = Screening level value
DNE = Does not exceed SLV
ND = Non-detect

Five alluvial sampling locations have exceedances for additional COCs (uranium, chromium, TNT, or perchlorate) and are co-located with RDX exceedances in alluvial sampling locations of Cañon de Valle. The five sampling locations are located along the CDV-2W reach of Cañon de Valle near the TA-16 260 Outfall; the TA-16 260 Outfall is the primary source of COCs associated with explosive compounds like TNT and RDX in this area (LA-UR-11-5478). Perchlorate is likely sourced from the same outfall because of its similar use in weapons production. Uranium contamination in the CDV-2W reach of Cañon de Valle is likely derived from the neighboring TA-14. Historical laboratory activities in TA-14 include radioactive explosive development and testing (LA-UR-12-0072). Consequently, the TA-14 site (also known as the Q-Site) is one of the most important sources of uranium to Cañon de Valle (LA-UR-11-5478).

EXHIBIT 4-23. NUMBER OF OBSERVATIONS AND EXCEEDANCES OF SCREENING LEVEL VALUES IN ALLUVIAL GROUNDWATER IN WATER WATERSHED



4.3.3.2 Intermediate Groundwater

A total of 3,301 observations from 22 sampling locations are available in the intermediate groundwater of Water watershed. Out of those observations, there are 227 SLV exceedances and the majority are detected results (Exhibit 4-24). COCs with the most exceedances are RDX and chromium, and COCs including americium-241, perchlorate, TNT, and uranium-235 are less common with only one exceedance each (Exhibit 4-24).

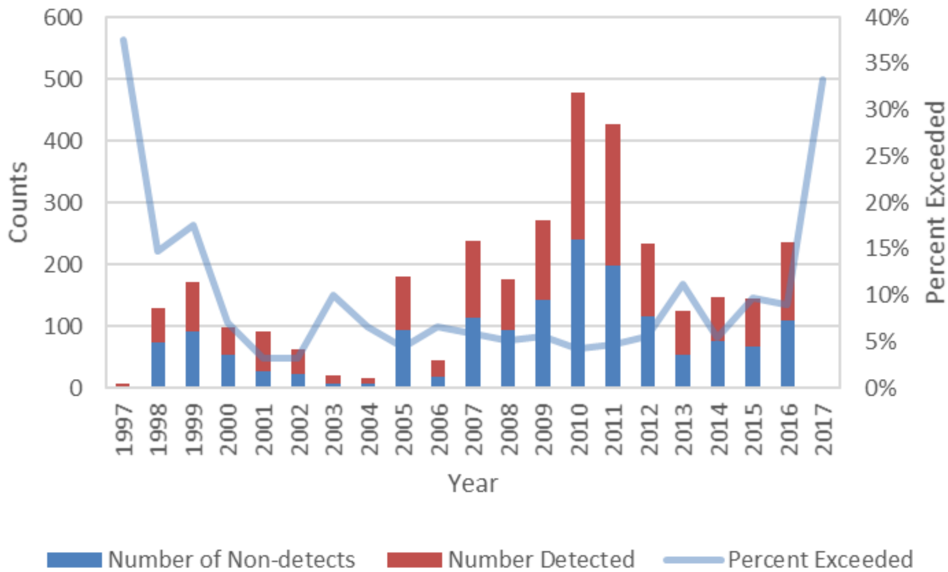
COC measures in perched-intermediate groundwater are available between 1997 to 2017 (Exhibit 4-25). Throughout the observation period, annual detected observations range between 43 and 71 percent. Exceedances are highest during 1997 and 2017 with 38 and 33 percent, respectively. Between 2000 and 2016, the percentage of SLV exceedances decreases and are less than 12 percent between 2003 and 2016. Percent annual SLV exceedances increases dramatically to 33 percent in 2017. However, only three observations are reported in 2017 compared to 2016, which had 235 observations.

EXHIBIT 4-24. EXCEEDANCES OF SCREENING LEVEL VALUES OF CONTAMINANTS OF CONCERN IN INTERMEDIATE GROUNDWATER IN WATER WATERSHED

PARAMETER†	DETECTED	EXCEEDS SLV	DETECTED AND EXCEEDS SLV	DETECTED BUT DNE SLV	ND BUT EXCEEDS SLV	ND AND DNE SLV
Americium-241	1	1	1	-	-	142
Cesium-137	-	-	-	-	-	142
Chromium (total)	276	46	46	230	-	203
Chromium (VI)	3	-	-	3	-	6
HMX	187	-	-	187	-	125
Perchlorate	183	1	-	183	1	46
Plutonium-238	-	-	-	-	-	141
Plutonium-239/240	2	-	-	2	-	138
RDX	220	177	175	45	2	90
Strontium-90	-	-	-	-	-	141
Technetium-99	-	-	-	-	-	4
Trinitrotoluene	34	1	1	33	-	273
Tritium	103	-	-	103	-	63
Uranium	389	-	-	389	-	45
Uranium-234	149	-	-	149	-	10
Uranium-235	-	1	-	-	1	22
Uranium-238	148	-	-	148	-	11
Total	1,695	227	223	1,472	4	1,602

† SLV sources are presented in Exhibit B-1 of Appendix B.
SLV = Screening level value
DNE = Does not exceed SLV
ND = Non-detect

EXHIBIT 4-25. NUMBER OF OBSERVATIONS AND EXCEEDANCES OF SCREENING LEVEL VALUES IN INTERMEDIATE GROUNDWATER IN WATER WATERSHED



Chromium SLV exceedances are found primarily in the R-25 OB, R-25 S1, and R-25 S2 intermediate sampling locations of Cañon de Valle. Maximum chromium concentrations are 430, 3,080, and 504 µg/L for R-25 OB, R-25 S1, and R-25 S2, respectively. The chromium SLV is 50 µg/L, therefore the maximum concentrations of these sampling locations are various orders of magnitude greater than the SLV. The location of chromium exceedances corresponds to the location of the RDX plume in perched-intermediate groundwater (see Section 5.3 of this report). The 260 Outfall is also a major source of chromium to the intermediate groundwater of Cañon de Valle (LA-UR-11-5478). Therefore, co-location of chromium with the RDX plume is expected based on the same effluent source.

4.3.3.3 Regional Aquifer

A total of 3,946 observations from 17 sampling locations are identified in the regional groundwater of Water watershed. The most encountered COC in regional groundwater is RDX (Exhibit 4-26). Chromium and uranium-235 are minor COCs with only one exceedance each. A total of 13 exceedances are observed and the majority are detected (Exhibit 4-26).

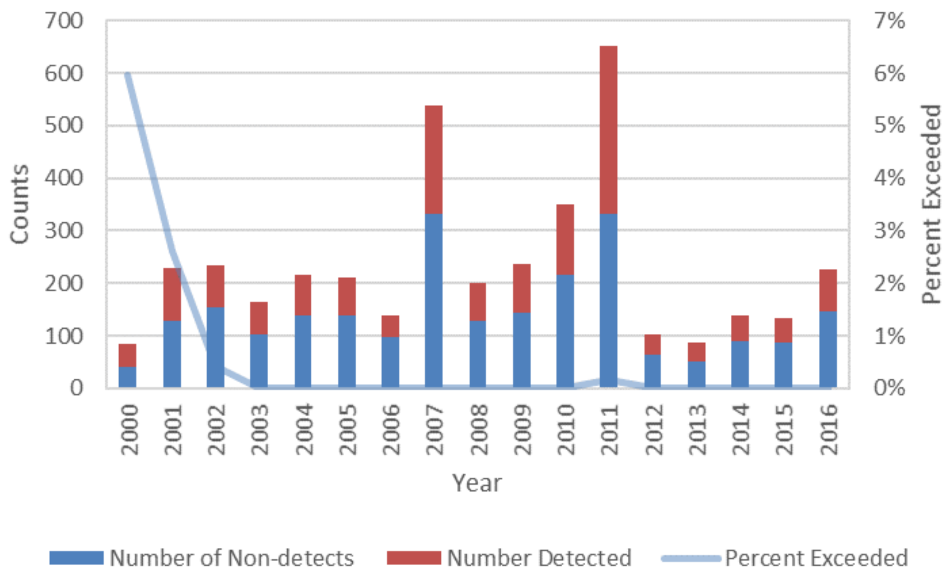
COC observations in regional aquifer groundwater are available between 2000 and 2016 (Exhibit 4-27). Throughout this period, annual detected observations range between 30 and 50 percent. SLV exceedances are highest during the year 2000 with six percent. From 2003 onward, there are no SLV exceedances, except for 2011, during which the percentage of exceedances is less than one percent.

EXHIBIT 4-26. EXCEEDANCES OF SCREENING LEVEL VALUES FOR CONTAMINANTS OF CONCERN IN THE REGIONAL AQUIFER IN WATER WATERSHED

PARAMETER†	DETECTED	EXCEEDS SLV	DETECTED AND EXCEEDS SLV	DETECTED BUT DNE SLV	ND BUT EXCEEDS SLV	ND AND DNE SLV
Americium-241	-	-	-	-	-	125
Cesium-137	-	-	-	-	-	123
Chromium (total)	342	1	1	341	-	378
Chromium (VI)‡	-	-	-	-	-	-
HMX	37	-	-	37	-	326
Perchlorate	196	-	-	196	-	136
Plutonium-238	-	-	-	-	-	122
Plutonium-239/240	1	-	-	1	-	121
RDX	69	11	11	58	-	297
Strontium-90	-	-	-	-	-	122
Technetium-99	-	-	-	-	-	2
Trinitrotoluene	29	-	-	29	-	335
Tritium	78	-	-	78	-	183
Uranium	531	-	-	531	-	96
Uranium-234	132	-	-	132	-	9
Uranium-235	1	1	1	-	-	14
Uranium-238	134	-	-	134	-	7
Total	1,550	13	13	1,537	-	2,396

† SLV sources are presented in Exhibit B-1 of Appendix B.
‡ This contaminant was not measured in the groundwater samples collected from sampling locations in the area of interest.
SLV = Screening level value
DNE = Does not exceed SLV
ND = Non-detect

EXHIBIT 4-27. NUMBER OF OBSERVATIONS AND EXCEEDANCES OF SCREENING LEVEL VALUES IN THE REGIONAL AQUIFER IN WATER WATERSHED



In the regional aquifer of Water watershed, chromium contamination and other radionuclides is less evident than for the alluvial and perched-intermediate groundwater. RDX contamination is dominant with 11 SLV exceedances (0.3 percent). However, the extent of contamination is smaller than that observed in alluvial and intermediate groundwater, which have each more than 100 SLV exceedances. For more detailed information on the RDX plume, refer to Section 5.4.4.

4.4 SCREENING LEVEL VALUE (SLV) ANALYSIS SUMMARY

The spatial distribution of groundwater COC SLV exceedances in and around LANL illustrates three primary areas of contamination: upper Los Alamos watershed, the Chromium Investigation Monitoring Group of Mortandad/Sandia watersheds, and underlying Cañon de Valle canyon in Water watershed. Each area of contamination has a unique vertical distribution of COCs in accordance with the geological structure of the area and the chemical behavior of the contaminants.

Radionuclides in upper Los Alamos watershed encountered downstream from several SWMUs and the decommissioned TA-02 Omega West Reactor are concentrated in the alluvial groundwater and are likely retained in this zone as a result of adsorption on mineral surfaces. Fewer COC exceedances of SLVs are observed in the deeper intermediate and regional groundwater. The variable spatial and temporal incidence of alluvial groundwater poses a challenge in defining the extent of this contamination (i.e., a plume). Nonetheless, the alluvial groundwater is a possible source of COCs that could potentially migrate deeper to the more continuous regional aquifer.

Contamination in Mortandad and Sandia watersheds is characterized by the chromium plume in the regional aquifer (see Section 5.3). In this area, radionuclides and perchlorate are co-located with chromium contamination in the alluvial and intermediate groundwater. Remedial activities of the

Chromium Investigation Monitoring Group are expected to include removal of chromium contamination and the co-located perchlorate contamination.

Finally, RDX contamination is concentrated underlying Cañon de Valle canyon in Water watershed (see Section 5.4). The SLV analysis identified perchlorate, TNT, and chromium in alluvial and intermediate sampling locations of Cañon de Valle. The SLV exceedance analysis demonstrates that contamination is present primarily in the unsaturated zone (alluvial and intermediate groundwater), and that the intermediate groundwater is a potential source of contamination to the regional groundwater of Cañon de Valle.

CHAPTER 5 | PLUME EVALUATIONS

5.1 INTRODUCTION

This chapter presents a detailed evaluation of the available chromium and RDX data and presents a summary of the data compilation and clean-up process. These two COCs comprise the greatest known extent of groundwater contamination at LANL. This chapter evaluates contaminant plumes through four metrics: 1) a summary of what is known about the pathways for contaminants to reach groundwater, 2) a description of the monitoring, investigations, and remediation of each contaminant that has occurred to-date, 3) a characterization of the available groundwater data in each zone of groundwater (alluvial, perched-intermediate, and regional), and 4) an evaluation of existing information regarding contaminant plume parameters relevant to the NRDA. For both chromium and RDX, the same process was applied for compiling and cleaning the data and for identifying and characterizing sampling locations pertinent to this evaluation.[27]

5.2 DATA PREPARATION

Details regarding data preparation and evaluation methods are described in Chapter 2, Appendix A, and Appendix C. For the chromium and RDX plume evaluations, the most recent Intellus contaminant data available through the online interface were downloaded and used, rather than the backup copy of the database provided by DOE on August 22, 2017.[28] The most recent data allowed for comparisons to sample results in recently published LANL reports (those published since 2017). The data cleanup SOP (Appendix A and Appendix C) was applied to the recent chromium and RDX sample results from Intellus and assigned data quality categories. In some cases where multiple results existed for a single sample, the data quality category was used to identify the best result.

Procedures were also standardized for identifying groundwater monitoring locations relevant to each plume evaluation. First, information from three location data sources was compiled:

1. The sampling location information table from the DOE database backup file originally received in August 2017.
2. The sampling location information table from the Intellus New Mexico online mapping tool.
3. The sampling locations included in the RDX and chromium datasets themselves (also from Intellus New Mexico online).

Next, the sampling locations were mapped in ArcMap (a geospatial information system [GIS] software) and relevant locations were identified for the plume evaluations using extended examination areas centered around the known plume locations and release sites (i.e., extended as compared to the

[27] In many instances, but perhaps not all, the location table includes location_ids for individual wells in addition to their well screens. Therefore, this report considers sampling locations to be defined as the x, y, z location of groundwater sample collection (the well and screen depth interval), as opposed to the x, y location of an individual well (i.e., reported counts of sampling locations will likely be higher than counts of individual wells). The “sampling location” terminology is used except when a unique well can be reasonably identified or a site report description uses the term “well.”

[28] Chromium and RDX data were downloaded from the Intellus New Mexico online interface on June 18, 2020 and August 3, 2020, respectively.

monitoring boundaries in these areas). Sampling locations and concentration data were compared to those reported in the IFGMP (2017), which provides summaries of monitoring activities and observations. In total, LANL has drilled hundreds of wells to explore groundwater across the Pajarito Plateau, with some wells drilled for specific studies, and others for ongoing monitoring. GIS mapping was used to categorize sampling locations based on the criteria in Exhibit 5-1. “Active” is defined as sampling locations for which data are available after 2014. All other sampling locations are considered inactive. Sampling locations were also characterized based on the number of samples available and whether reported concentrations exceeded baseline concentrations of RDX or chromium (IEc 2020).[29]

Analyses preformed in subsequent sections use data that were assigned quality codes of “UU” (Universal Use), meaning they are validated and meet the quality guidelines outline in the SOP (Appendix A). No filters were applied to remove results based on their detection or filtered status (i.e., detected, not-detected, filtered, and unfiltered results are all included in the evaluations).[30] At this stage of the NRDA, it is appropriate to characterize and report all available groundwater data to provide transparency regarding the full extent and magnitude of contaminant concentrations present in the area relevant to this data characterization effort. An updated dataset will be necessary for subsequent assessment activities since groundwater data continue to be collected in and around LANL as part of monitoring and remediation efforts.

EXHIBIT 5-1. LOCATION CHARACTERIZATION CRITERIA

ATTRIBUTE	CRITERIA
Active	sample date >= 2015
Substantial Data	> three data points
Exceedance	> 0.0 µg/L RDX or 7.48 µg/L chromium

5.3 RESULTS FROM EVALUATION OF CHROMIUM PLUME

The chromium contamination occurring in groundwater underlying Sandia and Mortandad Canyons is a primary focus of remedial actions at LANL, and one of the two priority compounds evaluated in this report. As described in Section 3.2, the primary source of chromium was hexavalent chromium in the blowdown water discharged from the TA-03 power plant cooling tower (IFGMP 2017). Other sources of chromium include the cooling tower at the Omega West Reactor (TA-02) in Los Alamos Canyon, and cooling towers and electroplating facilities in Mortandad Canyon (LA-UR-07-6018). The discharges from TA-03 to Sandia Canyon are the dominant source of surface water in Sandia Canyon, and the primary

[29] “Baseline concentrations” refers to those concentrations identified in IEc 2020, which were largely adopted from LANL’s Groundwater Background Investigation Report (LA-UR-16-27907). In the NRDA context, baseline can include other characteristics in addition to chemical properties, such as physical or biological properties. For a more thorough discussion of groundwater baseline in and around LANL, please refer to IEc 2020.

[30] Groundwater samples that are filtered provide insight into the amount of chromium or RDX fully dissolved in groundwater, as the filtering process removes contaminants absorbed to particulate matter that may also be present in the groundwater sample. Therefore, filtered records typically have lower contaminant concentrations than non-filtered records.

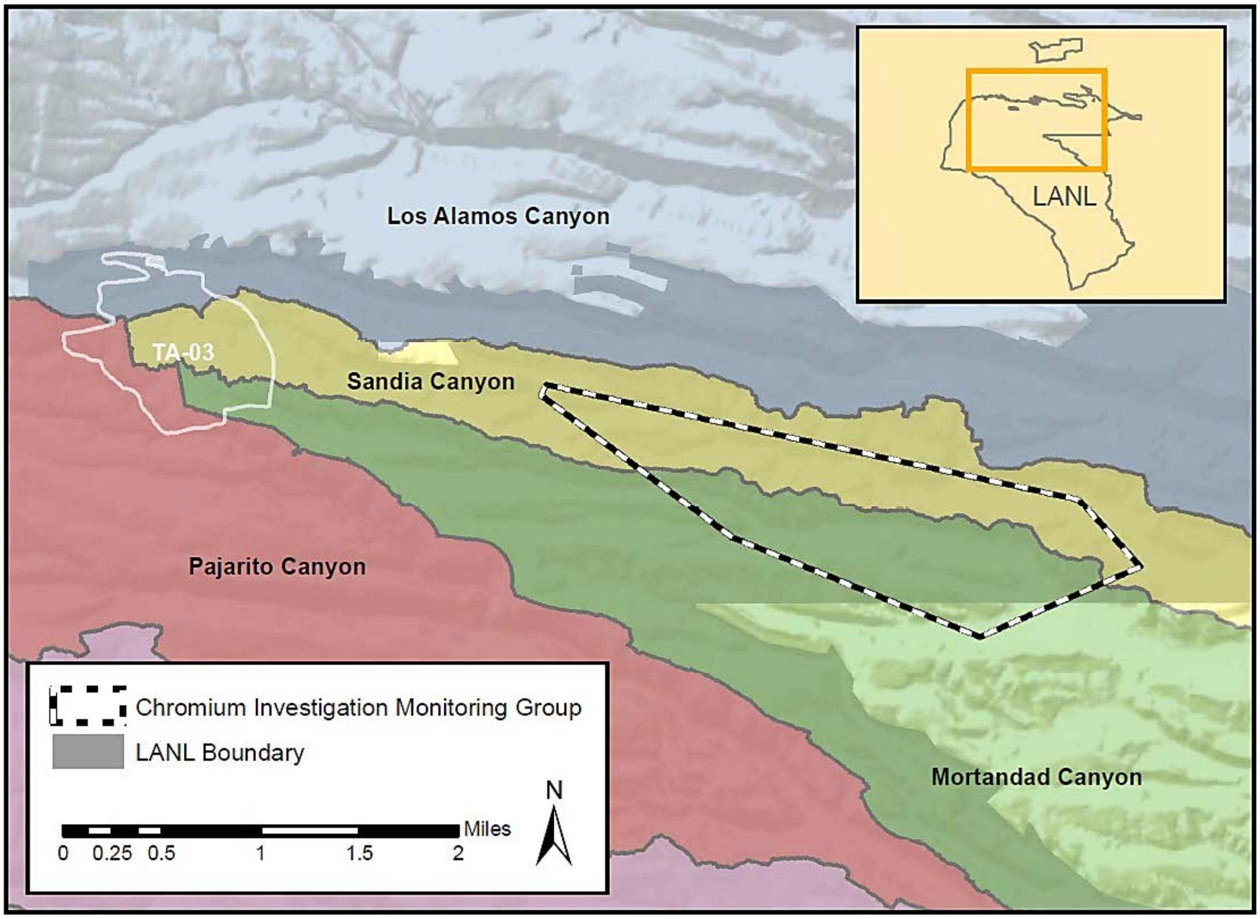
source of chromium surface and groundwater contamination at LANL. The chromium releases have resulted in contamination of surface water, springs, alluvium, the perched-intermediate zone, and the regional aquifer. In May 2006, NMED approved a LANL work plan to investigate the extent and nature of chromium contamination in the Los Alamos regional aquifer (NMED 2006). LANL continues to actively monitor, cleanup, and conduct related investigations of the chromium plume, which is an area within which chromium levels exceed 50 µg/L (the State of New Mexico groundwater standard) (Exhibit 5-2).[31] Through these efforts, LANL concluded that a large part of the Sandia Canyon chromium plume has migrated downgradient to beneath Mortandad Canyon.

While hexavalent chromium (Cr(VI), valence state +6) is highly toxic, trivalent chromium (Cr(III), valence state +3) is a micronutrient and is not considered a health hazard. However, both trivalent and hexavalent pose a risk to natural resources because, depending on the oxidation state and whether there are reducing electrochemical conditions in the subsurface, the valence state of chromium can change between hexavalent and trivalent, especially in the presence of reactive manganese (II, IV) (see Section 3.3 for more detail). Most evaluations of chromium contamination at LANL (e.g., plume maps) are based on measurements of total dissolved chromium, and thus include both valence states of chromium. In this section, "chromium" refers to both hexavalent and total chromium (which is composed of both trivalent and hexavalent forms) measured in groundwater samples; therefore, subsequent discussions do not distinguish between the trivalent and hexavalent states.

This section describes the pathway of chromium to groundwater; summarizes monitoring, remediation, and related investigations; and evaluates the occurrence of contaminated groundwater. Site reports and groundwater contaminant data are the primary sources of information presented. Of note, this section relies heavily on the recently published *Compendium of Technical Reports Conducted Under the Work Plan for Chromium Plume Center Characterization* discussed previously in Section 2.3. Reports of chromium occurrences elsewhere at LANL (i.e., not in or near Sandia and Mortandad Canyons) are discussed in Chapter 4.

[31] Chromium groundwater quality standard from NMAC 20.6.2.

EXHIBIT 5-2. LOCATION MAP FOR CHROMIUM PLUME EVALUATION



Note: The Chromium Investigation Monitoring Group boundary is an approximation from the IFGMP (2017).

5.3.1 CHROMIUM PATHWAY CHARACTERIZATION

Hydrogeology in the areas of Sandia and Mortandad Canyons is broadly similar to other areas of LANL (see Section 3.1). The geology of the area is the complex result of volcanism, sedimentation, erosion, and faulting, with localized deposits that interfinger with and overlie regional surficial deposits, ash-flow tuffs, and interbedded sedimentary deposits, alluvial fan deposits, and lava flows (LA-14263-MS). Infiltration of surface water in the Sandia and Mortandad Canyons occurs predominantly during spring snowmelt or after intense summer storms when runoff convenes in ephemeral reaches of the canyons (Birdsell et al. 2005). These sources contribute significant flow to Sandia and Mortandad Canyons, as well as their tributaries, such as Effluent Canyon. Perennial surface water in Sandia Canyon largely occurs from sanitary wastewater discharges from the Sanitary Effluent Reclamation Facility (SERF) (IFGMP 2017). These discharges have been so significant that a wetland has become established and continues to expand slowly upstream, as new cattails and willows occur along the channel. Effluent discharges to Mortandad Canyon no longer occur.

The three primary hydrogeologic units present in the vicinity of Sandia and Mortandad Canyons are described in Exhibit 5-3. Exhibit 5-4 is a conceptual cross section of hexavalent chromium transport through the perched-intermediate zone to the regional aquifer. Aquifer and tracer tests show considerable heterogeneity with respect to geologic, hydrologic, and geochemical conditions, which can result in complex transport and distribution of chromium both laterally and vertically. There is an apparent upward coarsening in the regional aquifer, which would tend to result in recharged contaminants moving horizontally within a relatively thin zone beneath the regional aquifer water table.

EXHIBIT 5-3. HYDROGEOLOGY OF SANDIA AND MORTANDAD CANYONS

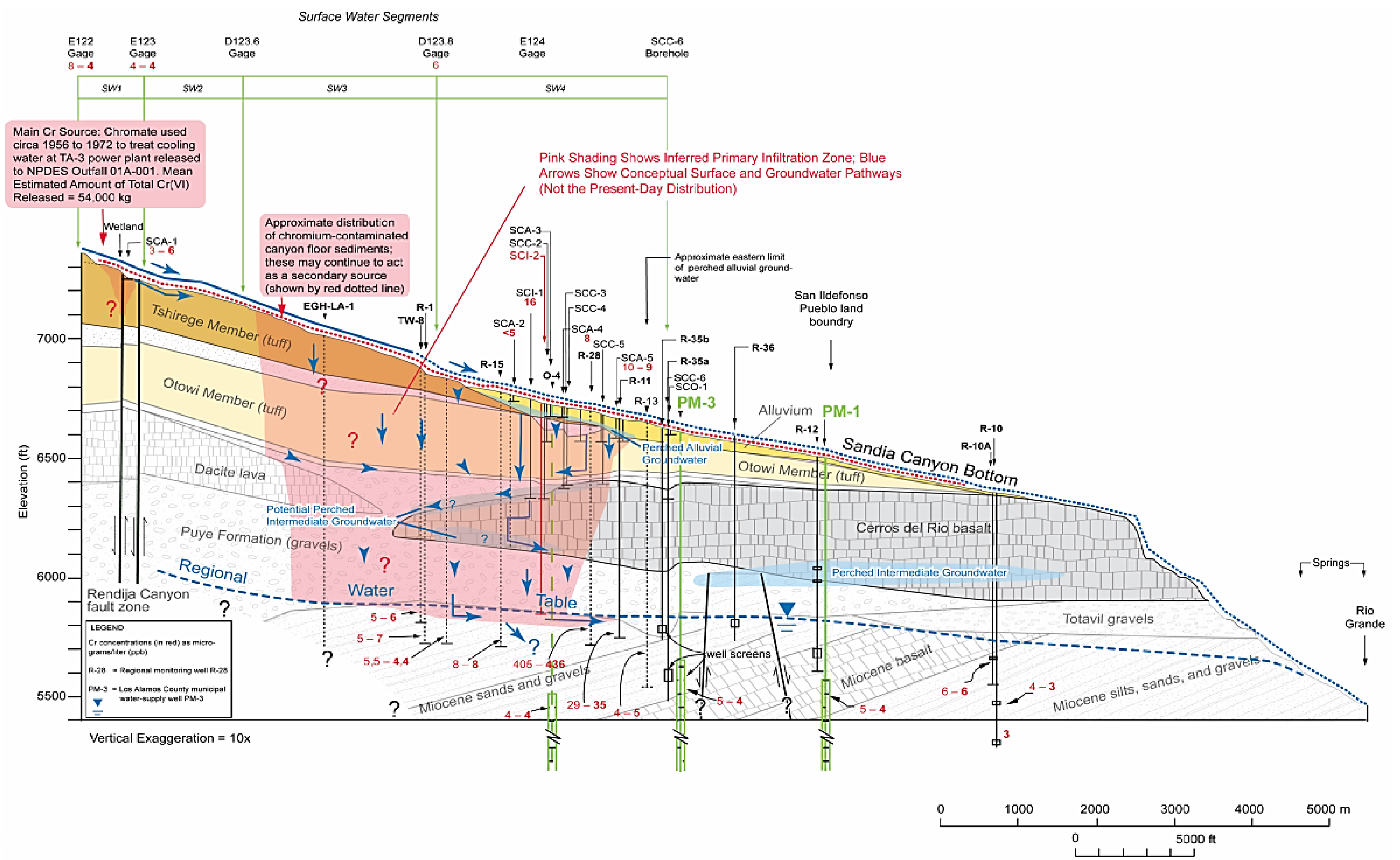
Alluvium. In Sandia Canyon, perched groundwater occurs in the upper and middle reaches of valley alluvium. The thin saturated alluvium is recharged by surface water flow from sources such as steam plant discharges continuing at Outfall 001 and by episodic stormwater and snowmelt. Water levels in the alluvium vary with the amount of recharge and, thus, with the amount of outfall discharge, which has been significantly reduced in recent years because of reuse occurring within TA-03 facilities. In Mortandad Canyon, alluvial groundwater is local in origin (i.e., it does not originate in Sandia Canyon) and the occurrence increases down canyon. The most significant discharge in Mortandad Canyon was effluent from the Radioactive Liquid Waste Treatment Facility at TA-50. This discharge occurred at Outfall 051 and supported variable alluvial saturation. The discharge ceased in late 2010 and the extent of saturation in the alluvium has decreased since then, as have chromium concentrations.

Intermediate zone. In the area of the Chromium Investigation Monitoring Group, the perched-intermediate zone extends to a depth of about 1,000 feet and contains at least two significant perching horizons. In the area of Sandia Canyon, the first perched horizon is within the Puye formation on top of the Cerros del Rio basalt. This horizon ranges in saturated thickness from one foot to 25 feet with a thinning trend to the west. The second perched-intermediate horizon is within fractured lavas and interflow breccias in the lower part of the Cerro del Rios basalt. The thickness ranges between 45 feet and 100 feet. This zone is observed only in a few wells and no perched-intermediate groundwater was encountered during drilling of several wells at the downgradient end of the Chromium Monitoring Group. Data from monitoring wells indicate that chromium-contaminated surface water in Sandia Canyon is transported generally southward through the vadose zone before entering the regional aquifer near Mortandad Canyon (LA-UR-18-21450).

Regional aquifer. The regional groundwater is supplied by inflow from west of Los Alamos and by recharge from the alluvial aquifer via the perched-intermediate zone. The regional aquifer is a primary source of public water supply for the region, including the Los Alamos County well field which has wells near the chromium plume, and Santa Fe's Buckman well field which lies just east of the Rio Grande. The regional aquifer contributes significant discharge to the Rio Grande through spring outlets and baseflow.

In the area of the Chromium Investigation Monitoring Group, the regional aquifer is unconfined with the water table located within the pumice and fanglomerate units of the Puye Formation. Recharge to this aquifer by way of the perched-intermediate zone contributes modern (post-1943) aged groundwater, which mixes with laterally flowing water that is decades or centuries older. Groundwater flow through porous and fractured materials follows the water table gradient to the east and southeast and is locally impacted by pumping of deeply-screened municipal wells, especially at monitoring well R-35a. Flow rates are highly variable due to the heterogeneity of the aquifer and can be meters per day along preferred pathways (LA-UR-18-21450). The water table gradient in the plume area is relatively flat compared to other parts of LANL, which indicates that the aquifer in the chromium plume area is relatively permeable. This higher hydraulic conductivity is attributed to the presence of north-south trending basin-fill sediments deposited by the ancestral Rio Grande. The largest water-level fluctuations are observed around Los Alamos County water supply well PM-3, most likely due to the variable municipal pumping that occurs there.

EXHIBIT 5-4. CONCEPTUAL CROSS-SECTION OF CHROMIUM MIGRATION BENEATH SANDIA CANYON (LA-UR-08-4702)



In addition to a thorough understanding of the subsurface geologic structure, understanding chromium fate and transport behavior is helpful when evaluating the potential for resource exposure. Cr(III) has low toxicity and is immobile under alkaline to slightly acidic conditions, relative to Cr(VI), which is considered mobile in the environment and acutely toxic (Palmer and Puls 1994 and references therein). However, Cr(VI) is a strong oxidant and can be reduced in the presence of electron donors, such as ferrous iron minerals, aqueous ferrous iron, reduced sulfur, and soil organic matter. Oxidation of Cr(III) to Cr(VI) is also possible, and is important to consider when evaluating natural attenuation potential. But only two constituents in the environment are known to do this: dissolved oxygen and manganese oxides (Palmer and Puls 1994). The regional aquifer in the vicinity of the chromium plume at LANL has a pH of approximately 8, a pH known to result in positively charged surfaces in clays and iron oxyhydroxides that may provide adsorption sites for chromium anions (LA-UR-18-21450 Attachment 1). Batch and column experiments using regional aquifer sediments found no retardation of chromium, suggesting a minor presence of iron or magnesium oxides (LA-UR-18-21450 Attachment 6). Additionally, push-drift tests in wells located in the chromium plume did not show appreciable desorption of chromium when injected with solutions that promote desorption of chromium (LA-UR-18-21450 Attachment 1). These observations suggest that chromium in the regional aquifer at LANL can be highly mobile.

It is estimated that approximately 25 to 40 percent of the total chromium released from the cooling-tower was converted to stable trivalent chromium (Cr(III)) (DOE 2015). Groundwater in the immediately surrounding alluvium is consistently found to be in a reducing condition, especially within the Sandia wetland, which strongly favors the conversion of hexavalent chromium to trivalent chromium to the point that toxic chromium is not found in wetland groundwater (EM2019-0091). However, these reducing conditions occur only in the vicinity of the Sandia wetland.

Remaining, mobile chromium has been transported in surface water over a distance of up to two miles, ultimately infiltrating vertically through thin alluvium and a geologically complex perched-intermediate zone, resulting in the observed chromium plume in the regional aquifer. In the upper portion of the regional aquifer where the chromium plume has been mapped, groundwater occurs under aerobic conditions with a neutral pH and chemistry dominated by calcium-sodium bicarbonate. Under these conditions, chromium can be expected to be dissolved and unlikely to precipitate out of solution (Longmire 2018). These conditions occur in all the areas where chromium contamination is found in Sandia and Mortandad Canyons. Furthermore, laboratory and field-based testing indicate that there is little to no natural attenuation of Cr(VI) in regional aquifer sediments (LA-UR-18-21450).

5.3.2 CHROMIUM MONITORING, INVESTIGATIONS, AND REMEDIATION

5.3.2.1 Monitoring

As described in Section 3.2, monitoring activities for the Chromium Investigation Monitoring Group are ongoing. Past activities have focused on characterizing the fate and transport of chromium and associated contaminants (e.g., nitrate and tritium) in the perched-intermediate and regional aquifer zones of Sandia and Mortandad Canyons (Exhibit 5-1) (IFGMP 2017).[32] In 2018, focus transitioned from monitoring fate and transport to performance monitoring related of an interim measure as well as plume-center characterization (described in more detail below) (IFGMP 2017). Active monitoring locations in this

[32] Alluvial groundwater and base-flow sampling locations are excluded from this monitoring group, and are included in the General Surveillance monitoring group, because the primary contaminants of concern are at low and stable concentrations (IFGMP 2017 and references therein).

group include perched-intermediate and regional aquifer sampling locations. Most of the network is sampled monthly, though some locations are sampled quarterly to semiannually (IFGMP 2017). The frequency of measuring certain classes of constituents (e.g., VOCs, polychlorinated biphenyls) at each location also varies (IFGMP 2017).

Annual monitoring occurs at the Sandia wetland, which builds on the baseline assessment that occurred from 2012 to 2014 (EM2019-0091). Monitoring activities include assessing the condition of the wetland to: 1) evaluate the effectiveness of a grade-control structure completed in 2013 and 2) monitor changes to LANL's operational practices that have affected effluent chemistry and discharge volumes from the outfall (EM20219-0091). The monitoring work addresses surface water (quantity and chemistry), alluvial groundwater (physical properties and chemistry), vegetation (type and distribution), and geomorphology (e.g., channel stability).

5.3.2.2 Remediation and Other Investigations

In 2005 and 2006, groundwater samples collected from a new regional groundwater monitoring well in Mortandad Canyon indicated the presence of chromium (DOE 2015). Since then, LANL has been conducting fate and transport investigations of the chromium and related contaminants (LA-UR-18-21450). LANL also identified the need for an integrated hydrogeologic and geochemical framework to evaluate and recommend remedial alternatives (LA-UR-18-21450). Several bench-scale and field tracer studies followed with the goal of implementing pilot-scale studies at small-scale intrawell locations (LA-UR-18-21450). The work supporting these efforts and the development of an interim measure was packaged in the 2018 *Compendium of Technical Reports Conducted Under the Work Plan for Chromium Plume Center Characterization*, which is referred to generally as "the Chromium Compendium" (LA-UR-18-21450). With ongoing monitoring and remediation, groundwater data continue to be collected in and around LANL. As such, an updated dataset will be necessary for subsequent assessment activities. For example, the total mass of dissolved chromium present in the vadose zone and regional aquifer beneath Sandia and Mortandad Canyons is an uncertainty that influences characterization and remediation of chromium in this area.

The Chromium Compendium studies were undertaken to 1) advance understanding of the nature and extent of contamination and contaminant sources, 2) advance the site conceptual model to support the interim measure, 3) evaluate remedial alternatives, and 4) provide a model for testing the conceptual site model and evaluate interim measure performance and remedial alternatives (LA-UR-18-21450). The related investigations and efforts included:

- Ongoing monitoring of perched-intermediate and deep groundwater to investigate the feasibility of removing chromium from the center of the plume.
- Ongoing monitoring of alluvial groundwater in Sandia Canyon to understand the nature and spatial variability of infiltration for the purposes of evaluating remedial actions and for use in models.
- Field tracer tests and long-term pumping tests to better characterize the distribution of chromium and conditions within the vadose zone and regional aquifer.[33]

[33] Field tests are conducted by injecting tracer solution into a well and collecting data on their fate and transport. Depending on the type of test and its goals, different pumping patterns would be implemented prior to sample collection (LA-UR-18-21450).

- A sonic coring program to characterize key aquifer attributes, such as heterogeneity and dual porosity, to evaluate potential in situ remediation strategies.[34]
- Modeling of the geochemical conditions surrounding the injection wells to support design of the interim measure and potential maintenance activities.
- Isotopic analysis of groundwater samples and bench-scale studies to evaluate natural attenuation, bioremediation, and chemical remediation. These studies directly led to the pilot-scale study mentioned above.[35]
- Groundwater fingerprinting and machine learning data analysis of geochemical data to evaluate whether multiple original sources of contaminants are discernable within the overall chromium plume footprint.
- Groundwater modeling to evaluate the performance of the interim measure and guide changes in operational strategies.

In parallel with the plume-center characterization efforts, LANL developed and implemented the interim measure to control plume migration. Three methods exist for actively remediating hexavalent chromium contamination in groundwater. The first is to reduce chromium toxicity through conversion to the trivalent form using biological or chemical amendments that create reducing conditions. This method is being tested by LANL using sodium dithionite in regional well R-42 and molasses in regional well R-28 (EM2019-0455). Amendment solutions were deployed to these wells in August and September 2017, respectively, and both show promising results at the pilot scale (EM2019-0455). The volumes of remediated regional aquifer groundwater surrounding wells R-28 and R-42, however, are not known with certainty because no observation wells were drilled near the two injection wells. The chemical reductants sodium dithionite and molasses are effective in reducing Cr(VI) to Cr(III), however, other naturally occurring metals and nonmetals, such as arsenic, are mobilized during remediation (P. Longmire, *personal communication*, 2021). The other two methods are removing the contamination (e.g., by extraction, treatment, and disposal or reinjection) or containing the contamination using a hydraulic or physical barrier.

The interim measure currently implemented addresses the removal and containment of contaminated groundwater. The interim measure is designed to pump contaminated groundwater from the chromium plume, treat it at the surface using ion exchange, and reinject it into wells located at the periphery of the plume to create a hydraulic barrier preventing further plume migration (IFGMP 2017). Pumping and injection began in late 2016 and continues through the present (IFGMP 2017). The goal is to maintain the plume within the LANL boundary while plume characterization continues and long-term corrective actions are evaluated and implemented. Performance evaluation monitoring of this interim measure also will provide information regarding the hydrogeology and geochemistry of the plume area (LA-UR-18-21450). Ultimately, LANL intends to rely on groundwater modeling as a tool in designing its remediation

[34] Each core hole was drilled using conventional methods. The sonic core was collected by driving a sonic core barrel into the sediments at the bottom of the hole using sonic vibration (LA-UR-18-21450).

[35] There is no evidence that natural attenuation of chromium contamination occurs at LANL, other than by the simple mixing of the arriving chromium plume with background groundwater with chromium typically in the range of two to six µg/L.

program. However, for the present, LANL has deferred numerical modeling of the plume remediation (NMED 2019).

5.3.3 CHROMIUM RECEPTOR CHARACTERIZATION

Groundwater sampling data from sampling locations at LANL indicate the presence of chromium contamination in the alluvial groundwater, perched-intermediate groundwater, and regional aquifer beneath Sandia and Mortandad Canyons. To evaluate the extent, fate, and transport of chromium in groundwater, samples have been collected and analyzed from a network of extraction and monitoring wells under the IFGMP (2017) and from locations supporting specific research efforts since at least 1980 (Exhibit 5-5) (DOE 2015, IFGMP 2017, LA-UR-18-21450). As described in Section 5.2, to independently evaluate these data in the NRDA context, data were reviewed from 232 sampling locations spanning February 1980 to March 2020 (Exhibit 5-5). Chromium concentrations were compared to a baseline of 7.48 µg/L and State of New Mexico WQCC groundwater standard of 50 µg/L. By convention, LANL defines the chromium plume is defined as the aerial extent where chromium concentrations in groundwater exceed the New Mexico State groundwater standard of 50 µg/L.

Exhibit 5-5 shows sampling locations in relation to TA-03 and the Chromium Investigation Monitoring Group. The Chromium Investigation Monitoring Group is where chromium contamination is most severe, and remediation has begun. Groundwater sampling locations in the dataset comprise 84 alluvial, 45 perched-intermediate, and 103 regional aquifer locations. The dataset used in this analysis includes 1,475 alluvial, 1,490 perched-intermediate, and 5,726 regional aquifer samples (Exhibit 5-6).[36] Approximately two percent of alluvial samples, 13 percent of perched-intermediate samples, and eight percent of samples from the regional aquifer exceed the chromium baseline concentration of 7.48 µg/L (see Exhibit 5-6 for detailed sample information).[37] Summary statistics of groundwater samples from these sampling locations indicate aquifer-specific arithmetic and geometric mean chromium concentrations are highest in the perched-intermediate system (43.3 µg/L and 6.7 µg/L respectively), moderate in the regional aquifer (33.2 µg/L and 6.5 µg/L respectively), and lowest in the alluvial system (8.6 µg/L and 3.1 µg/L) (Exhibit 5-6).

The highest chromium concentration in the entire chromium dataset is measured in the regional aquifer (2,980 µg/L from well R-9 in the Los Alamos Canyon in January 1998), followed by a sample from perched-intermediate groundwater (938 µg/L from well MCOI-8 in Mortandad Canyon in January 2006), and alluvial groundwater (662 µg/L from well MCO-0.6 in the Mortandad Canyon in July 2010). Approximately 26 percent of alluvial, 36 percent of perched-intermediate, and 55 percent of regional aquifer samples are filtered and have measured chromium concentrations above the detection limit (Exhibit 5-6).[38] Although perched-intermediate groundwater has the highest percentage of samples that exceeded the chromium baseline concentration (7.48 µg/L), the regional aquifer has the highest percentage of filtered samples with measured chromium concentrations above the detection limit. The

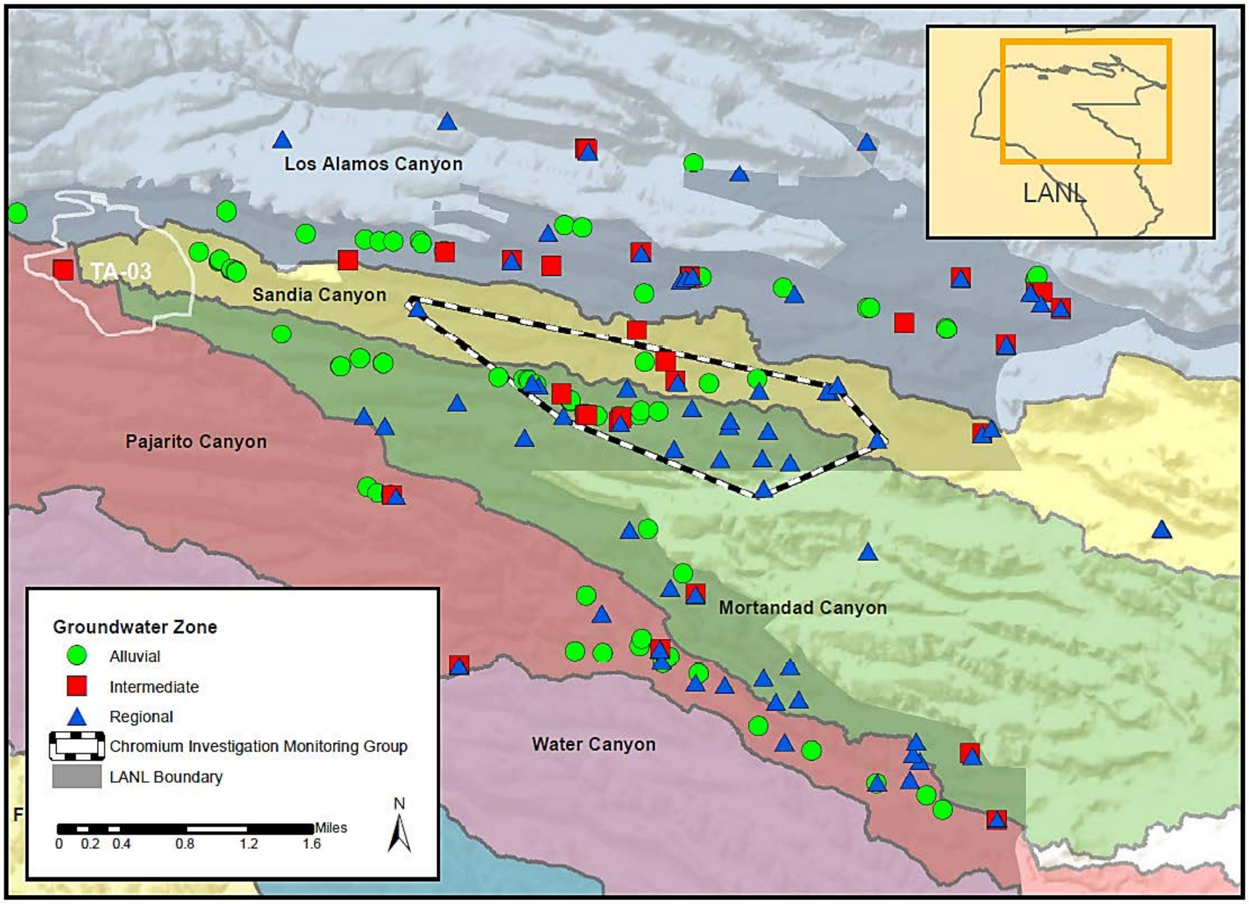
[36] The chromium plume dataset also includes surface water samples from regional streams and creeks. However, these are excluded from the chromium plume evaluation.

[37] The proportion of exceedances were calculated by dividing the number of values that exceeded 7.48 µg/L in a given groundwater system by the total number of samples collected in that groundwater system and multiplied by 100.

[38] Unfiltered or turbid water samples can bias contaminant concentrations high. See Chapter 6 for an explanation of uncertainties related to the characterization of existing groundwater data and information.

alluvial groundwater contains the lowest percentage of samples that exceed the chromium baseline concentration and the lowest percentage of filtered samples above the chromium detection limit. These observations suggest that high chromium concentrations are more prevalent, in terms of the number of sampling locations in which contamination is above 7.48 µg/L, within the perched-intermediate and regional groundwater and that Cr(VI) is mobile in the subsurface at LANL.

EXHIBIT 5-5. MAP OF SAMPLING LOCATIONS



Note: Several sampling locations selected within this region are geographically close to one another and are represented by a single datapoint at this scale.

EXHIBIT 5-6. SUMMARY STATISTICS OF CHROMIUM CONCENTRATIONS

PARAMETER	ALLUVIAL GROUNDWATER[1]	INTERMEDIATE GROUNDWATER[1]	REGIONAL GROUNDWATER[1]
Minimum (µg/L)	0.0	0.0	0.0
Minimum Detected (µg/L)	0.1	0.1	0.06
Median (µg/L)	3.2	5.5	4.9
Maximum (µg/L)	662.0	938.0	2,980.0
Maximum Detected (µg/L)	662.0	938.0	2,980.0
Average (µg/L)	8.5	43.2	33.2
Geomean (µg/L)[2]	3.1	6.7	6.5
25^{th} Percentile (µg/L)	1.6	2.6	3.3
75^{th} Percentile (µg/L)	10.0	10.0	9.5
Non-Detected	825	583	967
Detected	638	904	4,755
% Detected	43.6	60.8	83.1
Non-Filtered Sample Count	655	588	2,016
Filtered Sample Count	808	899	3,706
% Filtered	55.2	60.5	64.8
Does Not Exceed Baseline Sample Count[3]	1,433	1,298	5,272
Exceeds Baseline Sample Count[3]	30	189	450
% Exceeds Baseline[4]	2.1	12.7	7.9
Total Sample Count	1,463	1,487	5,722
Total Number of Sampling Locations	84	45	103

1. Negative concentrations were removed from these datasets. Concentrations of zero were preserved.
2. Because the geometric mean calculation does not allow for the value of zero, for this calculation, chromium concentrations of zero were replaced with 0.00001 µg/L.
3. A record "Exceeds" if it is greater than the chromium baseline concentration for the regional aquifer of 7.48 µg/L.
4. Exceedance proportion percentage includes detected/non-detected and filtered/non-filtered samples.

Units:
µg/L = micrograms per liter

5.3.3.1 Alluvial Groundwater

The arithmetic and geometric mean chromium concentrations in the alluvial groundwater dataset (February 1980 through October 2019) are 8.6 µg/L and 3.1 µg/L respectively, which are the lowest arithmetic and geometric mean concentrations of those measured in the three groundwater zones.[39] Approximately two percent of alluvial samples exceed the chromium baseline value for the regional aquifer of 7.48 µg/L, which is, again, the lowest percentage of exceedances compared to the other

[39] The dataset used to calculate the arithmetic mean and other chromium summary statistics includes filtered and unfiltered and detected and non-detected samples but excludes samples that had negative chromium concentrations. However, because the geometric mean calculation does not allow values of zero, when calculating the geometric mean of chromium concentrations across zones, chromium concentrations of zero were substituted with a concentration of 0.00001 µg/L.

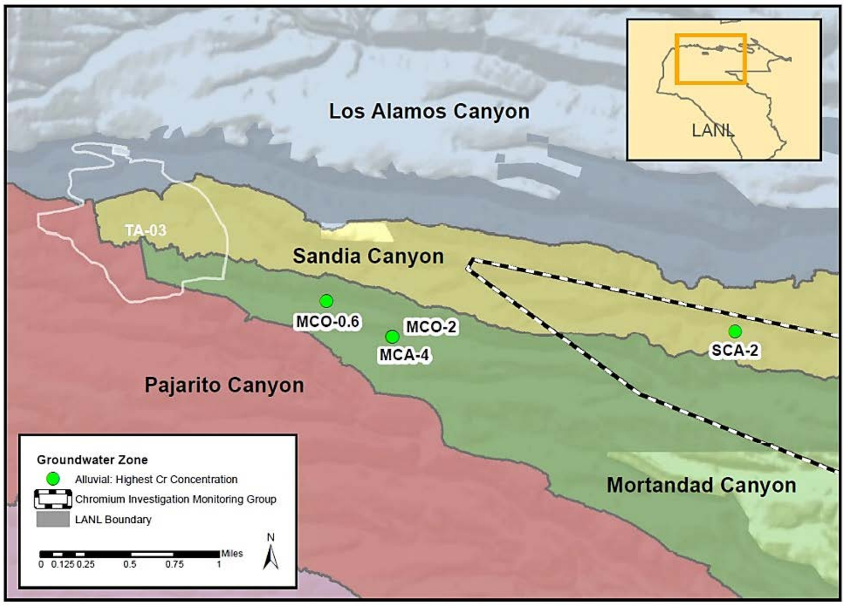
groundwater zones. When evaluating the entire chromium dataset, several time periods of high chromium concentrations are apparent in alluvial groundwater (Exhibit 5-7). Chromium concentrations peak to 81 µg/L in June 1993 and return to relatively lower values (approximately 10 µg/L) within a few days. From September 2005 until the end of the dates available in the alluvial groundwater dataset, March 2020, elevated chromium concentrations (between 30 and 700 µg/L) are observed. Between 2007 and 2010, relatively high chromium concentrations occur in September 2007 (101 µg/L, well MCA-4, Mortandad Canyon), November 2007 (552 µg/L, well SCA-2, Sandia Canyon), May 2008 (275 µg/L, well MCO-2, Mortandad Canyon), and July 2010 (662 µg/L, well MCO-0.6, Mortandad Canyon). High concentrations of chromium measured in wells MCO-2 and MC-0.6 located in Mortandad Canyon, downgradient of Effluent Canyon, a tributary canyon, are likely related to releases during laboratory operations since 1963 (LA-UR-06-6752, IFGMP 2017).[40] The relatively high chromium concentrations observed in well SCA-2 in the Sandia Canyon (552 µg/L in November 2007) may be from infiltration of effluent from National Pollutant Discharge Elimination System (NPDES) Outfall 001 in TA-03, which began in the 1950's and continues today (IFGMP 2017; LA-UR-15-27298).

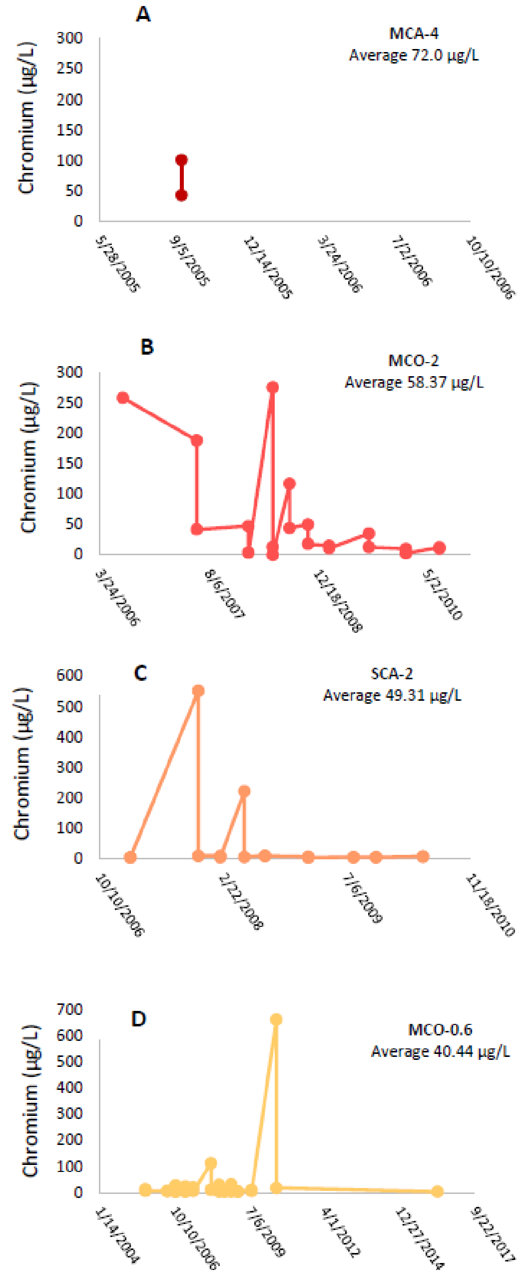
To further evaluate the most relevant sampling locations within the alluvial dataset, four sampling locations with the highest average chromium concentrations were selected for chemical time-series analysis (Exhibit 5-7).[41] Of these sampling locations, only well SCA-2 is located within the Chromium Investigation Monitoring Group area. The highest average concentrations of chromium are found in Sandia and Mortandad Canyons, which is consistent with historical operations and chromium releases originating from TA-03. The highest chromium concentrations within the alluvial system are observed in November 2007 (552 µg/L, well SCA-2, Sandia Canyon) and July 2010 (662 µg/L, well MCO-0.6, Mortandad Canyon), discussed previously (Exhibit 5-7 C and D, respectively). Since 2013, chromium concentrations appear to fluctuate from below detection to over 70 µg/L. Historical sampling results for the four wells have average chromium concentrations well above the baseline value of 7.48 µg/L, although, more recently, concentrations appear to be decreasing (Exhibit 5-7 A through D).

[40] The laboratory is currently releasing effluent into the Mortandad Canyon, although it is monitored closely for quality and meets all regulatory standards.

[41] Data plot on top of each other when visualizing all sampling locations in a groundwater zone. The analysis therefore focuses on the four sampling locations with the highest average concentration for this and subsequent sections.

EXHIBIT 5-7. MAP OF ALLUVIAL SAMPLING LOCATIONS WITH THE HIGHEST AVERAGE CHROMIUM CONCENTRATIONS AND THEIR CONCENTRATIONS OVER TIME





NOTES:

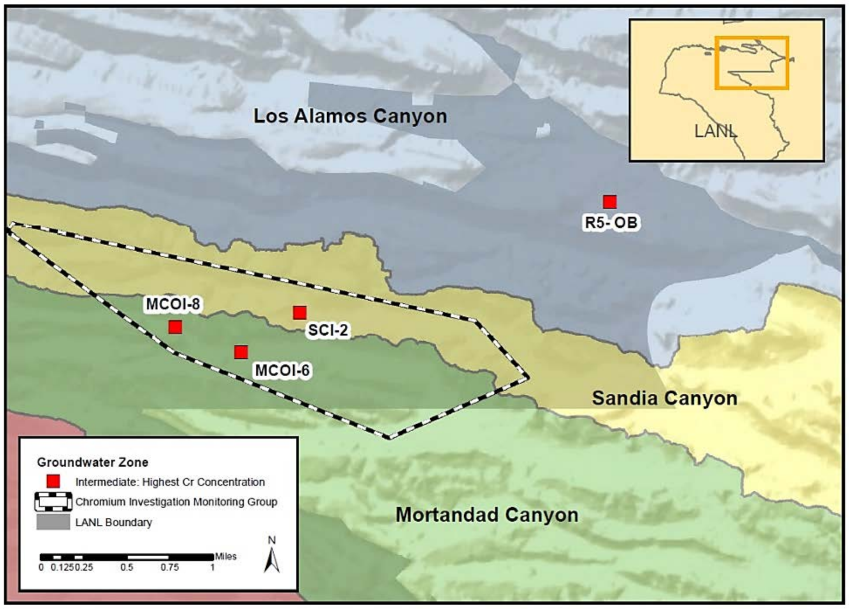
- AT THIS SCALE, THE LOCATION OF WELLS MCO-2 AND MCA-4 ARE DISPLAYED AS A SINGLE DATA POINT.
- THE X-AXIS FOR THE CHROMIUM CONCENTRATIONS TIME-SERIES PLOTS HAVE DIFFERENT X-AXIS DATE RANGES IN THIS FIGURE AND SUBSEQUENT ITERATIONS IN THE PERCHED-INTERMEDIATE AND REGIONAL AQUIFER SECTIONS.
- CHROMIUM CONCENTRATION TIME-SERIES PLOTS CONTAIN ALL AVAILABLE SAMPLES, INCLUDING FILTERED AND UNFILTERED DATA. THE ENTIRE DATASET HAS BEEN ASSIGNED DATA QUALITY CODES OF “UU” (UNIVERSAL USE), MEANING THEY ARE FULLY VALIDATED DATA AND MEET ALL QA/QC GUIDELINES.
- IN SOME INSTANCES, ONLY A FEW GROUNDWATER SAMPLES HAVE BEEN TAKEN FROM A SAMPLING LOCATION.

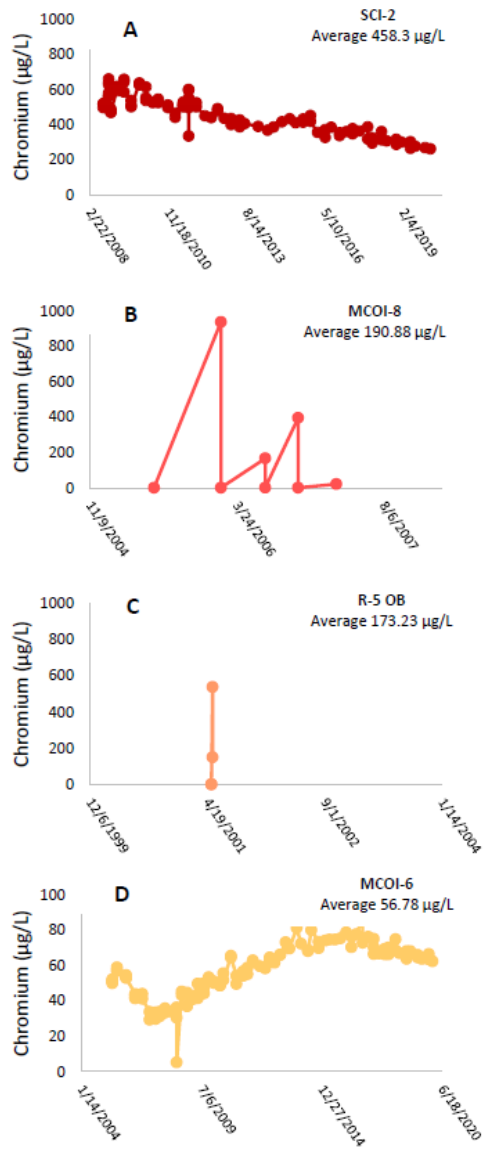
5.3.3.2 Perched-Intermediate Groundwater

The perched-intermediate groundwater dataset includes samples collected between February 1980 and January 2020. The arithmetic and geometric mean chromium concentrations in the perched-intermediate system are 43.3 µg/L and 6.7 µg/L respectively, making it the zone of groundwater with the highest arithmetic and geometric mean concentrations of chromium. Approximately 13 percent of samples from this system exceed the groundwater baseline value for the regional aquifer of 7.48 µg/L, which is the highest percentage of exceedances compared to the other zones of groundwater. Chronologically, high chromium concentrations are apparent in May 2001 (538 µg/L from sampling location R-5 OB in Los Alamos Canyon) and January 2006 (938 µg/L from well MCOI-8 in Mortandad Canyon). Between October 2008 and January 2020, chromium concentrations in well SCI-2 (Sandia Canyon) decline, but remain relatively high, decreasing from 640 µg/L in October 2008 to 262 µg/L in January 2020.

To further evaluate the degree of chromium contamination in perched-intermediate groundwater, time-series plots were created for four sampling locations with the highest average chromium concentrations (Exhibit 5-8). Within this selected dataset, chromium concentrations from Sandia Canyon steadily decrease over time, with well SCI-2 recording decreasing chromium concentrations from 660 µg/L in October 2008 to 262 µg/L in January 2020 (Exhibit 5-8 A). However, chromium concentrations appear to gradually increase in sampling locations located in the Mortandad Canyon, as seen in well MCOI-6, in which chromium increases from 30 µg/L in February 2007 to 62 µg/L in January 2020 (Exhibit 5-8 D). The four sampling locations with the highest average chromium concentrations, SCI-2, MCOI-8, R-5 OB, and MCOI-6, have average concentrations well above the chromium baseline value of 7.48 µg/L (Exhibit 5-8 A through D). Unlike in alluvial groundwater, the highest average concentrations of chromium are found in Sandia, Mortandad, and Los Alamos Canyons, suggesting that the highly contaminated groundwater has dispersed over a larger geographic area within the intermediate groundwater system compared to the alluvial groundwater system, where groundwater is restricted to canyon bottoms.

EXHIBIT 5-8. MAP OF PERCHED-INTERMEDIATE SAMPLING LOCATIONS WITH THE HIGHEST AVERAGE CHROMIUM CONCENTRATIONS AND THEIR CONCENTRATIONS OVER TIME





NOTES:

- THE X-AXIS FOR THE CHROMIUM CONCENTRATIONS TIME-SERIES PLOTS HAVE DIFFERENT X-AXIS DATE RANGES IN THIS FIGURE.
- CHROMIUM CONCENTRATION TIME-SERIES PLOTS CONTAIN ALL AVAILABLE DATA, INCLUDING FILTERED AND UNFILTERED SAMPLES. THE ENTIRE DATASET HAS BEEN ASSIGNED DATA QUALITY CODES OF "UU" (UNIVERSAL USE), MEANING THEY ARE FULLY VALIDATED DATA AND MEET ALL QA/QC GUIDELINES.
- IN SOME INSTANCES, ONLY A FEW GROUNDWATER SAMPLES HAVE BEEN TAKEN FROM A SAMPLING LOCATION.

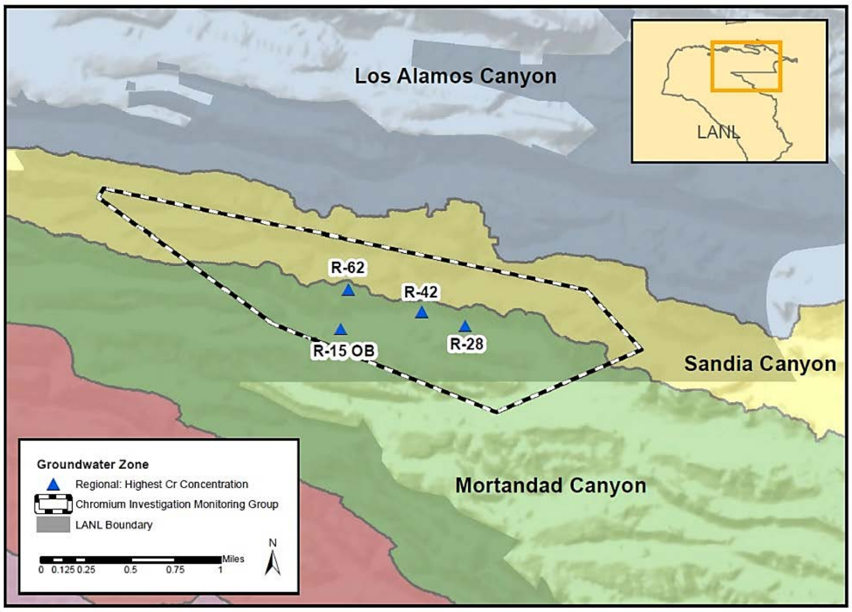
5.3.3.3 Regional Aquifer

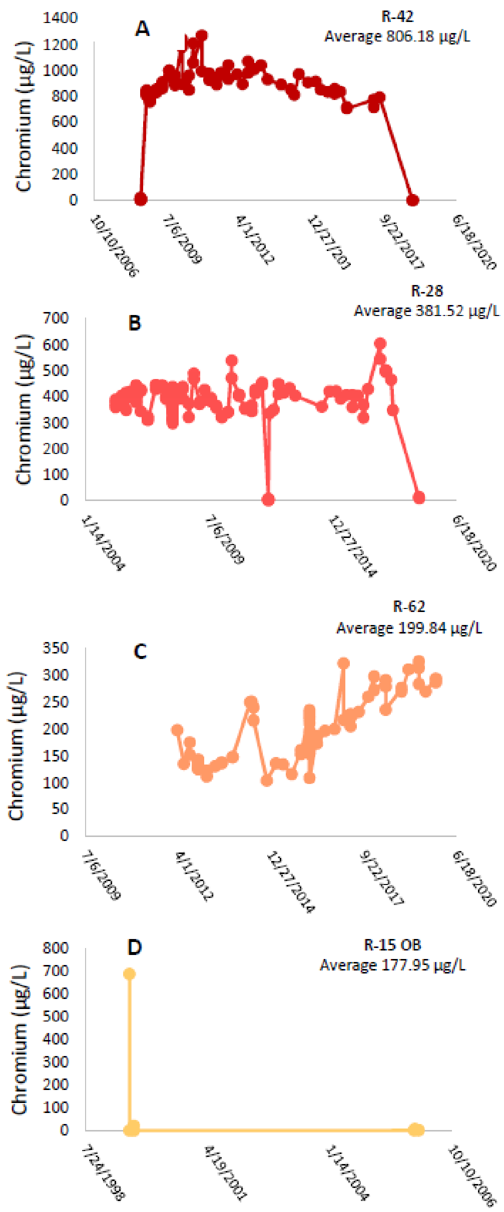
The regional aquifer dataset includes groundwater samples collected between February 1980 and March 2020. The arithmetic and geometric mean chromium concentrations in the regional aquifer are 33.2 µg/L and 6.5 µg/L respectively, which is greater than the arithmetic and geometric mean concentrations of chromium in the alluvial system, but less than the arithmetic and geometric mean concentrations in the perched-intermediate system. Approximately eight percent of samples from regional aquifer sampling locations exceed the chromium baseline value of 7.48 µg/L, which is in between the percentages of exceedances for the other zones of groundwater. Chromium concentrations increase in October 1997 and peak in January 1998, with a concentration of 2,980 µg/L in well R-9; the highest observed chromium concentration in the chromium plume evaluation dataset.[42] Chromium concentrations remain relatively low between 2000 and 2004 (averaging 33.3 µg/L) but are elevated thereafter, ranging between 200 to 1,300 µg/L, from May 2005 to January 2020 in wells R-42 and R-28. Wells R-42 and R-28 are located within the Chromium Investigation Monitoring Group, which consistently has chromium concentrations above the chromium baseline value of 7.48 µg/L.

Four sampling locations with the highest average chromium concentrations in the regional aquifer were selected for time-series analysis (Exhibit 5-9). Within this subset, all sampling locations are located within Mortandad Canyon and have average chromium concentrations that are well above the baseline value of 7.48 µg/L. Between September 2017 and November 2018, concentrations in wells R-42 and R-28 decrease substantially, ranging from nearly 800 µg/L in July 2017 to less than 1 µg/L in November 2018 (Exhibit 5-9 A and B, respectively). Some sampling locations show a recent decline in chromium levels, presumably from restricting chromium in effluents and other as-yet undetermined effects of remediation. For example, in 2013, NMED submitted a proposal to initiate the removal, treatment, and disposal of chromium-contaminated groundwater from existing wells R-28 and R-42 (NMED 2013). From the time-series graphs, wells R-42 and R-28 in Mortandad Canyon show decreasing trends in concentration following the start of remediation (Exhibit 5-9 A and B, respectively). In recent years, LANL has implemented a groundwater extraction, treatment, and injection loop (“Interim Measure,” see Section 5.3.2), and reports that the chromium concentrations at the southern boundary of the plume are below the state groundwater standard of 50 µg/L. This suggests the interim measure may be effective (Katzman 2019). However, the four sampling locations in the time-series graphs are not along the edges of the plume and have average chromium concentrations above the 50 µg/L New Mexico WQCC groundwater standard (Exhibit 5-9 A through D).

[42] Most chromium data for well R-9 are consistently 8 µg/L or less, with the notable exception of one 1998 data point which is reported at 2,980 µg/l - far greater than any value at any LANL well before or since. However, the Validation Qualifier code indicates that this sample was unfiltered and has a validation qualifier of “NQ,” meaning “not qualified.” As such, these data are included in the analysis.

EXHIBIT 5-9. MAP OF REGIONAL SAMPLING LOCATIONS WITH THE HIGHEST AVERAGE CHROMIUM CONCENTRATIONS AND THEIR CONCENTRATIONS OVER TIME





NOTES:

- THE X-AXIS FOR THE CHROMIUM CONCENTRATIONS TIME-SERIES PLOTS HAVE DIFFERENT X-AXIS DATE RANGES IN THIS FIGURE.
- CHROMIUM CONCETRATION TIME-SERIES PLOTS CONTAIN ALL AVAILABLE DATA, INCLUDING FILTERED AND UNFILTERED SAMPLES. THE ENTIRE DATASET HAS BEEN ASSIGNED DATA QUALITY CODES OF ‘UU’ (UNIVERSAL USE), MEANING THEY ARE FULLY VALIDATED DATA AND MEET ALL QA/QC GUIDELINES.
- IN SOME INSTANCES, ONLY A FEW GROUNDWATER SAMPLES HAVE BEEN TAKEN FROM A SAMPLING LOCATION.

5.3.4 EVALUATION OF THE CHROMIUM CONTAMINATION

This section presents available information on the inventory of chromium in groundwater and summarizes available information related to key NRDA parameters necessary for quantifying injury due to chromium contamination, including:

- Porosities of the plume-containing groundwater zones,
- Thickness of the plume in those zones,
- Area of the plume, and
- Recovery time to return to baseline (with or without remediation).

Based on available data, information gaps are highlighted and evaluated to determine whether sufficient information is available for injury quantification.[43]

5.3.4.1 Chromium Inventory in the Groundwater System

The historical TA-03 power plant releases of chromium are considered among the largest impacts of LANL operations on the regional aquifer (LA-UR-06-8481, LA-UR-07-6018). Effluent discharge from the cooling tower at TA-02 Omega West Reactor in Los Alamos Canyon and cooling towers in Mortandad watershed are also sources of chromium to groundwater in the Chromium Investigation Monitoring Group. However, the releases in upper Sandia Canyon by the TA-03 power plant are orders of magnitude greater than those in Los Alamos and Mortandad Canyons (LA-UR-07-6018).

Initial estimates in 2006 of total environmental releases of chromium at TA-03 in Sandia Canyon ranged from 57,320 to 231,485 pounds (26,000 to 105,000 kilograms) in an estimated 353,146,667 cubic feet (10 million cubic meters) of water (Table 2.0-2 of LA-UR-06-8372, Table 1 of LA-UR-06-8481). According to archival records and interviews with plant operators, estimates were revised in 2007 suggesting that the range of chromium release was narrower, between 68,343 and 158,733 pounds (31,000 and 72,000 kilograms) during the years 1956 and 1972 (LA-UR-07-6018).[44] This narrower range has been used in subsequent models and supported by additional investigations in Sandia Canyon (Appendix D of LA-UR-09-6450). As detailed below, modeling updates have also resulted in differences in the estimated distribution of chromium inventories throughout the three groundwater zones.

The *Fate and Transport Modeling Report for Chromium Contamination for Sandia Canyon* presents the initial, higher inventory estimate using the Physical System Conceptual Model (LA-UR-07-6018). This model determines chromium distributions by modeling infiltration. The regional aquifer component is modeled using a two-dimensional (2-D) numerical model that characterizes groundwater flow along the regional water table. The estimated inventory range suggests that at the time of the study most of the released chromium was within the regional aquifer, and results show that transport to the regional aquifer could account for as much as 83 percent of the released chromium.

[43] As part of this effort and future injury quantification efforts, groundwater contaminant plumes are the focus; however, plumes may include multiple contaminants of concern within a single footprint.

[44] The two primary sources of chromium contamination are the TA-03 Waste Water Treatment Plant in Sandia Canyon and the Omega West Reactor in Los Alamos Canyon. Chromium release from the TA-03 Waste Water Treatment Plant occurred from 1951 to 1992, and from the Omega West Reactor from 1957 to 1973 (LA-UR-07-6018).

Of the chromium remaining in the unsaturated zone, however, most was bound within the Cerros del Rio basalt (Table 5.1-1 of LA-UR-07-6018). This observation is supported by acid leaching experiments that found the highest concentrations of acid-soluble chromium in core samples from the Cerros del Rio basalt compared to the rest of the unsaturated zone (LA-UR-06-8372). The Cerros del Rio basalt contains minerals like olivine, pyroxenes, and iron oxides that have naturally occurring chromium or serve as adsorption surfaces for chromium. In LA-UR-06-8372, the authors did not differentiate between natural and anthropogenic chromium in the Cerros del Rio basalt because background chromium concentrations were not determined for these deeper stratigraphic units. This limitation may bias chromium concentrations high in the unsaturated zone.

The second inventory estimate was generated using a mass balance approach, as described in the *Contaminant Trends and Inventory study of the Investigation Report of the Sandia Canyon* (Appendix D of LA-UR-09-6450). Similar to the model presented in LA-UR-07-6018 (above), the unsaturated zone of Sandia Canyon was subdivided by lithologic units. However, instead of modeling the transport of chromium along the stratigraphic profile, core samples representing each stratigraphic unit were analyzed for chromium and the mass was determined using an assumed infiltration area of 1,394,755 square feet (129,577 square meters), unit thickness, and properties of the rock (e.g., rock density). The perched intermediate groundwater mass was estimated assuming the same infiltration area, a chromium concentration of 600 µg/L, thickness of 98 feet (30 meters) and porosity of 10 percent.[45] This method estimates that approximately 22 pounds (10 kilograms) of chromium per year entered the regional aquifer, resulting in an estimated inventory of 1,224 pounds (555 kilograms) in Sandia Canyon.

For purposes of comparison to results from the Physical System Conceptual Model, the mass estimates for the same stream reach investigated in the mass balance approach are presented in Exhibit 5-10.

EXHIBIT 5-10. CHROMIUM (VI) INVENTORY COMPARISON FOR SANDIA CANYON

CHROMIUM(VI) (POUNDS)	PHYSICAL SYSTEM CONCEPTUAL MODEL† (MIN-MAX)	MASS BALANCE APPROACH‡ (MIN-MAX)
Released	10,628 to 80,334	68,343 to 158,733
Adsorbed on minerals of the Vadose Zone	4,826 to 32,556	9,480 to 264,554
Porewater of Vadose Zone	3.1 to 8,695	220 to 1,102
Regional Aquifer	5,549 to 66,520	595 to 7,275

† LA-UR-07-6018.
‡ Appendix D of LA-UR-09-6450.

Contrary to the results of the Physical System Conceptual Model, the mass balance-based estimate suggests the majority of the released chromium is immobilized within the solid phase of the vadose zone. This results in a total mass estimate of chromium in the regional aquifer that is approximately an order of magnitude lower. Despite these differences in the distribution of the chromium mass across the hydrologic units of Sandia Canyon, both approaches highlight the importance of the adsorption of chromium throughout the rock units of the stratigraphic profile, as well as the importance of continued

[45] Porosity estimates for the Cerros del Rio basalt range between 10 to 30 percent (Exhibit 5-11).

monitoring of the unsaturated zone and development of more complex models that can characterize future mobilization. Nevertheless, both models agree that significant chromium contamination has reached the regional aquifer.

5.3.4.2 Chromium Plume Parameters of the Perched-Intermediate Groundwater

Chromium contamination is observed in both the perched-intermediate and regional aquifers in the vicinity of the Chromium Investigation Monitoring Group, which includes portions of Sandia, Mortandad, and Los Alamos Canyons. The upper perched-intermediate horizon is within the Puye formation on top of the Cerros del Rio basalt with an approximate thickness of 33 feet to 66 feet (10 to 20 meters) (Figure 3.0-1 of LA-UR-07-6018). The second perched-intermediate horizon is within fractured lavas and interflow breccias in the lower part of the Cerro del Rios basalt with thickness ranging between 49 and 98 feet (15 and 30 meters). The spatial distribution of the perched-intermediate groundwater is discontinuous and forms lens-shaped saturated horizons that are difficult to map with limited well observations. As a result, there is incomplete information on the spatial extent of intermediate groundwater in this area (Exhibit 5-11).

EXHIBIT 5-11. SUMMARY OF AVAILABLE INTERMEDIATE GROUNDWATER PARAMETERS FOR THE CHROMIUM PLUME

PARAMETER	AREA (SQUARE FEET)	THICKNESS OF PLUME (FEET)	POROSITY (PERCENT)	REFERENCE
INTERMEDIATE GROUNDWATER				
Stratigraphic Unit				
Cerros del Rio Basalt	-	98	10[†]	LA-UR-09-6450 Appendix D
	-	-	10 to 30	LA-UR-07-6018 Appendix D
	-	118 to 492	5 to 21[‡]	LA-UR-18-21450 Attachment 9
REGIONAL AQUIFER				
Stratigraphic Unit				
Puye	9,931,677 - <27,878,527*	49 to 75	-	DOE (2015)
	-	-	20	LA-UR-18-21450 Attachment 1
	1,840,301	-	-	LA-UR-18-21450 Attachment 9

[†] Assumed porosity for Cerros del Rio Basalt and Puye formation.
[‡] Porosity range for model nodes above, within and below basalts obtained from Table 2.1-6.
* Plume area greater than the 50 microgram per liter New Mexico groundwater quality standard (NMAC 20.6.2). The 9,931,677 square meters estimate was determined by IEc by digitizing, using ArcGIS, the chromium plume outline in Figure 1-2 in DOE 2015.

In 2018, a three-dimensional (3-D) coupled vadose-zone/regional-aquifer model calibrated with monitoring well data was released that predicts the distribution and thickness of the intermediate groundwater in Sandia and Mortandad Canyons (Figure 2.1-1 of LA-UR-18-21450 Attachment 9). Modeled perched-groundwater thickness is shown to be consistent with the authors' hydrogeologic conceptual model (Table 2.1-1 of LA-UR-18-21450 Attachment 9). However, the spatial extent of the plume was not completely described by the modeling (LA-UR-18-21450 Attachment 9). Consequently, the available parameters for perched-intermediate groundwater are limited to the thickness of the perched-intermediate groundwater and porosity (Exhibit 5-11). Additional characterization could define the extent of chromium contamination in the intermediate groundwater, which is a pathway for contamination to the regional aquifer.

5.3.4.3 Chromium Plume Parameters of the Regional Aquifer

LANL estimated the chromium plume area in the regional aquifer using the 50 µg/L concentration interval (the State of New Mexico groundwater standard) and reported the area as less than approximately 28 million square feet (approximately 643 acres) (DOE 2015) (Exhibit 5-11). This estimated area determined from groundwater sampling is an approximation and the eastern extent of the plume is uncertain (Exhibit 5-12). However, using ArcMap to digitize the plume presented in DOE 2015 (Figure 1-2) results in an estimate of approximately 10 million square feet (0.9 million square meters). In 2018, modeling of the regional aquifer plume was refined by the 3-D coupled vadose-zone/regional-aquifer model for the plume extent within the 50 µg/L concentration contour (Exhibit 5-13). Using this modeling approach, the estimated area of the plume is approximately 12 million square feet (approximately 230 acres) when digitized using ArcMap (Exhibit 5-11). Complete characterization of the volume and mass of the chromium plume(s) in the regional aquifer has not been achieved; several recently drilled wells that were anticipated to have background concentrations of chromium are contaminated. The vertical extent of chromium contamination has also not been established, based on increasing dissolved concentrations of chromium measured in deeper screens in regional aquifer wells. Importantly, the nearby supply well, PM-3, is potentially in hydraulic communication with groundwater at depth beneath the undefined vertical extent of contamination. In addition to the uncertainty in these estimates of the chromium plume area, changing the concentration level used to define the plume would also change the spatial scope (i.e., a lower concentration contour would result in a larger plume extent); this and other decisions regarding NRDA parameters will be determined as part of injury quantification efforts.

EXHIBIT 5-12. THE 2005 REGIONAL AQUIFER CHROMIUM PLUME (FIGURE 1-2 OF DOE 2015)

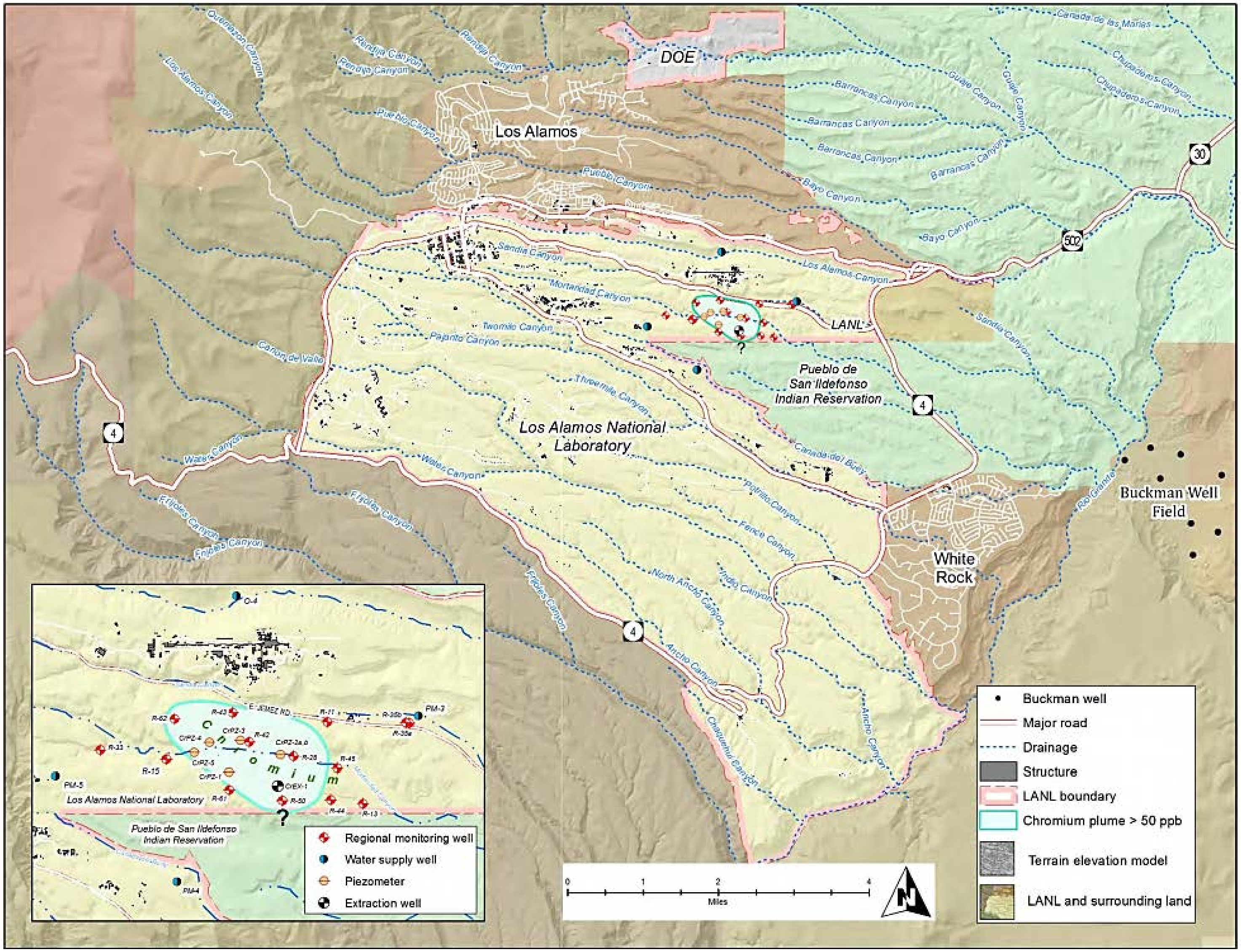
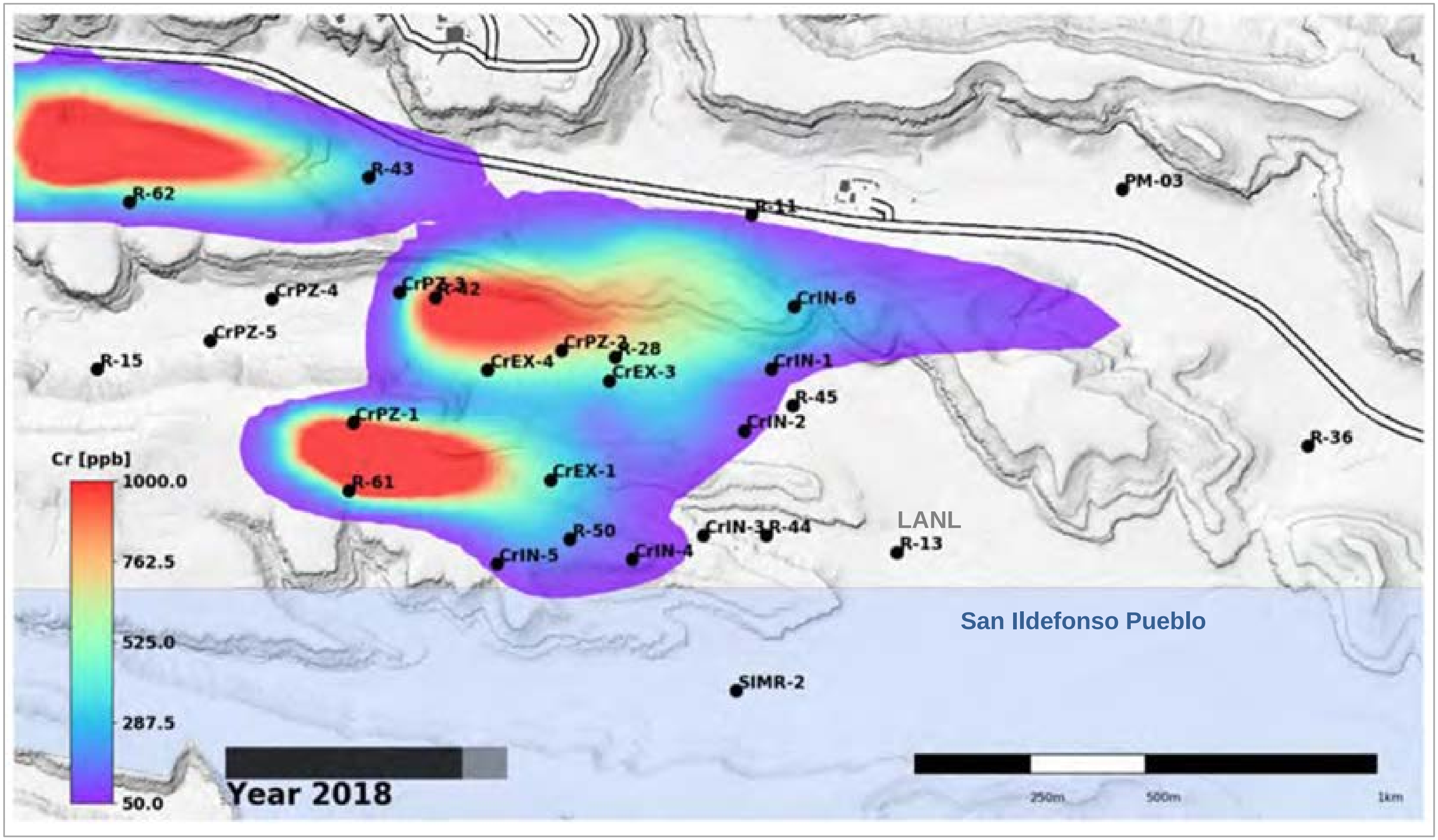


EXHIBIT 5-13. THE 2018 MODELED REGIONAL AQUIFER CHROMIUM PLUME (FIGURE 2.2-5 LA-UR-18-21450 ATTACHMENT 9)



Chromium contamination is located primarily in the upper portion of the aquifer with an estimated depth of 49 to 75 feet (15 to 23 meters) below the regional water table (DOE 2015). Groundwater flows eastward at a rate estimated between 0.98 and 6.5 feet (0.03 and two meters) per day, or 30 to 2,395 feet (nine to 730 meters) per year (LA-UR-18-21450 Attachment 1). Measured flow rates are highly variable due to the possible existence of preferential flow channels through high permeability regions within the strata (LA-UR-18-21450 Attachment 1). Some LANL sources have suggested this flow rate is not necessarily applicable to the transport of chromium in the regional aquifer because chromium species such as Cr(III) may adsorb to sediments of the regional aquifer. However, batch and column experiments using regional aquifer sediments found no retardation of chromium, suggesting a minor presence of iron or magnesium oxides that would be adsorption surfaces for chromium (LA-UR-18-21450 Attachment 6). Additionally, concentrations of hexavalent chromium have been rising in monitoring wells at the periphery of the plume in tandem with anions that are known to be conservative/nonreactive (e.g., sulfate, chloride, and nitrate) (LA-UR-18-21450 Appendix B of Attachment 1). Consequently, the measured groundwater flow rates are useful for estimating chromium transport in the regional aquifer because adsorption of chromium to regional aquifer sediments appears to be minor.

5.3.4.4 Evaluation of Available NRDA Parameters of Chromium Contamination

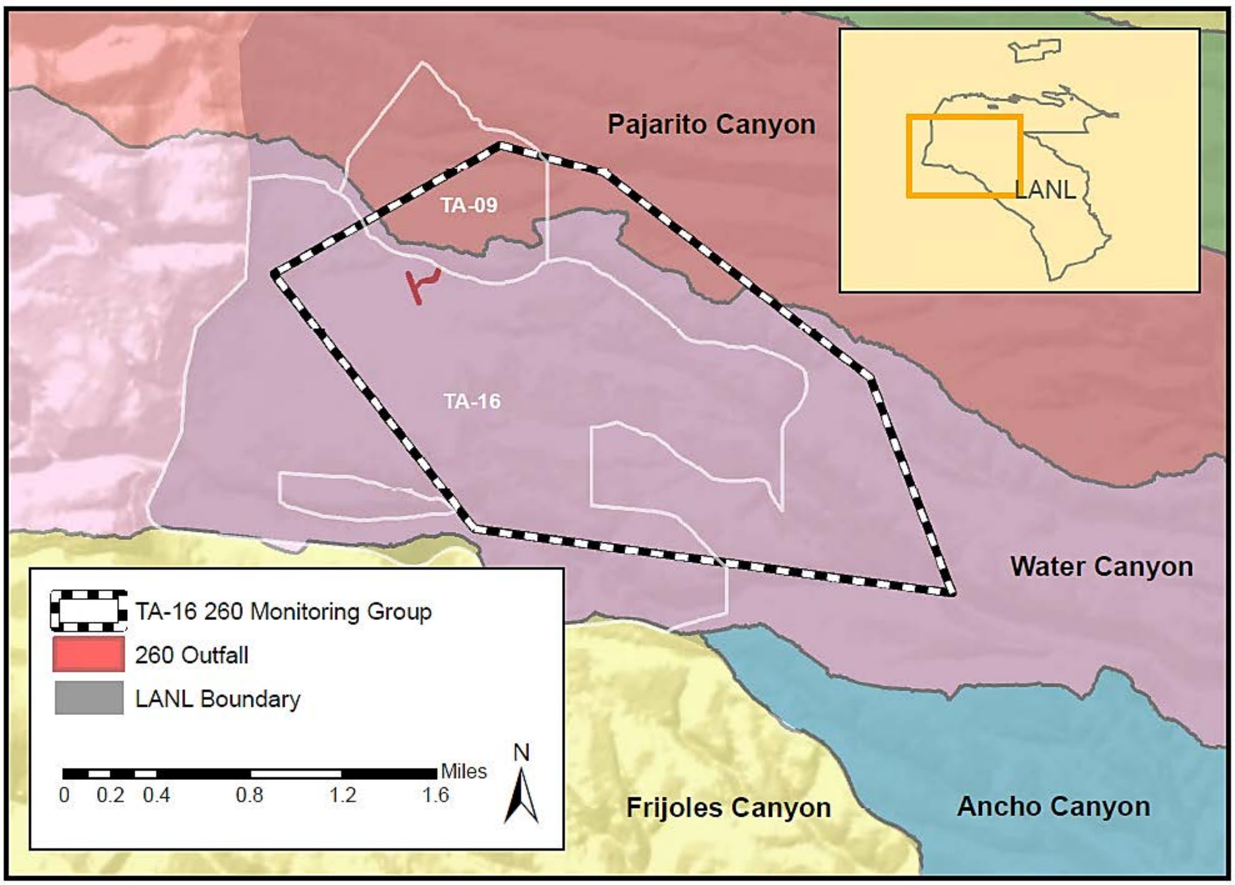
In summary, the parameters available for chromium in the regional aquifer are sufficiently constrained to determine a reasonable estimate of plume extent and contaminated volume. However, there is uncertainty regarding the spatial extent of the plume and more precise estimates of area and plume migration should be considered as they become available. Updates from the 3-D coupled vadose-zone/regional-aquifer model will be especially relevant because of the ability of that model to image the spatial distribution of both the intermediate and regional groundwater plumes. Additionally, the spatial extent of the plume from site reports is based on the 50 µg/L concentration contour, whereas a lower concentration contour, such as 7.48 µg/L (the baseline value of chromium in the regional aquifer), may be relevant for NRDA injury quantification purposes (and would result in a larger estimate of plume extent). Finally, an evaluation of the volume of chromium contamination in the Chromium Investigation Monitoring Group would capture other co-located COCs, such as radionuclides and perchlorate, which have elevated levels in the alluvial and perched-intermediate groundwater associated with releases from SWMUs in Mortandad Canyon (Section 4.3.2).

5.4 RESULTS FROM EVALUATION OF RDX PLUME

RDX is a high explosive compound that is relatively mobile at observed concentrations at LANL. RDX was released to the environment both through explosives manufacturing processes, and by controlled detonations and munition firings. As described in Section 3.2, high explosives (e.g., RDX) and inorganic compounds related to explosives machining processes were discharged to Cañon de Valle via the TA-16 260 Outfall from 1951 to 1996 (Exhibit 5-14) (IFGMP 2017). A significant amount of RDX contamination remains in the subsurface in the TA-16 area. RDX, a man-made product that does not occur in nature, has migrated from the alluvium through the perched-intermediate zone to the regional aquifer. The migration of RDX to the regional aquifer is a primary focus of investigations at LANL, and one of the two priority compounds evaluated in this report. RDX is in all three zones of groundwater at concentrations well above the U.S. EPA screening level for tap water of 6.1 µg/L.[46]

This section describes contaminant pathways to groundwater; summarizes monitoring, remediation, and related investigations; and evaluates the extent of RDX groundwater contamination. Site reports and groundwater contaminant data are the primary sources of information presented in this section, and this section primarily relies on two recently published comprehensive and relevant reports: The *Compendium of Technical Reports Conducted Under the Work Plan for Chromium Plume Center Characterization*, and the *Investigation Report for Royal Demolition Explosive in Deep Groundwater*, discussed previously in Section 2.3. Reports of RDX occurrences elsewhere at LANL (i.e., not in or near TA-16) are discussed in Chapter 4.

EXHIBIT 5-14. LOCATION MAP FOR RDX PLUME EVALUATION



Note: The TA-16 260 Monitoring Group boundary is an approximation from the IFGMP (2017).

[46] RDX concentrations are compared to the RDX EPA Tap Screening Level as reported in the 2017 Interim Facility-Wide Ground Monitoring Plan (IFGMP 2017). EPA screening levels are risk-based concentrations derived from standardized equations combining exposure information assumptions with EPA toxicity data.

5.4.1 RDX PATHWAY CHARACTERIZATION

The hydrogeology in the TA-16 area is like other areas of LANL; discussed in Section 3.1, above. The geology is the complex result of volcanism, sedimentation, erosion, and faulting with localized deposits that interfinger with and overlie regional surficial deposits, ash-flow tuffs, and interbedded sedimentary deposits, alluvial fan deposits, and lava flows (LA-14263-MS). Infiltration occurs predominantly during spring snowmelt or after intense summer storms when runoff convenes in ephemeral reaches of canyons (Birdsell et al. 2005). For example, ephemeral flow is supplied to Cañon de Valle, Fishladder Canyon, and Martin Spring Canyon by storm water and snowmelt runoff (EM2019-0235), whereas perennial surface water in TA-16 is derived from spring discharges, primarily from Burning Ground Spring (EM2019-0235). In the past, outfalls were also a source of intermittent surface flows and water ponding, including at TA-16 260 and other HE-processing building outfalls (e.g., TA-16 360) (EM2019-0235).

The three primary water bearing hydrogeologic zones present in the vicinity of TA-16 are described in Exhibit 5-15. Exhibit 5-16 is a north-south section across the axis of Cañon de Valle that highlights the hydrogeology in the lower part of the vadose zone and underlying regional aquifer. The thick perching zones illustrated in the figure are local to the TA-16 area and may not be contiguous with perching zones elsewhere at LANL because of spatial heterogeneity of aquifer materials (EM2019-0235).

EXHIBIT 5-15. HYDROGEOLOGY OF THE TA-16 AREA

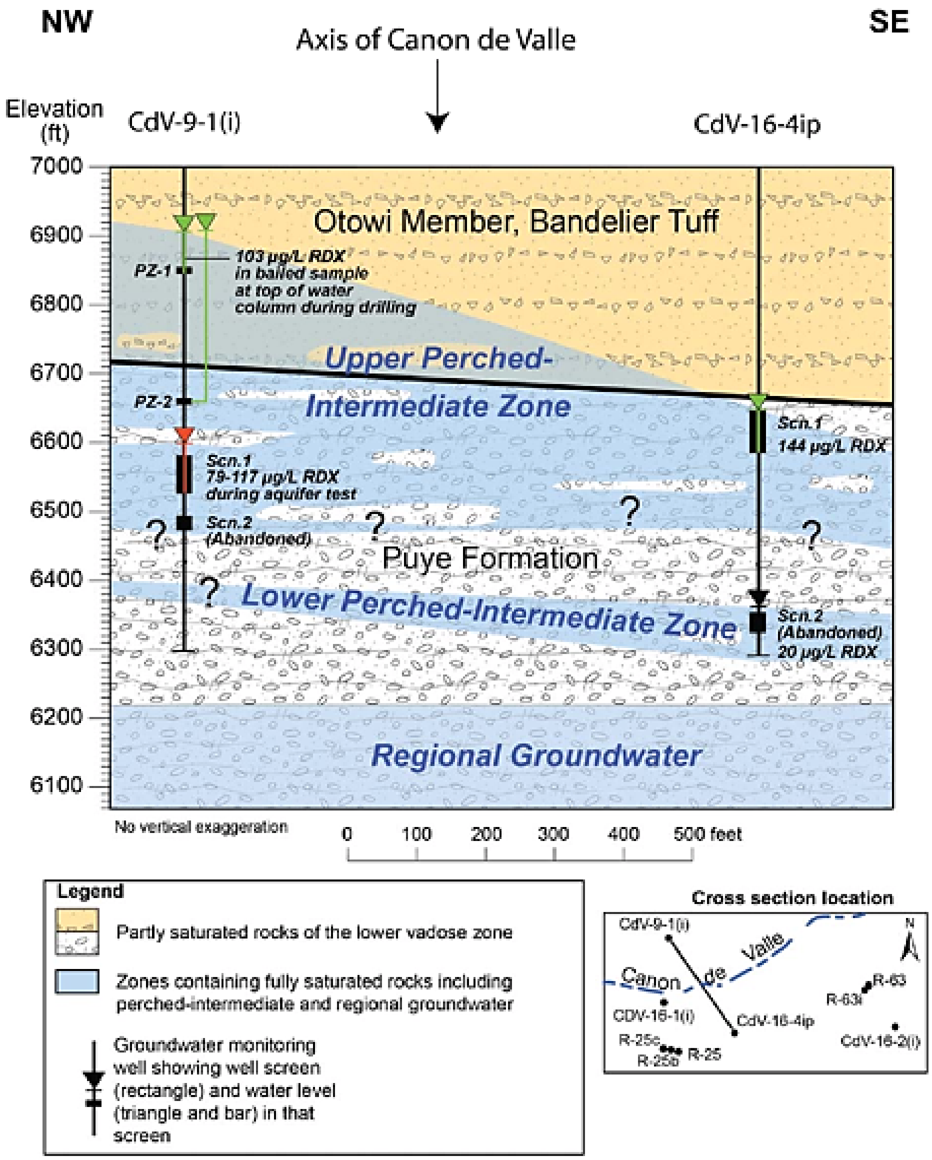
Alluvium. Perched groundwater occurs in the valley alluvium along Cañon de Valle, and in alluvium below Fishladder and Martin Springs. The saturated thickness is only a few feet thick and occurs only at and immediately downstream of inflow sources. Water levels are within a few feet of the land surface and respond to surface flows, including snowmelt and periodic stormflows. The alluvium was previously fed by seepage from wastewater discharges, of which the 1951 to 1996 discharges from TA-16 260 Outfall are the likely source of RDX in this area. Surface flows and alluvial groundwater are the primary pathways through which wastewater discharges migrate laterally, before infiltrating to deeper units.

Intermediate zone. The detailed hydrology of the intermediate zone is not well known, but the flow system has been conceptually established. Uncontaminated groundwater flows into this zone from the west. Downward unsaturated flow occurs through basalt fractures and tuff matrices. Substantial vertical differences in material properties (i.e., anisotropy) can result in lateral displacement of such flow. A shallow suite of perched water zones occurs less than 200 feet from the mesa top and is the source of discharge to the SWSC, Burning Ground, and Martin Springs. Two significant deep perched zones (with areas of more than 500 acres each) are known to occur at greater depths. Groundwater within the perched zones is interpreted as generally flowing from west to east with some indication of a local southerly component (LA-14263-MS). Due to the complex nature of the intermediate zone, however, flow paths are uncertain.

At one time it was believed that the presence of a thick vadose zone precluded contamination of the regional aquifer from surface sources. It is now known that surface discharges can reach the regional aquifer within a matter of decades, with possible lateral displacement along the way. Detailed flow paths have not been established but fracture pathways are likely important in light of aquifer tests that quantify very low values of hydraulic conductivity for matrix flow (e.g., one inch per day) (see LA-UR-17-22550). Survey data suggest that flow paths occur through vertical pipe-like structures (LA-14263-MS and references therein).

Regional aquifer. The regional aquifer is a complex heterogeneous suite of sedimentary and volcanic units that are at least a few thousand feet thick. This unit is permeable with flow west to east with local directional variations. The regional groundwater table is unconfined and found at depths approximately 1,000 to 1,300 feet below the mesa surface. Confined conditions occur at depth and vertical permeability is often low. The aquifer is supplied by inflow from regional recharge areas west of Los Alamos and by recharge from the alluvial aquifer via the intermediate zone. The aquifer is the primary source of public water supply to the region and contributes significant discharge to the Rio Grande. Water levels at TA-16 show no significant influence from water supply pumping at the Los Alamos or Santa Fe well fields.

EXHIBIT 5-16. NORTH-SOUTH GEOLOGIC CROSS SECTION ACROSS CAÑON DE VALLE (LA-UR-15-24545)



In addition to a thorough understanding of the subsurface geologic structure, an understanding of the fate and transport behavior of RDX is necessary when evaluating the potential for resource exposure and remediation. Laboratory and field-based research on the Pajarito Plateau indicate that RDX is mobile in oxic groundwater at TA-16. RDX has a low vapor pressure (4.1×10^{-9} millimeters of mercury at 20 degrees Celcius), moderate aqueous solubility (42 to 60 milligrams per liter), and low soil organic carbon-water coefficient (1.80; K_{OC}) (EPA 2014, NPIC 2016, NCBI 2020).[47] A low vapor pressure indicates that RDX does not readily evaporate from water, while a moderately high aqueous solubility means it has a propensity to dissolve into and move with water (Newman et al. 2007, ATSDR 2012, EPA 2014, NCBI 2020). Similarly, its low K_{OC} means it is less likely to bind with organic carbon in soil or sediment relative to other organic COCs (Chiou and Kile 2000). Studies of RDX have found, however, that the mobility of RDX is affected by soil or sediment type, as well as clay and organic matter content. Despite its low K_{OC}, sorption is higher (i.e., mobility is decreased) in soils or sediments with high clay and organic matter content (Heerspink et al. 2017). According to a study conducted by LANL, very little clay minerals were present in the Puye formation sediments and little to no solid organic matter was found in the Otowi Member volcanics and Puye formation sedimentary samples collected from TA-16 and adjacent areas (Heerspink et al. 2017). The Bandelier Tuff and Puye Formation do not contain significant amounts of solid organic matter to allow for adsorption of RDX in the subsurface. As such, opportunities for RDX to adsorb to soils in the TA-16 region are few. Rather, RDX can migrate conservatively (i.e., without being attenuated) via matrix flow in shallow formations at TA-16, which are dominated by nonwelded to moderately welded porous tuffs, as well as via vertical pathways where horizontal flow intersects fractures and faults in the densely welded tuffs and basalt (Heerspink el at. 2017, EM2019-0235). Some retardation of RDX may occur within the clay-bearing Puye formation sediments of the deep perched zone. Within the oxic regional aquifer, RDX is expected to experience minimal retardation as the host rock consists of gravels dominated by dacite lava fragments that are partially coated with fine-grained tuffaceous sediments and possess minor clay contents as coatings (Heerspink et al. 2017).

In addition to the presence of RDX, monitoring data from TA-16 also indicate the occurrence of trace amounts of RDX degradation product, including MNX (hexahydro-1-nitroso-3,5-dinitro-1,3,5-triazine), DNX (hexahydro-1,3-dinitroso-5-nitro-1,3,5-triazine), and TNX (hexahydro-1,3,5-trinitroso-1,3,5-triazine) (Heerspink et al. 2017). Although phototransformation is a primary degradation mechanism for RDX in aqueous solutions, this is not likely to be relevant to groundwater contamination at LANL due to the attenuating properties of soil preventing photons of radiation from reaching RDX (OECD 2007, ATSDR 2012, EPA 2014).[48] Rather, the presence of RDX degradation products in groundwater at LANL is attributed to the activity of microorganisms capable of degrading RDX (Wang et al. 2016, Heerspink et al. 2017). However, analyses of groundwater from TA-16 illustrated that the geochemical conditions of the groundwater represent a nutritionally limited medium that is not very conducive to microbial degradation of RDX activity at the site (Wang et al. 2016). Regardless, laboratory tests indicate that the transport of MNX, DNX, and TNX is very similar to RDX (Heerspink et al. 2017). Therefore, it is expected that these degradation products will demonstrate similar fate and transport behaviors across the

[47] According to the National Pesticide Information Center, low water solubility is less than 10 milligrams per liter (mg/L), moderate water solubility is between 10 and 1,000 mg/L, and high-water solubility is greater than 1,000 mg/L.

[48] Phototransformation involves the transformation of a chemical resulting from the direct absorption of solar photons (OECD 2007).

rock types at TA-16, with some potential retardation in areas of the deep perched zone of the Puye Formation that have higher clay-content (Heerspink et al. 2017).

5.4.2 RDX MONITORING, REMEDIATION, AND INVESTIGATIONS

5.4.2.1 Monitoring

As described in Section 3.2, monitoring activities for the TA-16 260 monitoring group are ongoing and focused on HE and VOCs in the upper Cañon de Valle watershed (IFGMP 2017). In general, groundwater monitoring provides information about the constituents present and their trends and variability (IFGMP 2017). Active monitoring activities in this group have focused on characterizing the fate and transport of contaminants in the alluvial, perched-intermediate, and regional sampling locations, as well as springs. Most of the TA-16 260 monitoring network is sampled semiannually, though some locations are sampled quarterly (IFGMP 2017). The frequency of measuring certain classes of constituents (e.g., metals, polychlorinated biphenyls) also varies (IFGMP 2017).

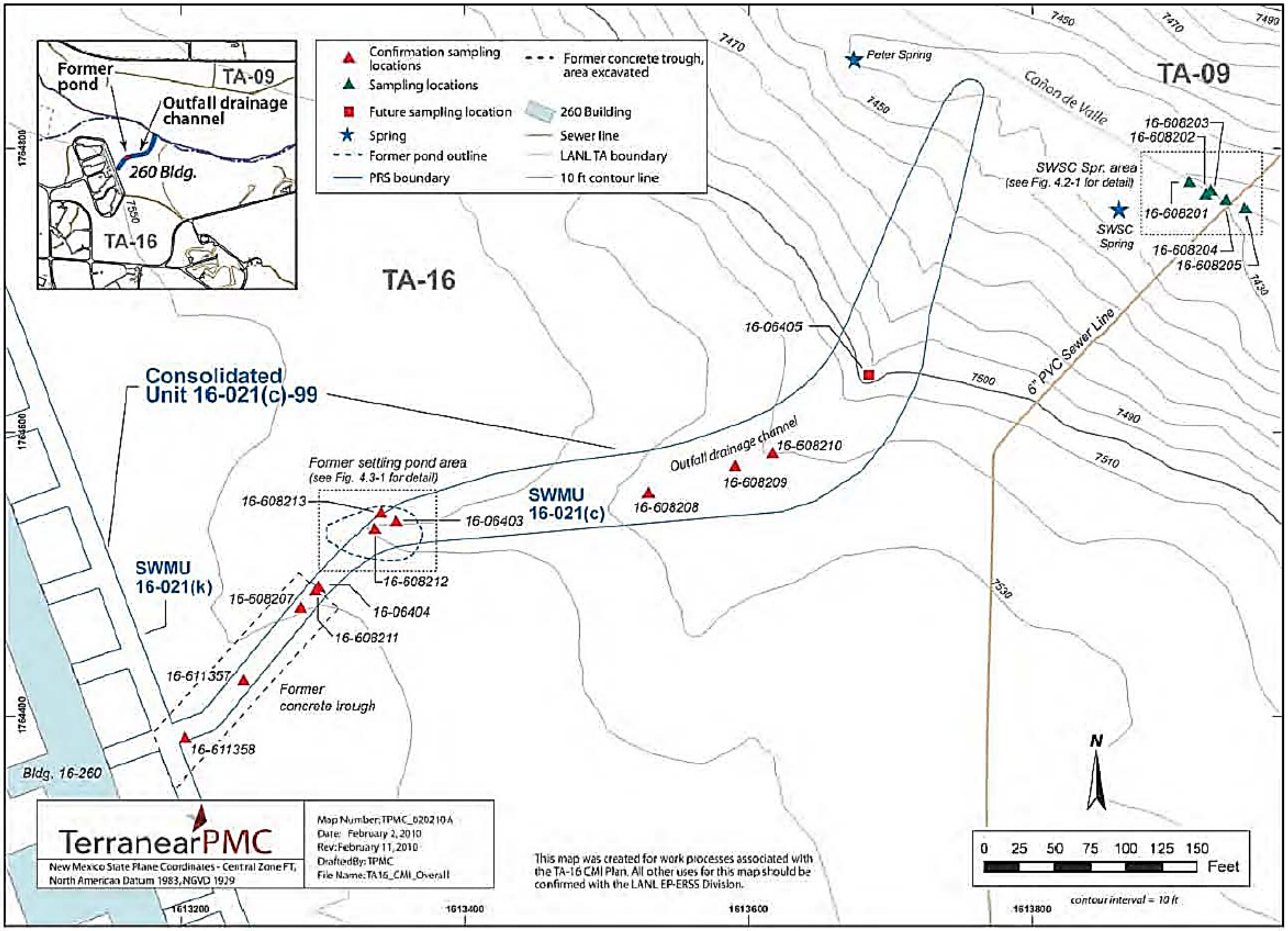
5.4.2.2 Remediation and Related Investigations

TA-16 was first investigated in 1990 and two source removal actions occurred in 2000-2001 and 2009-2010 (EM2019-0235). Sources of RDX contamination include former laboratory discharges to drainage channels and ponds (Exhibit 5-17) (EM2019-0235). However, the principal sources for contamination in perched-intermediate groundwater are the highly contaminated reach of Cañon de Valle and the 260 Outfall pond and drainage (EM2019-0235).[49]

- **Source Removal Interim Measure removal action (2000-2001):** The first source removal effort was an interim measure to remove soils exceeding 100 milligrams per kilogram RDX in the settling pond area. More than 1,300 cubic yards (yd^3) of soil was removed with high explosives composing 90 percent (or 18,740 pounds) of the total amount removed (EM2019-0235). The remaining part (an estimated 1,435 pounds) included high explosives that were present in a surge bed below the settling pond area and in sections of the drainage channel (EM2019-0235).
- **Corrective Measures Investigation removal action (2009-2010):** The second removal effort removed a relatively small amount (less than 100 yd^3) of soil with elevated concentrations of high explosives that remained near the 260 Outfall. An additional 40 yd^3 of soil and sediment were also removed from the former settling pond and within the 260 Outfall drainage channel because this that material could be mobilized by stormwater runoff.

[49] Recent LANL RDX investigations focused on conditions in TA-09, north of Cañon del Valle. While some low-level contamination has been identified in that area, TA-09 is a minor secondary source of RDX compared to TA-16 260 (EM2019-0235).

EXHIBIT 5-17. FEATURES ASSOCIATED WITH THE 260 OUTFALL (FROM LA-UR-10-0947)



Contaminated soils from these removal actions were disposed of offsite (LA-UR-17-27678). Other remediation activities included removing the concrete outfall trough, capping and grouting the former settling pond, and installing carbon filters for the treatment of spring water. LANL had submitted a report detailing the results of these efforts to NMED in March 2010 (LA-UR-10-0947, EM2019-0235). However, as a result of the Las Conchas fire, a series of storms produced damaging floods between July 28 and August 21, 2011 that affected the remediation technologies in this area (EM2019-0235). LANL assessed the damage and, with NMED's approval, implemented cleanup recommendations from November 2016 to June 2017 (EM2019-0235). These activities included debris removal, plugging and abandoning damaged monitoring wells, restoring springs, and installing a replacement alluvial monitoring well. NMED ultimately approved of the remediation in this area in November 2017 and LANL has now transitioned to long-term monitoring of alluvial groundwater, base flow, and springs in addition to inspections of the cap above the former settling pond (LA-UR-17-27678, EM2019-0235).

The investigation of intermediate and regional groundwater RDX contamination has been separated from the surface and near-surface activities described above. The primary goal of the deep groundwater investigation is to determine the extent of RDX in perched-intermediate and regional groundwater resulting from the former 260 Outfall (EM2019-0235). Additional goals include: 1) determining the rate at which RDX moves down gradient toward potential exposure points, 2) investigating the directions of groundwater flow and the hydraulic gradients within the intermediate and regional zones, and 3) identifying contaminants of potential concern for the TA-16 regional groundwater Corrective Measures Evaluation (CME).

As outlined in the 2005 Consent Order, LANL was required to submit an investigation report for perched-intermediate and regional groundwater to NMED and, upon approval, prepare a CME (Consent Order 2005, EM2019-0235). NMED issued a Notice of Deficiency (NOD) for the CME in April 2008. As a result of the NOD, LANL conducted additional investigations. Additional studies not directed by the 2008 NOD also were needed to address data gaps initially identified in the 2008 NOD, including: 1) the nature of the contaminant source, 2) the nature and extent of contamination, 3) additional details on the conceptual model, 4) potential remedial technologies, and 5) groundwater models available for evaluation of contaminant fate and transport and potential corrective actions (LA-UR-18-21326). Results from this work was ultimately packaged in the *Compendium of Technical Reports Related to the Deep Groundwater Investigation for the RDX Project at Los Alamos National Laboratory*, referred to generally as "the RDX Compendium" (LA-UR-18-21326). This work also informed the deep groundwater investigation report submitted in August 2019 (EM2019-0235).

The related investigations and efforts included:

- Geophysical studies to map the vadose zone and determine the extent of perched intermediate groundwater. This work was used to determine where to install additional monitoring wells and better understand the subsurface stratigraphy.
- Installing additional perched-intermediate and regional groundwater monitoring wells and reconfiguring Westbay sampling system wells to single screen, purgeable sampling systems.
- Aquifer tests, including cross-hole and in-hole multi-level tests, to develop data on aquifer properties that impact groundwater flow.

- Deployment of multiple nonreactive tracers in the two deep-perched zone wells (CdV-16-1(i) and R-25b) located farthest upgradient to measure groundwater transport directions and rates.
- Evaluation of microbial communities and RDX degradation in perched-intermediate groundwater and associated sediments. The findings showed that the geochemical conditions of the groundwater are not optimal for vigorous microbial activity (Wang et al. 2016). Specifically, insufficient organic carbon prevents anaerobic conditions conducive of RDX degradation (LA-UR-18-21326).

Groundwater remediation and institutional controls are needed to eliminate use of regional groundwater underlying TA-16 for consumption now and into the future. Although an imminent threat to the public water supply was not identified since the deep groundwater containing RDX is more than three miles from the nearest public water supply well (EM2019-0235), RDX in the regional aquifer might pose a future risk were RDX in the perched intermediate zone to migrate in sufficient concentration and quantities into the deeper zone. It was therefore recommended that a fate and transport groundwater model be used to evaluate risk and uncertainty and to support evaluation of remedial alternatives in a CME (EM2019-0235). Currently, remediation of the intermediate-perched groundwater has not been thoroughly investigated because intermediate-perched wells have low sustainable pumping rates that correspond to insufficient RDX removal rates (EM2019-0235).

5.4.3 RDX RECEPTOR CHARACTERIZATION

As noted above, RDX contamination is in the Cañon de Valle and a result of discharge from the TA-16 260 Outfall pond (and drainage). To evaluate the extent, fate, and transport of RDX in the groundwater and in the aquifer beneath LANL, groundwater samples have been collected and analyzed from a network of monitoring wells in the TA-16 260 Monitoring Group since at least 1951. Sampling locations in this network are measured for water level and many locations are sampled quarterly for laboratory analysis (IFGMP 2017). As described in Section 5.2, to independently evaluate these data in the NRDA context, sampling data were reviewed from 77 sampling locations spanning October 1997 to December 2019 (Exhibit 5-18). RDX concentrations were compared to the EPA Tap Water Screening Level of 6.1 µg/L as set forth in the IFGMP. However, because RDX is a manmade compound, it would otherwise not be expected to occur in groundwater absent anthropogenic contamination.

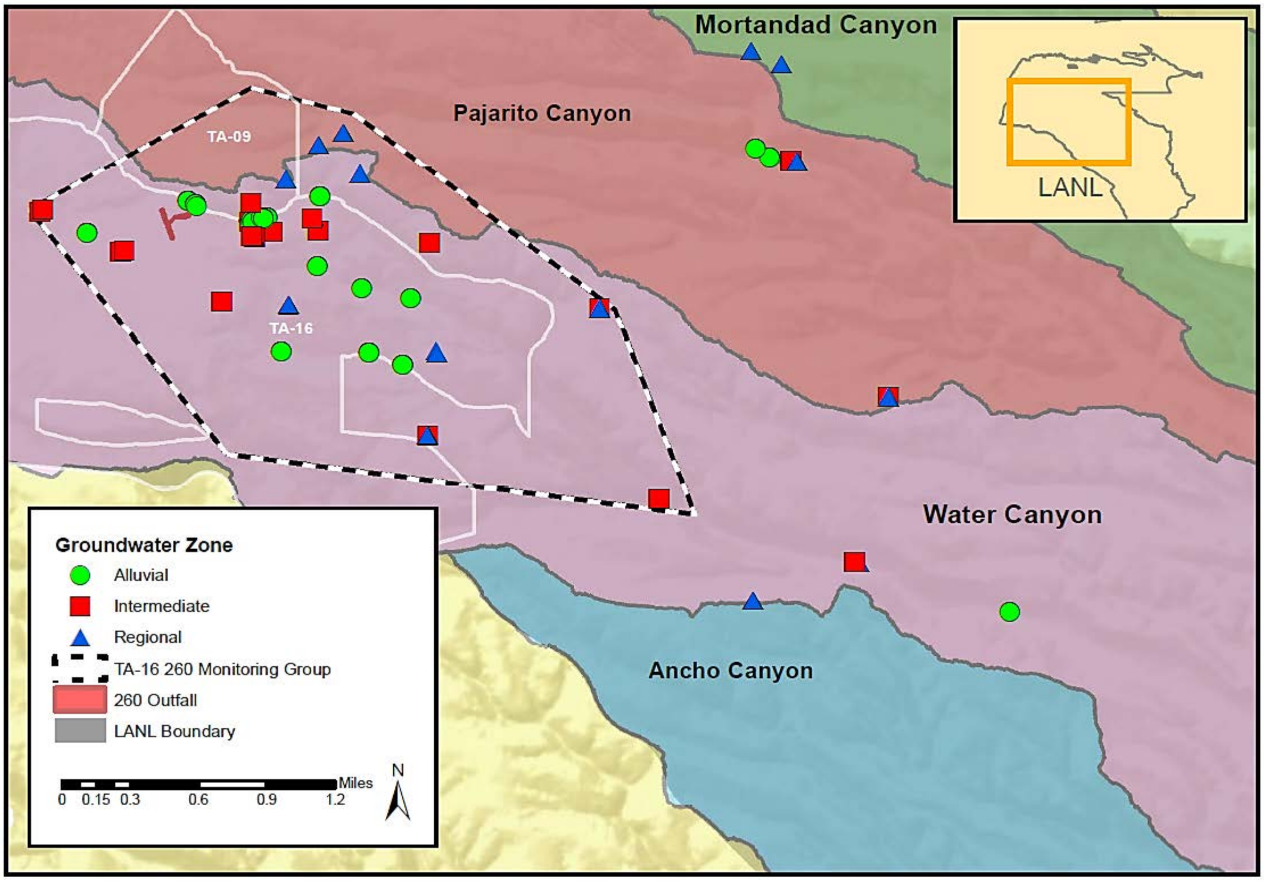
Exhibit 5-18 shows sampling locations in relation to TA-16, the TA-16 260 Outfall, (the principal sources of RDX contamination in the area) and the TA-16 260 Monitoring Group boundary (EM2019-0235). Groundwater sampling locations in the dataset comprise 22 alluvial, 25 perched-intermediate, and 30 regional aquifer locations. The dataset includes 393 alluvial, 448 perched-intermediate, and 638 regional aquifer samples (Exhibit 5-19). Approximately 67 percent of alluvial samples, 66 percent of perched-intermediate samples, and 26 percent of regional aquifer samples are above detection limits. Furthermore, approximately 27 percent samples from the alluvial system, 53 percent in the perched-intermediate system, and seven percent from the regional aquifer exceed the U.S. EPA Tap Water Screening Level of 6.1 µg/L (IFGMP 2017) (see Exhibit 5-19 for detailed sample information).[50] Summary statistics of groundwater samples from these sampling locations indicate that aquifer-specific arithmetic mean RDX concentrations are highest in the perched-intermediate system (30.2 µg/L), moderate in the alluvial

[50] The proportion of exceedances are calculated by dividing the number of values that exceeded 6.1 µg/L in a given groundwater system by the total number of samples collected in that groundwater system and multiplied by 100.

system (11.1 µg/L), and lowest in the regional aquifer (1.5 µg/L) (Exhibit 5-19). The geometric means of RDX concentrations are all lower than the arithmetic means, but are similarly highest in the perched-intermediate system (4.5 µg/L), moderate in the alluvial system (1.6 µg/L), and lowest in the regional aquifer (0.34 µg/L).

The two highest RDX concentrations in the RDX dataset are in the alluvial aquifer (759 and 310 µg/L from well CDV-16-02657 in the Cañon de Valle in March 2001 and June 1999, respectively); followed by perched-intermediate groundwater (281 µg/L from well 90LP-SE-16-02669 near Building TA-16-260 in March 1998 and 265 µg/L from well CDV-16-02657 in Cañon de Valle Canyon in August 2010). Within the alluvial groundwater system, approximately four percent of samples are filtered, and approximately three percent of samples are filtered and above their detection limits. Within the perched-intermediate groundwater, less than one percent of samples are filtered, and approximately one half of one percent of samples are filtered and above their detection limits. Within the regional aquifer no samples are filtered, and approximately 26 percent are above their detection limits (Exhibit 5-19). Although the perched-intermediate groundwater has the highest percentage of samples that exceeded the U.S. EPA Tap Water Screening Level concentration (6.1 µg/L), the alluvial groundwater has the highest percentage of filtered samples that are detected, suggesting that relatively high levels of RDX contamination are prevalent, in terms of the number of sampling locations in which contamination above 6.1 µg/L is found, in the alluvial groundwater system. Conversely, the regional aquifer contains the lowest percentage of groundwater samples that exceed the U.S. EPA Tap Water Screening Level and the lowest percentage of filtered and detected groundwater samples, suggesting that the regional aquifer has the least amount of RDX contamination, in terms of the number of sampling locations in which contamination above 6.1 µg/L is found, when compared to the alluvial and perched-intermediate groundwater systems. In terms of exceedances, perched-intermediate groundwater contains the highest percentage of RDX concentrations that exceeded the U.S. EPA Tap Water Screening Level value (approximately 54 percent), the alluvial groundwater contains the moderate proportion of samples that exceed the U.S. EPA Tap Water Screening Level value (approximately 27 percent), and the regional aquifer contains the lowest percentage of samples that exceed this value (approximately seven percent). These observations suggest that high RDX contamination is more prevalent, in terms of the number of sampling locations in which contamination above 6.1 µg/L is found, within the alluvial and perched-intermediate groundwater.

EXHIBIT 5-18. MAP OF SAMPLING LOCATIONS



Note: Several sampling locations selected within this region are geographically close to one another and are represented by a single datapoint at this scale.

EXHIBIT 5-19. SUMMARY STATISTICS OF RDX CONCENTRATIONS

PARAMETER	ALLUVIAL GROUNDWATER[1]	INTERMEDIATE GROUNDWATER[1]	REGIONAL GROUNDWATER[1]
Minimum (µg/L)	0.086	0.013	0.078
Minimum Detected (µg/L)	0.092	0.027	0.088
Median (µg/L)	0.87	8.1	0.33
Maximum (µg/L)	759.00	281.00	28.00
Maximum Detected (µg/L)	759.00	281.00	28.00
Average (µg/L)	11.13	30.20	1.49
Geomean (µg/L)	1.56	4.53	0.34
25th Percentile (µg/L)	0.33	0.33	0.26
75th Percentile (µg/L)	7.60	33.45	0.33
Non-Detected Sample Count	128	154	473
Detected Sample Count	265	294	165
% Detected	67.4	65.6	25.9
Non-Filtered Sample Count	378	446	638
Filtered Sample Count	15	2	0
% Filtered	3.8	0.4	0
Does Not Exceed Baseline Sample Count[2]	285	208	593
Exceeds Baseline Sample Count[2]	108	240	45
% Exceeds Baseline[3]	27.5	53.6	7.1
Total Sample Count	393	448	638
Total Number of Sampling Locations	22	25	30

1. Summary statistics are based on the entire RDX dataset.
2. A record "Exceeds" if it is greater than the RDX baseline concentration of 0.0 µg/L.
3. Exceedance proportion percentage includes detected/non-detected and filtered/non-filtered samples.

Units:
µg/L = micrograms per liter

5.4.3.1 Alluvial Groundwater

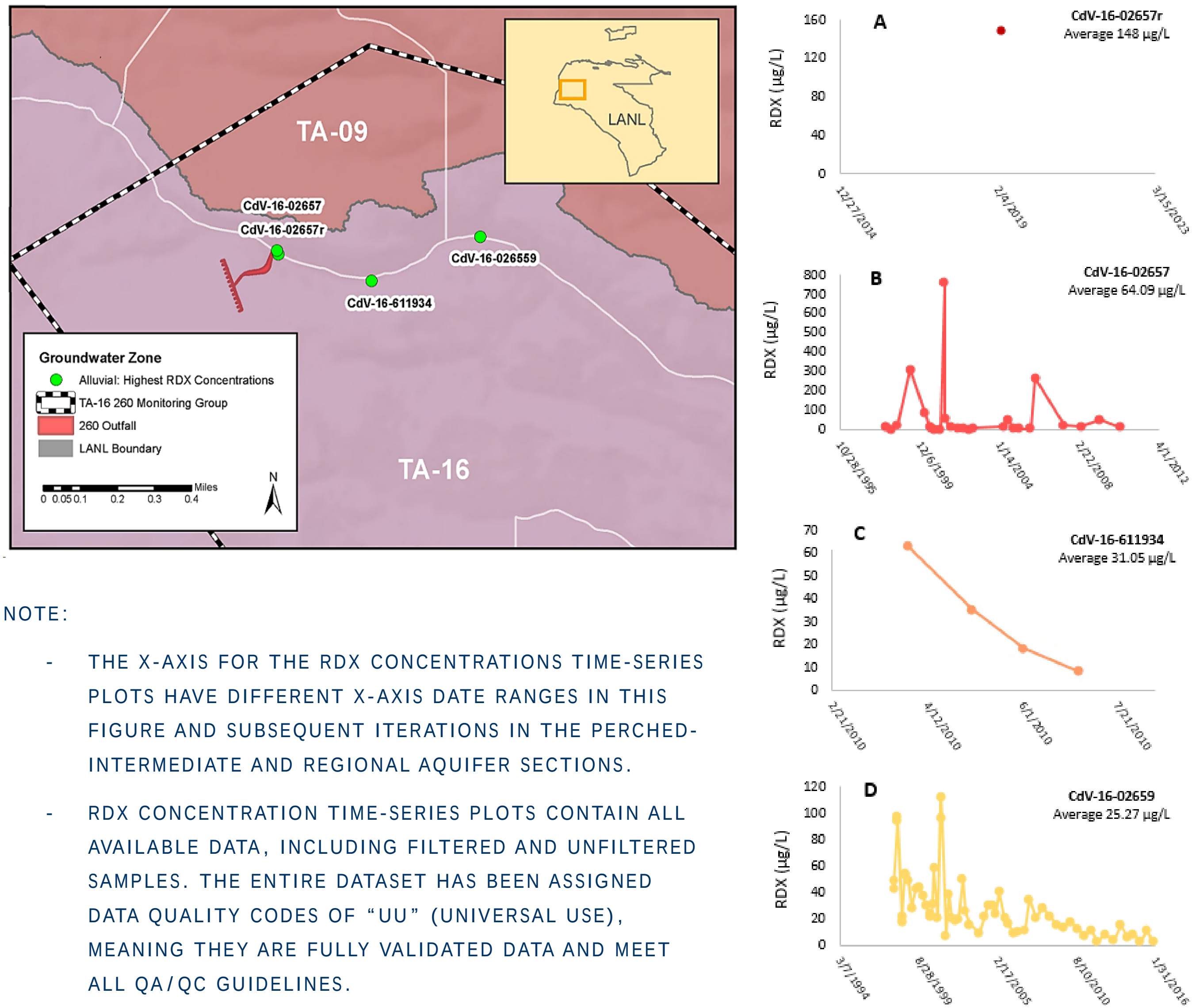
The arithmetic mean RDX concentration in the alluvial groundwater dataset (December 1997 through August 2019) is 11.1 µg/L, which is in between the arithmetic mean concentrations for perched-intermediate and regional groundwater. The geometric mean RDX concentration in the alluvial groundwater dataset is 1.6 µg/L, which is also in between the geometric mean concentrations for perched-intermediate and regional groundwater. [51] Approximately 28 percent of alluvial samples exceeded the U.S. EPA Tap Water Screening Level of 6.1 µg/L, which is in between the percentages for the other zones of groundwater. When evaluating the entire RDX dataset, several time periods of high RDX concentrations are apparent. RDX concentrations peak to 310 µg/L in June 1999 in sampling location

[51] The arithmetic and geometric mean are calculated based on the entire RDX dataset. No samples are excluded for these calculations.

CDV-16-02657, increase to 759 µg/L in March 2001, followed by a third, local maximum of 264 µg/L in November 2005. In 2009 well CDV-16-02657, located near the discharge point of the 260 Outfall to the Cañon de Valle, was destroyed by flooding and replaced by well CDV-16-02657r, which was drilled in approximately the same location as CDV-16-02657. In March 2019, well CDV-16-02657r recorded an RDX concentration of 148.3 µg/L, among the higher observed values in the dataset. The high concentrations of RDX in these sampling locations can be attributed to their proximity to the TA-16-260 Outfall and Cañon de Valle, through which Building TA-16-260 discharged RDX-contaminated water (IFGMP 2017). Well CDV-16-02659, located slightly downgradient from CDV-16002657r in Cañon de Valle, similarly shows elevated RDX concentrations, although concentrations appear to be a decreasing over time. Specifically, between December 1997 and September 2011, RDX concentrations in well CDV-16-02659 decrease from 112 µg/L to approximately 10 µg/L, with peak concentrations occurring in March 1998 (97.4 µg/L) and March 2001 (112 µg/L); but concentrations have remained below 20 µg/L since March 2008. Because RDX does not readily degrade in this oxic environment, the decreasing RDX concentrations in this sampling location confirm that RDX is mobilized within the alluvial groundwater system. However, this also suggests that the alluvial groundwater system is discontinuous because all other sampling locations in the dataset record low concentrations of RDX.

To further evaluate the most relevant sampling locations within the alluvial dataset, four sampling locations with the highest average RDX concentrations are selected for time-series analysis (Exhibit 5-20). These four sampling locations are located within the Cañon de Valle and TA-16-260 Monitoring Group area, which aligns with site history descriptions of the RDX contamination originating from the TA-16-260 building and TA-16 Outfall. Local maxima of RDX concentrations within these selected wells include: CDV-16-02657 (Cañon de Valle) (Exhibit 5-20 B) in June 1999 (310 µg/L), March 2001 (759 µg/L), November 2005 (264 µg/L); and CDV-16-02657r in March 2019 (148 µg/L), as discussed previously (Exhibit 5-20 A). Similarly, sampling locations CDV-16-611934 and CDV-02659, located downgradient from well CDV-16-02657(r) in the Cañon de Valle, have RDX concentrations slightly less than average RDX concentrations in the upgradient well CDV-16-02657r (Exhibit 5-20 C and D). Aside from the high RDX concentration in well CDV-16-02657r in 2019 (148 µg/L), RDX, concentrations appear to be trending downward, and concentrations fluctuate from less than 5 µg/L to approximately 20 µg/L since 2010 (Exhibit 5-20 A through D). The four sampling locations have average RDX concentrations well above the U.S. EPA Tap Water Screening Level of 6.1 µg/L (Exhibit 5-20 A through D) (IFGMP 2017). Furthermore, these sampling locations are all located within the Cañon de Valle, and inside the TA-16-260 Monitoring Group area, which confirms the existence of elevated RDX contamination in groundwater in the areas where LANL focused their remediation efforts relative to other areas where no remediation activities have occurred.

EXHIBIT 5-20. MAP OF ALLUVIAL SAMPLING LOCATIONS WITH THE HIGHEST AVERAGE RDX CONCENTRATIONS AND THEIR CONCENTRATIONS OVER TIME



NOTE:

- THE X-AXIS FOR THE RDX CONCENTRATIONS TIME-SERIES PLOTS HAVE DIFFERENT X-AXIS DATE RANGES IN THIS FIGURE AND SUBSEQUENT ITERATIONS IN THE PERCHED-INTERMEDIATE AND REGIONAL AQUIFER SECTIONS.
- RDX CONCENTRATION TIME-SERIES PLOTS CONTAIN ALL AVAILABLE DATA, INCLUDING FILTERED AND UNFILTERED SAMPLES. THE ENTIRE DATASET HAS BEEN ASSIGNED DATA QUALITY CODES OF "UU" (UNIVERSAL USE), MEANING THEY ARE FULLY VALIDATED DATA AND MEET ALL QA/QC GUIDELINES.
- IN SOME INSTANCES, ONLY A FEW GROUNDWATER SAMPLES HAVE BEEN TAKEN FROM A SAMPLING LOCATION.

5.4.3.2 Perched-Intermediate Groundwater

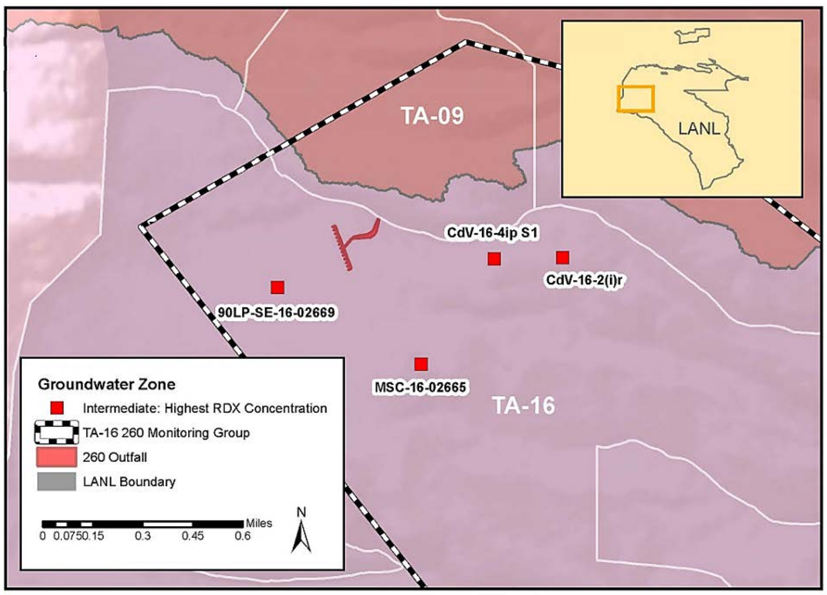
The perched-intermediate groundwater dataset includes samples collected between October 1997 and December 2019. The arithmetic average RDX concentration in the perched-intermediate system is 30.2 µg/L, making it the zone of groundwater with the highest average RDX concentration. Similarly, the geometric mean RDX concentration in the perched-intermediate concentration is 4.5 µg/L, the highest geometric mean RDX concentration compared to the alluvial and regional groundwater. Approximately 54 percent of groundwater samples from this system exceed the U.S. EPA Tap Water Screening Level of 6.1 µg/L, making it also the zone of groundwater with the highest percentage of exceedances (IFGMP 2017). Chronologically, high concentrations of RDX are apparent beginning in March 1998 (281 µg/L from well 90LP-SE-16-02669 near building TA-16-260). RDX concentrations of approximately 50 µg/L persist in sampling location R-25 S1 (upper zone) between November 2000 through October 2007. Relative maximum RDX concentrations are observed between October and August of 2010 with RDX concentrations of 96.5 µg/L in sampling location 16-26644 in October 2010, 167 µg/L in sampling location CDV-16-4ip S2 in September 2010, and 265 µg/L in sampling location CDV-16-4ip S1 in August 2010. Between May 2007 and December 2019, RDX concentrations in well CDV-16-2(i)r steadily increase by roughly 70 µg/L, with a concentration of 48.4 µg/L in March 2006 and concentration of 122 µg/L in December 2019. Conversely, from August 2010 to December 2019, RDX concentrations in sampling location CDV-16-4ip S1 steadily decrease by approximately 130 µg/L, from a maximum of 265 µg/L in August 2010 to 130 µg/L in December 2019.

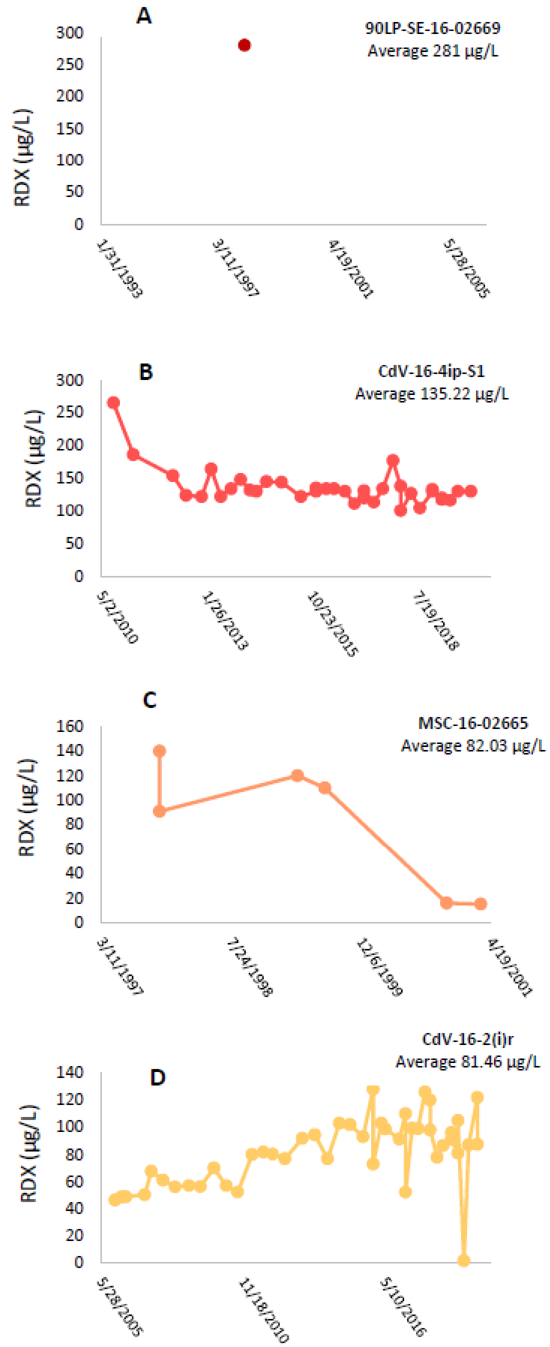
To further evaluate the degree of RDX contamination in perched-intermediate groundwater, time-series plots are created for four sampling locations with the highest average RDX concentrations (Exhibit 5-21). Within this selected dataset, it is apparent that RDX concentrations near the Cañon de Valle remain elevated relative to more distant sampling locations. However, RDX concentrations appear to be increasing in some sampling locations and decreasing in others, with concentrations in well CDV-16-2(i)r increasing between May 2007 and December 2019, and concentrations in sampling location CDV-16-4ip S1 declining between August 2010 and December 2019 (as discussed previously; Exhibit 5-21 D). Both of these sampling locations are within what LANL interprets as the "upper zone" of the perched-intermediate groundwater system (Exhibit 5-22).[52] The four selected sampling locations in the intermediate-perched groundwater have average RDX concentrations well above the U.S. EPA Tap Water Screening Level value of 6.1 µg/L.[53] Similar to the alluvial system, within the perched-intermediate system, the highest average concentrations of RDX are found in near Cañon de Valle and the TA-16-260 building, suggesting that contaminated groundwater in the alluvial system has percolated locally into the intermediate groundwater system (Exhibit 5-21 and Exhibit 5-22).

[52] According to a 2019 summary report from LANL the "upper zone" of the perched-intermediate groundwater system is more laterally extensive than the "lower zone," but the lower zone is of interest because it is not far above the regional aquifer.

[53] Filtered, unfiltered, detected, and undetected samples are included when calculating the arithmetic average for this dataset.

EXHIBIT 5-21. MAP OF PERCHED-INTERMEDIATE SAMPLING LOCATIONS WITH THE HIGHEST AVERAGE RDX CONCENTRATIONS AND THEIR CONCENTRATIONS OVER TIME





NOTE:

- THE X-AXIS FOR THE RDX CONCENTRATIONS TIME-SERIES PLOTS HAVE DIFFERENT X-AXIS DATE RANGES IN THIS FIGURE AND SUBSEQUENT ITERATIONS IN THE PERCHED-INTERMEDIATE AND REGIONAL AQUIFER SECTIONS.
- RDX CONCENTRATION TIME-SERIES PLOTS CONTAIN ALL AVAILABLE DATA, INCLUDING FILTERED AND UNFILTERED SAMPLES. THE ENTIRE DATASET HAS BEEN ASSIGNED DATA QUALITY CODES OF "UU" (UNIVERSAL USE), MEANING THEY ARE FULLY VALIDATED DATA AND MEET ALL QA/QC GUIDELINES.
- IN SOME INSTANCES, ONLY A FEW GROUNDWATER SAMPLES HAVE BEEN TAKEN FROM A SAMPLING LOCATION.

EXHIBIT 5-22. MAP OF RDX PLUME IN PERCHED-INTERMEDIATE ZONE (FIGURE 3.1-3 FROM EM2019-0235)

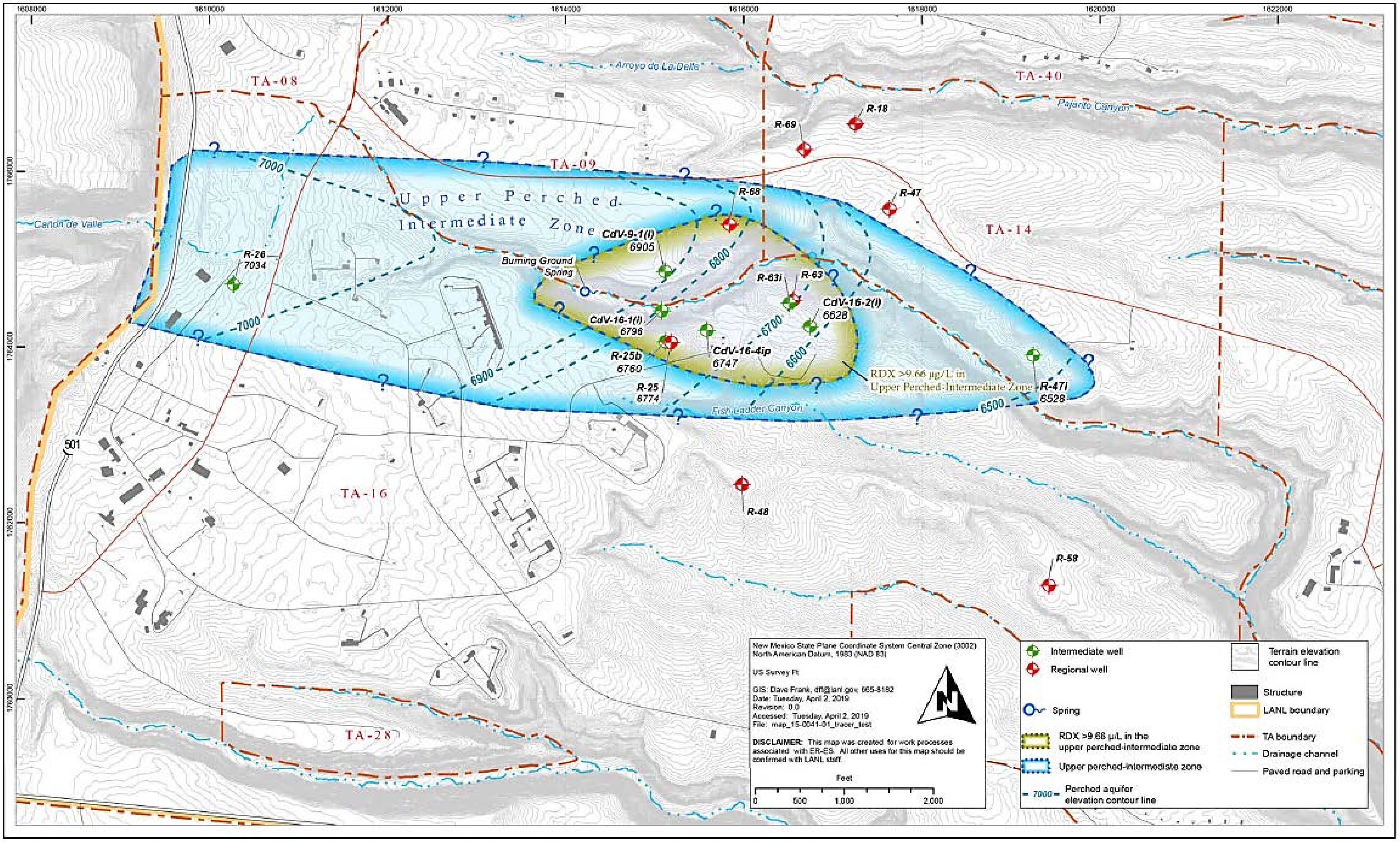


Figure 3.1-3 **Map showing RDX extent and water table contours for the upper perched-intermediate groundwater zone at TA-16**

Note: Green inner zone is extent of RDX contamination >9.66 µg/L in the upper perched-intermediate groundwater

5.4.3.3 Regional Aquifer

The regional aquifer groundwater dataset includes samples collected between September 2000 and December 2019. The arithmetic average RDX concentration in the regional aquifer is 1.5 µg/L, and the geometric mean is 0.34 µg/L, which is lower than the respective arithmetic and geometric averages of the alluvial and perched-intermediate groundwater systems. Approximately seven percent of samples from regional aquifer sampling locations exceed the U.S. EPA Tap Water Screening Level value of 6.1 µg/L, which similarly is the lowest percentage of exceedances compared to samples from the perched-intermediate and alluvial groundwater. RDX concentrations in the regional aquifer range from below detection to a maximum of 28 µg/L. Chronologically, RDX concentrations decrease in regional aquifer well R-25 (S8, S7, S5, and S6), which is located near Building TA-16-260 (Exhibit 5-23).[54] Between October 2000 and August 2002, the largest decrease in RDX concentrations is recorded in sampling location R-25 S8, from 28 µg/L in December 2000 to 1.9 µg/L in August 2002. Between 2002 and 2013, concentrations generally remain low (less than 5 µg/L). Exceptions include sampling location R-17 OB, located in Pajarito Canyon, which records a concentration of 10 µg/L in December 2005, and well R-63 (Cañon de Valle) which experiences a brief peak of 15.8 µg/L in January 2011 (Exhibit 5-23). Given the location of sampling location R-17 OB, however, its slightly elevated concentration demonstrates that RDX contamination is widespread within the regional aquifer. Within the remainder of the dataset, RDX concentrations increase in three wells: R-18 (Pajarito watershed and within LANL's interpretation of the RDX plume in the regional aquifer); R-63 (Cañon de Valle), which has been increasing slowly since approximately 2010; and well R-68 (Pajarito watershed), which increased by a factor of two between 2017 and 2019 (from 8.08 to 17.9 µg/L). Conversely, RDX in sampling location R-69 S1, located in the Pajarito Watershed and within LANL's interpretation of the RDX plume, has decreased between November 2018 and December 2019 (from to 21 to 10.6 µg/L).

Like the alluvial and perched-intermediate evaluations, four sampling locations with the highest average RDX concentrations in the regional aquifer were selected for time-series analyses (Exhibit 5-24). Within this subset, one sampling location, R-17 OB, which has one of the highest average RDX concentrations out of all groundwater samples, is not located within the LANL's interpretation of the regional aquifer RDX plume (Exhibit 5-24). Out of the four selected sampling locations, only three have average RDX concentrations that are above the U.S. EPA Tap Water Screening Level value of 6.1 µg/L, suggesting that RDX concentrations in the regional aquifer, as a whole, are lower than the RDX concentrations in the shallower groundwater zones above. Regardless, the preponderance of relatively high average RDX concentrations in sampling locations R-68, R-69 S1, and R-25 S-8 generally confirm LANL's interpretation of the geographic extent of the RDX plume in the regional aquifer (Exhibit 5-24 A, B, and D). A decrease in RDX concentrations in sampling location R-69 S1, and an increase in in well R-25 may indicate the southward movement of the RDX plume (Exhibits 5-24 B and D).

[54] These data come from one well that has multiple screen depths. It is suspected that some data from the deeper screens of this well have been contaminated by intermediate groundwater during well drilling. These results are presented for transparency and additional discussion is provided in Section 5.4.4 as well as Chapter 6.

EXHIBIT 5-23. MAP OF RDX PLUME IN REGIONAL AQUIFER (FIGURE 3.1-5 FROM EM2019-0235)

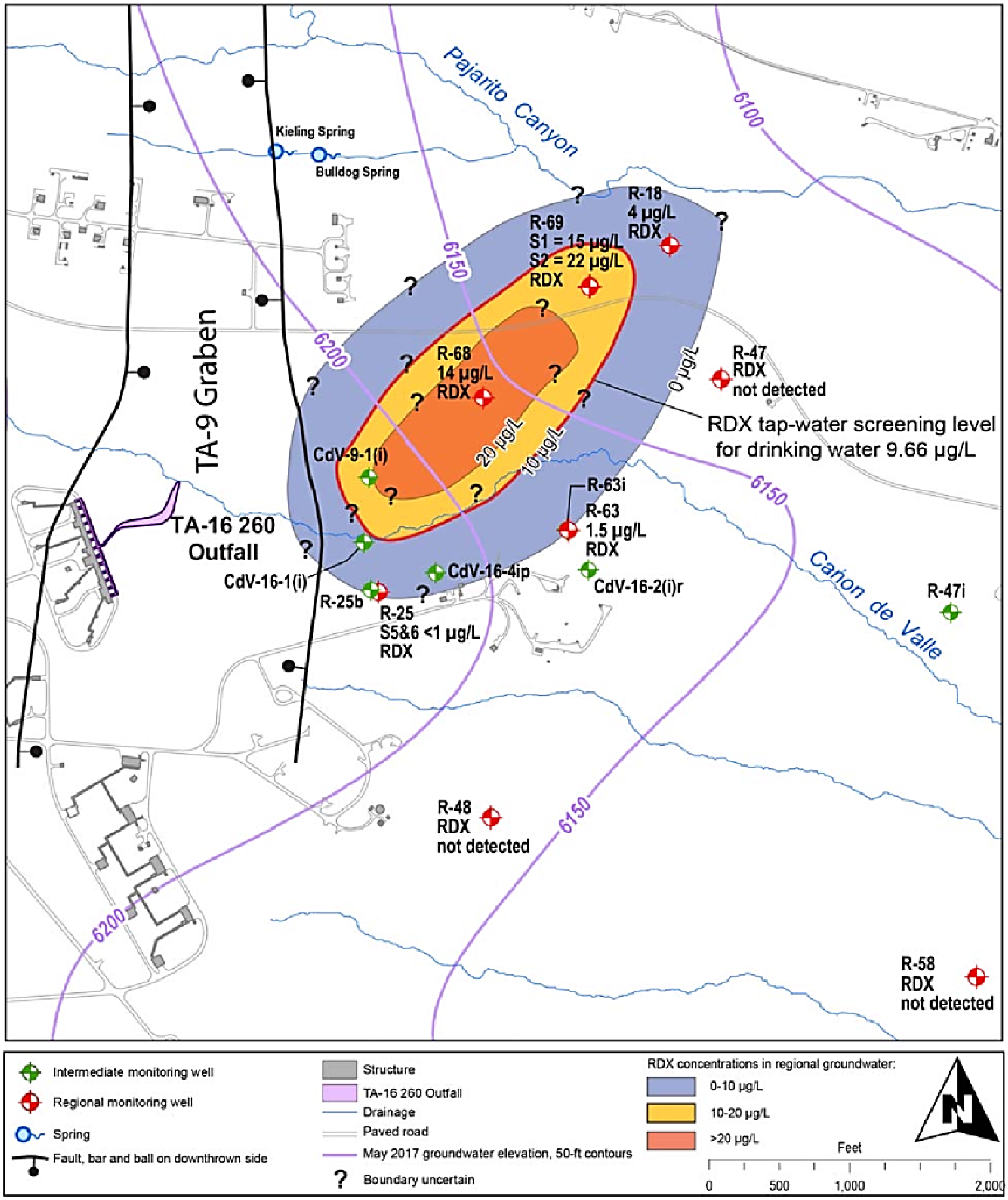
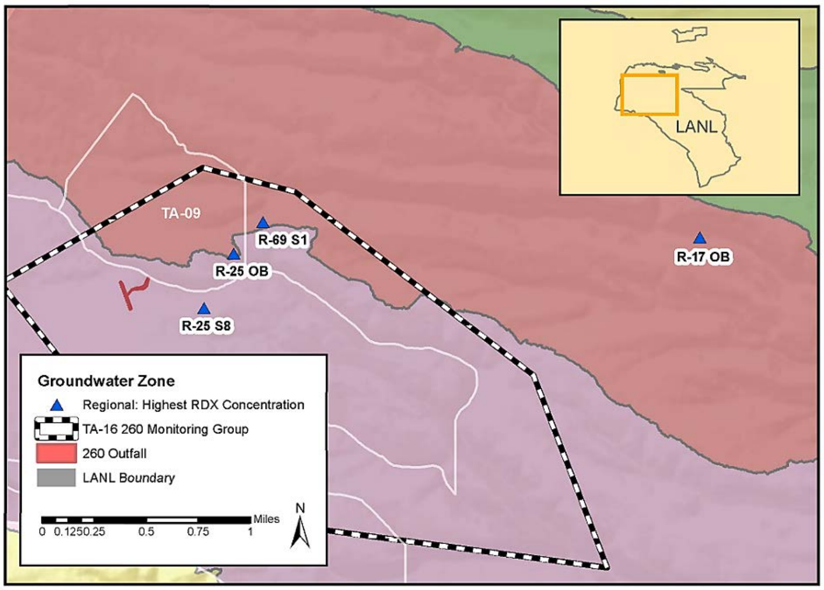
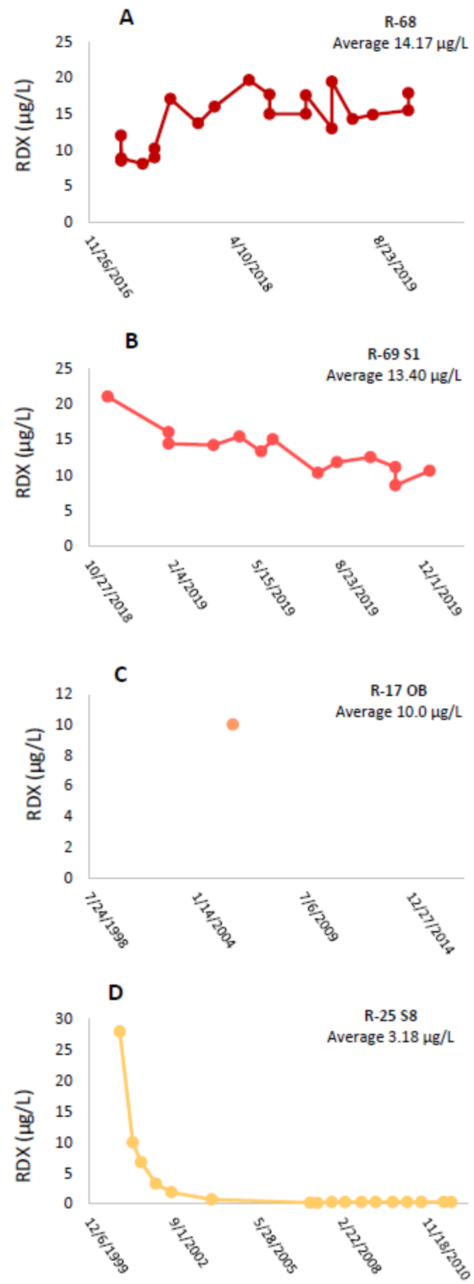


EXHIBIT 5-24. MAP OF REGIONAL SAMPLING LOCATIONS WITH THE HIGHEST AVERAGE RDX CONCENTRATIONS AND THEIR CONCENTRATIONS OVER TIME





NOTE:

- THE X-AXIS FOR THE RDX CONCENTRATIONS TIME-SERIES PLOTS HAVE DIFFERENT X-AXIS DATE RANGES IN THIS FIGURE AND SUBSEQUENT ITERATIONS IN THE PERCHED-INTERMEDIATE AND REGIONAL AQUIFER SECTIONS.
- RDX CONCENTRATION TIME-SERIES PLOTS CONTAIN ALL AVAILABLE DATA, INCLUDING FILTERED AND UNFILTERED SAMPLES. THE ENTIRE DATASET HAS BEEN ASSIGNED DATA QUALITY CODES OF “UU” (UNIVERSAL USE), MEANING THEY ARE FULLY VALIDATED DATA AND MEET ALL QA/QC GUIDELINES.
- IN SOME INSTANCES, ONLY A FEW GROUNDWATER SAMPLES HAVE BEEN TAKEN FROM A SAMPLING LOCATION.

5.4.4 EVALUATION OF THE RDX CONTAMINATION

This section presents available information on the inventory of RDX in groundwater and summarizes available information related to key NRDA parameters necessary for quantifying injury due to RDX contamination, including:

- Porosities of the plume-containing groundwater zones,
- Thickness of the plume in those zones,
- Area of the plume, and
- Recovery time to return to baseline (with or without remediation).

Based on available data, information gaps are highlighted and evaluated to determine whether sufficient information is available for injury quantification.[55]

5.4.4.1 RDX Inventory in the Groundwater System

As presented in the preceding sections, all of the groundwater zones have been impacted at TA-16 in Cañon de Valle (i.e., RDX contamination exists in alluvial, perched intermediate zone, and regional groundwater). Given that physicochemical conditions in groundwater in these zones do not promote meaningful RDX degradation, a reasonable assumption would be that, aside from the remediated quantities (Section 5.4.2), most RDX released at TA-16 currently remains in the environment (largely in dissolved form) (LA-UR-17-27678, Attachment 6 of LA-UR-18-21326). The three primary investigations to quantify RDX distribution in the groundwater system are:

- **The 2016 Geostatistical RDX Plume Model:** Modeling effort employed to estimate an RDX inventory for the intermediate and regional groundwater zones by placing the centroid of the plume at the location of the highest sampled RDX concentration (LA-UR-18-21326 Attachment 1).
- **The 2017 Update of the RDX Inventory Report:** “2017 RDX Inventory” herein, is an update of a similar effort published in 2005 (LA-UR-06-5510) seeking to estimate the RDX inventory of seven units of the TA-16 hydrologic system (LA-UR-18-21326 Attachment 1).
- **The 2019 Regional Aquifer RDX Inventory Update:** Building from observations used in the 2017 RDX Inventory, the 2019 update uses new data and a more sophisticated modeling approach to estimate the RDX inventory in the regional aquifer (Appendix E of EM2019-0235).

The 2017 RDX inventory results show that as much as 41 percent of RDX contamination is in the intermediate zone, followed by 28 percent in the alluvium, and a smaller proportion (12 percent) has reached regional groundwater (Exhibit 5-25) (LA-UR-18-21326).

[55] As part of this effort and future injury quantification efforts, groundwater contaminant plumes are the focus; however, plumes may include multiple contaminants of concern within a single footprint.

EXHIBIT 5-25. RESULTS FROM THE 2017 UPDATE OF THE RDX INVENTORY REPORT (LA-UR-18-21326)

LOCATION	MINIMUM POUNDS	MINIMUM PERCENT OF TOTAL	MAXIMUM POUNDS	MAXIMUM PERCENT OF TOTAL
260 Outfall former settling pond area, after interim measure	1,420	42	1,420	18
Vadose zone directly under 260 Outfall former settling pond area	1,202	36	2,072	26
SWSC and Burning Ground Springs	73	2	123	2
Cañon de Valle alluvial sediments	11	0	22	0
Vadose zone under Cañon de Valle alluvial aquifer	18	1	141	2
Intermediate to regional groundwater (228–345 meters)	580	17	3,258	41
Regional groundwater (392–438 meters)	77	2	915	12
TOTAL	**3,380**		**7,954**	

In contrast to the 2017 RDX inventory, LA-UR-06-5510 relied on a limited set of groundwater chemistry data. For example, in the case of the perched-intermediate groundwater, only 12 samples from two locations were used to derive the mass estimates. Also, the regional aquifer estimates were subject to significant uncertainty because samples collected from the deep screens of well R-25 were contaminated by intermediate groundwater during well drilling (see discussion of uncertainties in Section 6.2) (LA-UR-18-21326). RDX concentrations in the deep screens (five through eight) were between 15 and 30 µg/L in the early 2000s then rapidly decreased to less than one µg/L by 2010 (Figure 3.7-1 from Attachment 1 of LA-UR-18-21326). The early observations from R-25 used for the inventory calculations in LA-UR-06-5510 were later deemed unreliable and likely resulted in an overestimate of RDX mass in the regional aquifer (LA-UR-18-21326). The 2017 RDX inventory also improves upon this previous work by including additional intermediate well observations from wells CdV-16-4(i)p, R-25b, and CdV-9-1(i). Additionally, more regional aquifer data were incorporated from six new regional wells, three of which showed new RDX detections (wells R-18, R-63, and R-68). The additional data incorporated in the 2017 RDX inventory resulted in an 84 percent decrease in the maximum mass estimate and a narrower range of 7,954 and 3,380 pounds (3,608 and 1,533 kilograms) (Figure 3.0-1 of LA-UR-18-21326). The 2017 RDX inventory reveals how sensitive current RDX plume models are to available data. Continued RDX monitoring will likely narrow the range in RDX mass of the various hydrologic units (LA-UR-18-21326). It is worth noting a 2019 modeling effort that used new data and a more sophisticated modeling approach is also available (Appendix E of EM2019-0235). However, this effort only estimated the RDX inventory in the regional aquifer, so is not compared directly to the 2005 and 2007 estimates here but is described in more detail below.

The 2017 and 2019 RDX inventory estimates mentioned above have partially relied on past work and have utilized multiple modeling approaches, summarized in Exhibit 5-26. The initial 2016 geostatistical approach models the plume by placing the centroid of the plume at the location of the highest sampled RDX concentration. Subsequently, concentrations decrease and are interpolated outwardly from the centroid of the plume (LA-UR-18-21326). In the 2017 simple geometry modeling approach (implemented in LA-UR-18-21326 and LA-UR-06-5510 reports), well drilling reports are used to determine the spatial extent and thickness of the groundwater-bearing unit of the intermediate zone. The regional aquifer plume is modeled by the extent of contamination rather than by the dimensions of the aquifer because the regional aquifer is continuous (LA-UR-18-21326). The 2019 3-D modeling study does not calculate RDX inventories for perched-intermediate groundwater. However, a more complex construction of the RDX plume in the regional aquifer is developed using 2-D plan and cross-sectional views to create a 3-D representation of the plume (EM2019-0235). Additionally, a porosity distribution was utilized to determine the mean porosity over the spatial and temporal domain of the RDX plume in the regional aquifer (EM2019-0235). A single porosity mean value is obtained from the distribution and applied to all of the grid cells in the regional aquifer plume.

Despite the fact that the initial 2016 geostatistical approach calculates substantially higher pore water volumes than the 2017 simple geometry approach, the calculated RDX mass in perched-intermediate groundwater is within the range of the 2017 simple geometry approach. However, the mass of RDX in the regional aquifer is markedly lower for the 2016 geostatistical approach (Exhibit 5-26). In contrast, the 2019 3-D model applied a mean porosity of 27 percent within a 10 µg/L contour, resulting in an RDX mass of 33.7 pounds (15.3 kilograms) and contaminated volume of 1.26 billion gallons (4.77 billion liters). There is still a high degree of uncertainty with the 2019 3-D approach based on the placement of the concentration gradient and the assumed porosity. Uncertainty estimates are still being investigated but preliminary uncertainty analysis focusing on porosity suggests that the RDX mass in the regional aquifer may range from 11.11 to 54.9 pounds (5.04 to 24.9 kilograms) (EM2019-0235).

Finally, at least one additional estimate was reported in the *Summary Report for Intermediate Groundwater System Characterization Activities at Consolidated Unit 16-021(c)-99* from April 2017 (LA-UR-17-22550). The RDX inventory referenced therein is derived from the simple geometry approach shown in Exhibit 5-26.

EXHIBIT 5-26. COMPARISON OF RDX INVENTORY ESTIMATES

MODEL YEAR:	2016†	2017†	2019‡
MODEL APPROACH:	GEOSTATISTICAL	SIMPLE GEOMETRY	3-D MODELING
PERCHED-INTERMEDIATE GROUNDWATER			
Contaminated Pore Water Volume (billion gallons)	12.42	2.28 to 3.11	-
RDX Mass in Geologic Unit (pounds)	1,433 to 3,486	580 to 3,258	-
REGIONAL AQUIFER			
Contaminated Pore Water Volume (billion gallons)	22.45	2.72 to 4.83	1.26
RDX Mass in Geologic Unit (pounds)	4.0 to 18.7	77 to 915	33.7

† 2017 Update of the RDX Inventory Report, LA-UR-18-21326 Attachment 1.
‡ 2019 Update of RDX Inventory in the Regional Aquifer, Appendix E of EM2019-0235.

5.4.4.2 Plume Characteristics of the Perched-Intermediate and Regional Groundwater

Given that RDX is mobile and has already been distributed over a large vertical distance and horizontal area of groundwater, with low degradation rates it is reasonable to assume that some portion of the released RDX will eventually reach the regional aquifer. However, challenges with estimating the full potential scope of the contamination in transit to the regional aquifer remain, such as having a complete understanding of RDX concentrations and the timeframe for migrating contamination. Regarding the former, continued monitoring in the regional aquifer will help further refine plume modeling by further refining the horizontal and vertical distribution of contamination. Regarding the latter, fate and transport models in the unsaturated zone (where perched-intermediate groundwater is located) have been successful in simulating plume migration, but incomplete parametrization and boundary conditions for the regional aquifer have posed challenges for modeling plume migration in this zone (Attachment 8 of LA-UR-18-21326).

The authors of the 2017 RDX inventory present an estimate of the volume of contaminated water in the intermediate zone of 2.4 to 3.2 billion gallons (nine to 12 billion liters) (Exhibit 5-26). Observed concentrations of RDX in the intermediate zone (mostly a few µg/L to tens of µg/L) are consistent with releases of the magnitude identified above into that hydrologic unit. Given the RDX quantities estimated in the reports cited above, the affected volume of regional water could be billions of gallons (tens of billions of liters). At present, the plume is within LANL boundaries and there is no direct threat to existing water supply wells, which are three miles (4.8 kilometers) downgradient of the RDX-contaminated regional groundwater (EM2019-0235). Limitations on researchers' ability to forecast the future migration of the regional aquifer plume represent an area of uncertainty.

5.4.4.3 Evaluation of Available NRDA Parameters of RDX Contamination

In summary, parameters needed for characterizing contaminated groundwater in the intermediate groundwater zone are sufficiently constrained to determine a reasonable estimate of the contaminated volume (Exhibit 5-27). For the regional aquifer plume, there is less agreement between modeling approaches. Nonetheless, recent observations from new regional wells have expanded understanding of the hydrogeologic parameters and RDX distribution in the regional aquifer, and sufficient information is available for injury determination and quantification despite uncertainty in the time frame of plume migration. However, plume parameters should be updated as more information becomes available. Finally, an evaluation of the volume of contaminated groundwater in the intermediate groundwater zone would also capture other co-located COCs, such as TNT, perchlorate, and chromium which share the same release sources as RDX (Section 4.5.3) (Attachment 1 of LA-UR-18-21326, Reid et al. 2005).

EXHIBIT 5-27. SUMMARY OF PLUME PARAMETERS FOR RDX MODELING IN TA-16

PARAMETER	AREA (SQUARE FEET)	THICKNESS OF PLUME (FEET)	POROSITY (PERCENT)	REFERENCE†
INTERMEDIATE GROUNDWATER				
Upper-perched zone	1,428,586	-	-	LA-UR-18-21326
	4,696,506	-	-	LA-UR-18-21326‡
Stratigraphic Unit				
Otowi	-	125.0	40 to 46	LA-UR-18-21326
	-	≤239.5	-	LA-UR-18-21326‡
Puye	-	125.0	18 to 33	LA-UR-18-21326
	-	≤239.5	-	LA-UR-18-21326‡
Lower-perched zone	1,686,155	-	-	LA-UR-18-21326
	1,228,130	-	-	LA-UR-18-21326‡
Stratigraphic Unit				
Puye	-	24.9	18 to 33	LA-UR-18-21326
	-	≤78.7	-	LA-UR-18-21326‡
REGIONAL AQUIFER				
Stratigraphic Unit				
Puye	3,982,940	150.9	18 to 33	LA-UR-18-21326
	2,403,816	≤78.7	-	LA-UR-18-21326‡
	-	≤295.3	27	EM2019-0235*

† LA-UR-18-21326 Attachment 1 presents plume parameters for the simple geometry modeling approach and a geostatistical approach further described in Weston (2016).
‡ Plume areas from Figure 5.0-1 were calculated using ArcGIS. Unit thickness derived from transect B-B' of Figure 5.0-1.
* Unit thickness calculated from Figure 1 in Appendix E.

CHAPTER 6 | CONCLUSIONS

The long operational history and early waste disposal practices at LANL have led to the release of hazardous substances to the environment, including groundwater. LANL has conducted extensive groundwater sampling and continues to monitor targeted areas and generally surveille groundwater across the Pajarito Plateau (IFGMP 2017). As part of the LANL NRDA, the Trustees intend to quantify groundwater injury and plan appropriate restoration actions to compensate the public for groundwater service losses (LANLTC 2014). The primary goal of this report is to compile and summarize available information on current and past groundwater conditions to determine whether sufficient information exists to proceed with groundwater injury quantification.[56] The finding of this assessment activity is that existing data and information are sufficient to proceed with groundwater injury quantification. However, some uncertainty remains that will be addressed in subsequent phases of the groundwater NRDA. Section 6.1, below, summarizes the findings presented in this report, data gaps, and next steps, and Section 6.2 summarizes uncertainties.

6.1 SUMMARY OF FINDINGS, DATA GAPS, AND NEXT STEPS

The preceding chapters of this report describe how available information on groundwater in and around LANL are compiled, summarized, and evaluated. This included: conducting a thorough information and data review (Chapter 2); applying data cleanup and processing SOPs to prepare the groundwater data for analysis (Appendix A); conducting a screening level analysis to identify where exceedances occur for LANL-related groundwater COCs (Chapter 4); and evaluating in detail the two primary groundwater contaminants, chromium and RDX (Chapter 5). A brief summary is provided below.

- **Information and Data Sources:** This report relies upon a wide range of information sources including contaminant chemistry data (principally from Intellus), written documents, and presentations from state, federal, and other authorities. In-person and phone meetings were also conducted with relevant stakeholders.
- **Groundwater Contamination:** Groundwater occurs in three zones within the Pajarito Plateau; in the alluvium, perched-intermediate groundwater, and the regional aquifer. LANL's monitoring wells are completed in each of these zones throughout six area-specific monitoring groups (TA-21, Chromium Investigation, MDA C, TA-54, TA-16 260, and MDA AB). Wells that do not fall into these six monitoring groups are assigned to the "General Surveillance" monitoring group. The most significant pathways through which contamination has and continues to reach groundwater are through liquid waste effluents (e.g., outfalls) and infiltration from surface sources (e.g., PRSs).
- **Contaminants of Concern:** To develop an independent understanding of the nature and extent of groundwater contamination in and around LANL, raw data from Intellus are reviewed and evaluated. This analysis suggests that there are seven COCs responsible for the majority of contamination present in groundwater: RDX, chromium, strontium-90, perchlorate, tritium, cesium-137, and americium-241. However, chromium and RDX contamination make up the

[56] Note that the information in this report will be utilized in combination with the findings from the two other subtasks in this assessment activity, the baseline and services efforts (covered in separate reports).

primary groundwater plumes and thus have received the most targeted study by LANL to-date; as such, these plumes are evaluated in greater detail in this report.

- **Plume Evaluations:** Three comprehensive and relevant reports were recently published by LANL regarding the chromium and RDX plumes at the site, which serve as the primary references for describing the investigation of these contaminants (LA-UR-18-21450, LA-UR-18-21326, EM2019-0235). This report leverages data from Intellus to perform an independent review of the spatial and temporal trends of chromium and RDX contamination. Available information related to parameters relevant for injury quantification are also identified and summarized, including contaminant inventories in source areas and various zones, plume area, thickness, and porosity. Information is sufficient to move forward with quantifying injury due to chromium and RDX contamination, although some uncertainties remain in key NRDA parameters (e.g., spatial and vertical extents of chromium plume, masses of chromium and RDX present in the vadose zone between perched-intermediate and regional groundwater).
- **Quantifying Groundwater Injury:** As noted above, information is sufficient to quantify injury within the chromium and RDX plumes. Injury quantification will require confirming spatial and vertical extents (e.g., deciding on the contaminant concentration to use to define the injured area), porosity, thickness, volume, and time period for injury. Finally, multiple contaminants of concern appear to be present within the plume footprints. As described in Chapters 4 and 5, some observed exceedances of other contaminants are co-located with the chromium and RDX plumes. As such, most of the groundwater injury would likely be captured by quantifying the injured volume of the chromium and RDX plumes.[57] However, the variable spatial and temporal incidence of alluvial and perched-intermediate groundwater poses a challenge to defining the extent of contamination in these zones.

6.2 EXPLANATION OF UNCERTAINTIES

This section explains key uncertainties related to characterization efforts of existing groundwater data and information, as well as the efforts undertaken to mitigate these uncertainties.

- **Data sources.** This report relies primarily on data collected by LANL and NMED, as the two entities responsible for groundwater monitoring and oversight, respectively, in and around LANL (IFGMP 2017).[58] The available data span decades, study objectives, and media types, and are housed in the Intellus database, which has itself been maintained by a variety of LANL staff and contractors through time. As with any multi-media, multi-decadal database, data input and

[57] Additional LANL-related contaminants may be identified and included in the NRDA subsequent to this report. For example, the Trustees are investigating whether PFAS were released from LANL operations and the potential for groundwater contamination with these substances. As such, these substances may be incorporated as part of injury quantification.

[58] Data collected by each Pueblo government in and around LANL and data collected from Pueblo lands will be characterized separately.

validation protocols tend to change over time to implement improvements and address errors. An additional complication is that, due to the semi-manual nature of data input, individual data submitters could have made data entry mistakes. For example, inconsistencies in reported method and instrument detection limits associated with some data were observed.[59] Though some obvious inconsistencies were detected when working with the data, DOE implements a systematic data validation process to ensure high quality data are available. Therefore, the prevalence of this type of uncertainty is expected to be relatively low. In working with Intellus data *en masse* (i.e., not on the TA or PRS scale), some areas have been identified where the accuracy of data records is uncertain. For example, locations sampled by both NMED and LANL do not always display at the same location on a map or differ from the location shown in a map included in a report.[60] Further, both screen intervals and well locations are included in the location table from Intellus, which do not always follow an obvious identification format. Therefore, this report defaults to describing sampling locations rather than well locations to more directly tie back to the database. In other words, this report considers sampling locations to be defined as the x, y, z location of groundwater sample collection (the well and screen depth interval), as opposed to the x, y location of an individual well. As such, the count of sampling locations is likely higher than the count of individual wells discussed in this report.

- **Data utilized.** This report utilizes all available data, including filtered and unfiltered groundwater samples, to screen for potential instances of contamination. However, contaminant concentrations in unfiltered and/or highly turbid water samples can be biased high. Depending on the specific objectives of future analyses, data from such samples may be excluded such that only filtered water samples are used, which measure the concentration of dissolved contaminants.
- **Plume modeling and delineation.** LANL has conducted numerous studies to understand contaminant transport and behavior and to characterize the subsurface hydrogeology and structure of the Pajarito Plateau, particularly in the vicinities of the RDX and chromium plumes. However, all groundwater plume modeling is subject to uncertainties in input parameters, limitations associated with computer hardware and software and the mathematical representation of complex systems, and uncertainties associated with understanding the behavior of poorly observed phenomena. Such uncertainties can be minimized to some extent by calibrating models to empirical conditions. The most recent RDX and chromium plume groundwater models are calibrated to the latest data or are in the process of improving their calibrations. Attachment 8 of the *Compendium of Technical Reports Related to the RDX Project* (LA-UR-18-21326) describes those model parameters that have significant effects on the water balance, flow velocities, occurrences of perched water in the vadose zone, and/or RDX transport processes, as well as the resultant uncertainty in regional aquifer arrival time estimates for RDX. Although future groundwater conditions can sometimes be approximated by modeling existing data, the groundwater models are only as accurate as their inputs and the models understanding of the subsurface environment (e.g., groundwater flow rate, flow path, pumping rate, plume definition and characterization, etc.). However, the calculation of injured groundwater volume will likely

[59] Such inconsistencies appear to be generally less prevalent when using data at smaller spatial and temporal scales. This is likely data collected for a similar purpose or to investigate a particular area were input into Intellus in a consistent manner.

[60] In cases such as these, the position was assumed and documented based on aerial imagery, ground elevation, or the site report.

rely on estimates of present-day plume extents and future conditions may rely on assumptions rather than computer modeling. Uncertainties surrounding the maps will be appropriately evaluated during injury quantification.

- **Well drilling and development.** Three issues regarding well development may contribute to uncertainty in this analysis: The mud rotary method of drilling wells, the installation and use of multi-port wells, and the downward leakage of shallower groundwater. Comments received on the LANL DAP from citizen groups have raised concerns over the validity of samples taken from LANL monitoring wells drilled using the mud rotary method (LANLTC 2014). Based on discussions with NMED personnel, this issue has reportedly been addressed through changes in drilling methods and rehabilitation of older wells. The *Well Screen Analysis Report Revision 1* (LA-UR-07-0873) supports the conclusion that LANL's field procedures are reliable for the purposes of obtaining water samples that represent the aquifer groundwater. Report EP2007-0539 documents changes in drilling methods. Additionally, there have been concerns over the reliability of multi-port (Westbay) wells for which development may not have been entirely effective. Based on available information, all such wells in TA-16 are or will be either abandoned or converted to a single or dual sampling point (LA-UR-18-21326). For multi-port wells, the sample port used is identified. In addition, Section 5.4.4 notes where some data may have resulted from downward leakage during drilling and are not representative of actual conditions in the regional aquifer (LA-UR-18-21326). Given the use of the mud rotary method, potential issues associated with multi-port wells, and the downward leakage observed in well R-25, analytical results from such wells may be uncertain. All data meeting the quality criteria outlined in Appendix A and Appendix C have been included in this report. Samples from these wells during the affected timeframes will be appropriately excluded during the injury quantification phase.
- **Geographic scope.** Groundwater at LANL has been sampled from an extensive network of wells drilled across the Pajarito Plateau. These wells serve primarily as monitoring locations for groundwater contamination, but also include locations drilled for specialized studies of contaminant fate and transport. Also, a small proportion of the wells are municipal supply wells managed by Los Alamos County and sampled regularly by LANL. A major limitation with groundwater characterization is that sampling can only be conducted at drilled wells or natural springs (at which point the water is often considered surface water in the context of NRDA). Additionally, alluvial and perched-intermediate groundwater is discontinuous and present as thin lenses or perched zones in the unsaturated (vadose) zone. Groundwater conditions in areas without wells are therefore uncertain. Given that LANL's existing well network targets locations where releases to groundwater were known or likely as well as locations where contaminants may have migrated, it is likely that groundwater contamination has been at least partially characterized in most areas of the site.
- **Treatment of non-detects.** Non-detects and estimated values arise in environmental datasets because analytical methods have limited sensitivities and may have changed with time with different analytical methods and laboratories (IEc 2017b). The LANL NRDA Trustees have already considered this issue in detail and identified approaches for working with such data (IEc 2017b). Given the limited focus of this report on characterizing groundwater (as opposed to conducting quantitative analyses), the non-detect treatment methods identified in IEc (2017b) have

not been applied at this time. However, the counts of non-detect records are presented to provide a sense of the extent of these results.

- **Temporal scope (historical and future conditions).** Groundwater represents the earliest sampled media type at LANL, with sampling dates beginning in the early 1940s. Despite this, early sampling was spatially limited, and the analytical methods used for measuring contaminant concentrations have improved over time. Therefore, although it is possible to glean some understanding of early groundwater conditions at LANL, there is not complete spatial or temporal coverage for the site during the early years. Most groundwater samples in Intellus have been collected more recently, since approximately 2000, which provide a better picture of contemporary groundwater conditions. Another temporal aspect affecting alluvial and perched-intermediate wells is the ephemeral nature of shallow groundwater. In some instances, alluvial or perched-intermediate groundwater may have only occurred due to historical wastewater discharges and may no longer be present. Similarly, variability in precipitation can cause some shallow wells to be dry during some sampling events. There may be uncertainty, therefore, in how accurately data reflect actual groundwater conditions over time due to fluctuating temporal coverage in some areas.

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APPENDIX A | DATA REVIEW AND CLEANUP STANDARD OPERATING PROCEDURE

INTRODUCTION

The goal of this Standard Operating Procedure (SOP) is to document the approach Industrial Economics, Incorporated (IEc) took to assess and categorize the quality of existing environmental data contained within the Los Alamos National Laboratory (LANL) Intellus/Environmental Information Management (EIM) database to develop a dataset containing only unique records of known quality for use in future natural resource damage assessment (NRDA) efforts.[61]

IEc received a backup copy (in SQL) of the EIM database from the U.S. Department of Energy (DOE) on August 22, 2017 containing tables identified by IEc staff as being potentially relevant to the NRDA. The list of tables requested is provided in Attachment A. All New Mexico Environment Department (NMED) data were downloaded from Intellus from the 1990's to July 6, 2017. IEc then merged the NMED and LANL data into a single database, preserving the existing LANL database structure. The steps taken to review and characterize the quality of and clean the database are detailed below. The associated code for these steps may be run on the database to accomplish the steps outlined herein.

STEP ONE: ASSESS DATA QUALITY

IEc performed a systematic evaluation of the quality of the data with the objective of assigning each record a quality code in accordance with the LANL NRDA Quality Management Plan (QMP) and Quality Assurance Project Plan (QAPP) detailed in the *Final Work Plan: Compilation, Review, and Characterization of Existing LANL Information* (LANL NRTC 2014, 2016). The quality assignments listed in the QMP and reproduced in the QAPP are:

- **Universal Use (UU)** for fully validated data that meet all current QA/QC guidelines;
- **Qualitative Use Only (QUO)** for data of suspect quality due to lack of validation or QA/QC information or impairment sufficient to introduce substantial uncertainty into analyses performed with such data;
- **Qualitative Use Only* (QUO*)** for data categorized as QUO that may have new data quality information provided after further inspection from the data generating agency.
- **Limited or Provisional Use (LPU)** for data of unverifiable quality, but suspected good quality (i.e., data with limited supporting information available); and
- **Not Acceptable for Use (NAFU)** for data with apparent QA/QC issues and/or extremely limited to no information about quality available.

All data were assigned one of these labels. To achieve this, a new field in the Results Table in the database was created and labeled "IEc_Data_Quality_Category" and populated with the assigned quality code in four main steps. First, we evaluated the extent to which data had already been validated and looked for trends by year and collecting agency; and performed some minor data clean-up steps to rectify date discrepancies. Second, we assigned preliminary data quality categories to previously validated records based on the Validation_Qualifier and associated definition fields. Third, we finalized these preliminary categorizations based on decision rules related to the interpretation of codes populated in the

[61] Version dated July 20, 2020.

Validation_Qualifier and Validation_Reason_Code fields. Fourth, we systematically addressed records that had not previously been validated (i.e., records for which the Validation_Qualifier field was blank)[62] based on decision rules related to the interpretation of codes populating the Lab_Qualifier field. The following details the decision rules applied in each of these steps. Only data categorized as UU, QUO, QUO* and LPU were carried through to the subsequent Step Two of this SOP.

1. **Year/Date/Data Generating Entity:** Data were reviewed across years (based on Sample_Date) and data generating entity (i.e., LANL or NMED). The objective was to identify trends in data validation or data quality over time (e.g., to identify entire years where no data validation was performed). We reviewed the Validation_Qualifier and Lab_Qualifier fields for each data generating entity and year and also identified the quantities of records with populated data quality fields.

    a. **Date Discrepancy**: Numerous sample results with a Sample_Date of 1/1/1950 were confirmed to be the erroneous result of autopopulation of this field during data entry[63]. To address this issue we used the following decision rule:

        i. If Sample_Date was not 1/1/1950, the record maintained its populated date and was carried through subsequent steps.

        ii. If Sample_Date was 1/1/1950, we used the Analysis_Date field instead and carried these records through subsequent steps. No records were identified with both Sample_Date and Analysis_Date of 1/1/1950.

    b. **Years with no indication of data quality**: There were entire years for both data generating entities where records contained no indication of data quality (i.e., both Validation_Qualifier and Lab_Qualifier were NULL), suggesting that laboratory metadata accompanying these samples likely were not entered into EIM[64]. Because such metadata may exist, and could be attributed to these records at some point in the future, we categorized records in those years as Qualitative Use Only with an asterisk (QUO*) to continue to track them.

        i. For NMED data, we identified years where none of the records had Validation_Qualifier or Lab_Qualifiers for the entire year. NMED data prior to 1994 (i.e., 1993 and earlier) do not have any indicator of data quality (i.e., both Validation_Qualifier and Lab_Qualifier were NULL): NMED records in this date range were categorized as QUO*.

        ii. For LANL data, we identified years where none of the records had a Validation_Qualifier or Lab_Qualifier for the entire year (e.g., 1942, 1951, 1952, 1953). The data in these years were marked as QUO*.

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62 Personal communications via email from Nita Patel, LANL, on Sept 14, 2017 stated that blank Validation_Qualifiers indicated that records were not subject to a validation process based on a subset of data reviewed.

63 Personal communications via email with Nita Patel, LANL, Sept. 14, 2017.

64 Validation_Qualifier and Lab_Qualifier are NULL for all NMED data prior to 1994 (2,438 records). Validation_Qualifier and Lab_Qualifier are NULL for 78,612 records of LANL-sourced data from the same time period. However, these NMED and LANL records represent a small fraction (0.66%) of the available data overall (12,273,743 records).

2. **Preliminary Quality Categorization**: Records with assigned Validation_Qualifiers (the vast majority of data[65]) were considered validated. We assigned preliminary quality categories of UU or Not for UU to values populated in the Validation_Qualifier field as follows:

   a. Data categorized as UU based solely on the Validation_Qualifier code are listed in Table 1 with their corresponding code definitions.[66]

TABLE 1. VALIDATION QUALIFIER PRELIMINARY CATEGORIZATION FOR UNIVERSAL USE

VALIDATION QUALIFIER	DEFINITION
A	The contractually-required supporting documentation for this datum is absent.
B1	No definition – could indicate the analyte was found in the associated blank
B1, R3	No definition
B1, S2	No definition
D1	No definition - could indicate a diluted sample
IUP	The U indicates the result is not detected. The P means that professional judgment was applied. The meaning of I is lost but may indicate Inorganic analyses
J	The analyte is classified as detected but the reported concentration value is expected to be more uncertain than usual.
J-	The analyte is classified as detected but the reported concentration value is expected to be more uncertain than usual with a potential negative bias.
J+	The analyte is classified as detected but the reported concentration value is expected to be more uncertain than usual with a potential positive bias
J-J+	No definition- Assumed combination of J+ and J-
JN-	Presumptive evidence of the presence of the material at an estimated quantity with a suspected negative bias.
JN+	Presumptive evidence of the presence of the material at estimated quantity with a suspected positive bias.
JPM	The analyte is classified as detected but the reported concentration value is expected to be more uncertain than usual. Manual review of raw data is recommended to determine if the observed non-compliances with quality acceptance criteria adversely impacts data use
NJ	(Organic) - Analyte has been tentatively identified and the associated numerical value is estimated based upon 1:1 response factor to the nearest eluting internal standard
NQ	No validation qualifier flag is associated with this result, and the analyte is classified as detected
NUP	The U indicates the result is not detected. The P means that professional judgment was applied. The meaning of N is unknown, but may indicate general chemistry analyses.
P	Use professional judgment based on data use. A decision must be made by the project manager or a delegate with regard to the need for further review of the data. This review should include some consideration of potential impact that could result from using the P-qualified data
PM	Manual review of raw data is recommended to determine if the observed non-compliances with quality acceptance criteria adversely impacts data use.
R3	No definition

[65] Ninety-eight percent of LANL data (11,686,210 records) and 43 percent of NMED data (170,818 records) were deemed to have been validated due to the presence of a populated Validation_Qualifier field.

[66] This approach was intended to be inclusive of validated data — that is, we defaulted to categorizing validated data as UU if Validation_Qualifier codes were unclear or seemed innocuous on the presumption that if egregious errors were uncovered in the validation process, data would have been categorized as rejected.

VALIDATION QUALIFIER	DEFINITION
RUP	The U indicates the result is not detected. The P means that professional judgment was applied. The meaning of R is lost but may indicate rad. analyses
S2	No definition
U	The analyte is classified as not detected
U-LAB	The reported sample result is below the analytical laboratory detection limit and is not detected
UJ	The analyte is classified as not detected, with an expectation that the reported result is more uncertain than usual
UR	No definition - some type of below detection assumed
VUP	The U indicates the result is not detected. The P means that professional judgment was applied. The meaning of V is lost but may indicate analyses conducted in GAS sample type i.e. Vapor

b. Validation_Qualifier codes preliminarily labeled as Not for UU[67] are listed in Table 2:

TABLE 2. VALIDATION QUALIFIER PRELIMINARY CATEGORIZATION AS NOT FOR UNIVERSAL USE

VALIDATION QUALIFIER	DEFINITION
R	These samples were rejected during autovalidation due to serious non-compliances in quality control
GUP	Non-detect samples that used professional judgment, however, all results qualified as GUP had reason codes that demonstrated units and matrix to be inconsistent
I	Calculated sums are considered incomplete due to lack of one or more congener results
N[68]	Presumptive evidence of the presence of the material.
Q	Result has potential quality issues[69]
RPM	Result is rejected to serious non-compliances regarding quality control acceptance criteria

3. **Final Quality Categorization**: All results were then assigned final quality codes (i.e., UU, QUO, LPU, NAFU) using the combination of Validation_Qualifier codes and their corresponding Validation_Reason_Codes[70]. In some cases, Validation_Reason_Codes (i.e., the justification of the categorization in the Validation_Qualifier field) were the same for multiple Validation_Qualifiers. The following decision rules were therefore used to make final quality category determinations.

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[67] If there were few results for the Validation Qualifier or we wanted more context, we reviewed the number of results, reason codes types, and sample types. If there were few results or a reason code that did not pass QA/QC criteria, we preliminarily screened samples into the "Not for UU" category.

[68] There was only one sample with this Validation_Qualifier and the Validation_Reason_Code indicated that the internal standard retention time deviated by 30 seconds. The other results with this Validation_Reason_Code were categorized as rejected.

[69] Q qualified results are only for air samples.

[70] Final quality category designation for Validation_Qualifier and Validation_Reason_Codes are listed in the spreadsheet: "Data Quality Categorization_10252017".

a. Validated data preliminarily categorized as for UU in the preliminary screening (see #2.a. above), for which Validation_Reason_Codes were unique, were assigned UU as their final quality categorization[71].

b. Where multiple Validation_Qualifiers had the same Validation_Reason_Codes, the combinations were analyzed individually using the following decision rules:

   i. For Validation_Qualifiers preliminarily categorized as UU:

      1. If there was no Validation_Reason_Code description or the description was unclear, we defaulted to the preliminary UU quality category assigned to the Validation_Qualifier.

      2. In circumstances where records with Validation_Qualifiers categorized as for UU shared the same Validation_Reason_Code as records categorized as Not for UU, we presumed that the autovalidation process properly accounted for quality issues so we defaulted to the preliminary UU quality category assigned to these Validation_Qualifiers.

      3. If the Validation_Reason_Code indicated that there was a discrepancy between the units reported by the lab and the analytical matrix, these records preliminary categorized as for UU were re-categorized as NAFU.

      4. For Validation_Reason_Codes that indicated that the data user should revisit the original data or data report to make a determination about data usability, we defaulted to the preliminary UU quality category assigned to the Validation_Qualifier.

      5. Validation_Reason_Codes that were defined as “this code can only be used under advisement by the LANL project chemist” were categorized as QUO.

   ii. For Validation Qualifiers preliminarily categorized as Not for UU[72]:

      1. If reason codes indicated a serious problem with data quality, records were categorized as NAFU[73].

      2. If a reason code indicated only minor problems with data quality or simply that the data were potentially biased low, records were categorized as QUO[74].

      3. Where no reason code description was provided or the reason code was unclear, records were categorized as LPU.

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[71] All quality designations that were preliminarily categorized as not for UU were evaluated for their individual pairing with Validation_Reason_Codes, even if they did not share that Validation_Reason_Code with any other Validation_Qualifier.

[72] If preliminary categorization was not for UU, they can only be categorized into one of the three categories below UU (i.e., QUO, LPU, NAFU), but cannot be categorized as a higher quality code (e.g., UU).

[73] Examples of definitions for Validation_Reason_Codes that were categorized as NAFU are exceedances of associated retention times that shifted by more than 0.05 minutes from calibration or recoveries are below ten percent for any of the following: calibration standards, lab control samples, matrix spikes or matrix spike duplicates, or surrogates.

[74] Examples of definitions for Validation_Reason_Codes that were categorized as QUO are surrogate failed low; holding time was exceeded; code can only be used by a LANL project chemist; or spike recovery is low.

4. For NMED and LANL data that do not have a populated Validation_Qualifier, which IEc understands have therefore not been formally validated[75], we took the extra step of relying on information provided in the Lab_Qualifier field. These data were categorized using the following decision rules[76]:
   a. For records with only a single lab qualifier (e.g., U, J, R):
      i. If the definition of the Lab_Qualifier code led us to believe data were generally reliable without significant quality issues, the qualified record was categorized as LPU[77].
      ii. If the definition of the Lab_Qualifier code was unclear or we would need more information to evaluate the quality of the data in the context of the Lab_Qualifier code, the record was categorized as QUO[78].
      iii. If the definition of the Lab_Qualifier code led us to believe the data were of poor quality, the record was categorized as NAFU[79].
   b. For records with combinations of one or more lab qualifiers (e.g., UJ; C,D,U):
      i. If each of the individual Lab_Qualifier codes was categorized as LPU, the combination of the Lab_Qualifier codes was categorized as LPU.
      ii. If each of the individual Lab_Qualifier codes was categorized as QUO, the combination of the Lab_Qualifier codes was categorized as QUO.
      iii. If each of the individual Lab_Qualifier codes was categorized with different quality codes, we defaulted to the lower quality code based on the hierarchy of LPU>QUO>NAFU with LPU understood to be the category with the highest quality.
   c. Data with the Lab_Qualifier codes listed in Table 3 were categorized as LPU.

TABLE 3. LAB QUALIFIERS CATEGORIZED AS LPU

LAB QUALIFIER	DEFINITION
C	Legacy: AXYS - Co-eluting congener. NMSSL - Spike recovery between 80% and 120%. Columbia - confirmation of the TCDF compound
C,D	See C code and D code
C,D,J	See C code, D code, and J code
C,D,U	See C code, D code, and U code
C,J	See C code and see J code
C,NQ	See C code and see NQ code

[75] Personal communications via email from Nita Patel, LANL, on Sept 14, 2017 indicated that blank Validation_Qualifiers indicated that records were not subject to a validation process based on a subset of data reviewed.

[76] Final quality category designation for Lab_Qualifiers are listed in the spreadsheet: "Data Quality Categorization_10252017".

[77] Examples of definitions for Lab_Qualifier codes that were categorized as LPU are co-eluting congener; spike recovery between 80-120%; confirmation of TCDF compound; results reported from a dilution; analyte concentration is not detected above the reporting limit; non-detects (U); or estimated concentration (J).

[78] Examples of definitions for Lab_Qualifier codes that were categorized as QUO are low surrogate recovery; analytical holding time exceeded; or spike recovery not within specified control limits.

[79] Examples of definitions for Lab_Qualifier codes that were categorized as NAFU are rejected data where the definition indicates that the data are not usable.

LAB QUALIFIER	DEFINITION
CON	Legacy: TestAmerica - Confirmation analysis
C,U	See C code and see U code
C,U,D	See C code, U code, and D code
D	Legacy: (Organic) - Analytes analyzed at a secondary dilution. NMSSL - Spike recovery < 80% or > 120%. AXYS - Dilution Data. (Paragon) - Radchem DER for duplicate exceeds control limit of 2.13. STSL, TA - Result was obtained from the analysis of a dilution
D,C	See D code and see C code
D,C,J	See D code, C code, and J code
D,J	See D code and see J code
D,U	See D code and see U code
D,U,C	See D code, U code, and C code
J	Legacy: (Inorganic)-The associated numerical value is an estimated quantity. (Organic) - The associated numerical value is an estimated quantity. AXYS - Result >= MDL, < RL. TestAm - Estimated result-result < RL. TestAm - method blank contamination
J,C	See J code and see C code
J,NQ	See J code and see NQ code
NQ	Legacy: AXYS - Data not quantifiable. (Paragon) - Net Quantification - the nuclide is not detected or supported at any level above the reported MDC and can be considered a non-detect
R4	Legacy: (NMSSL) - Result based on 4 or more replicates
U	Legacy: (Inorganic) - material analyzed for, not detected above level of associated numeric value. Associated numerical value either sample quant. limit or sample detection limit. (Organic) - material analyzed for, but not detected. Quant. limit is estimated quantity
U,C	U,C: See U code and see C code
U,D	See U code and see D code
U,J	Material was analyzed for, but not detected. (Inorganics) Value is an estimate. (Organics) quant. limit is an estimate
Blanks	No qualifier for data, so records in the years where Lab_Qualifiers were used to determine quality indicate the data are not qualified and good to use as they are

d. Data with Lab_Qualifier codes listed in Table 4 were categorized as NAFU.

TABLE 4. LAB QUALIFIERS CATEGORIZED AS NAFU

LAB QUALIFIER	DEFINITION AND JUSTIFICATION
R	Legacy: AXYS - Co-eluting congener. NMSSL - Spike recovery between 80% and 120%. Columbia - confirmation of the TCDF compound
U,G,R	Based on the R code
U,R	Based on the R code

e. All remaining records with Lab_Qualifier codes were categorized as QUO[80].

STEP TWO: HIGH LEVEL DATA REVIEW

[80] Final quality category designation for Lab_Qualifiers are listed in the spreadsheet: "Data Quality Categorization_10252017".

IEc reviewed the data and determined that select media would need to be treated differently (e.g., air and filter samples) due to how the data were populated and the decision rules pertaining to multiple results. IEc applied the following decision rule for air and filter samples:

1. If the Sample_Type = Air (Air) or Filter (F), then the IEc_Good_Result_Flag was assigned as 'AIR/F'.
2. If the data are from QC samples, they are assigned an 'N' in the IEc_Good_Result_Flag field and excluded from subsequent steps. QC samples are identified using the Sample Purpose field or the Location ID field in a few select cases as described below (sub-part b).
    a. The following Sample Purpose values are included in subsequent steps of this SOP: NA, REG, SS, and UA.[81] All other Sample Purpose values are excluded (see "Sample Purpose_QC Sample Exclusion List" for the full list of codes, descriptions and exclusion status).
    b. The following Location IDs are also excluded as QC samples: DI Blank, Organics Trip Blank, and Spiked Sample.

There were inconsistencies in the Location IDs between LANL and NMED, where the same Location IDs had different latitude and longitude values between the two data sources. We examined the location table and corrected inconsistencies, where possible by applying the following:

3. For NMED samples that did not have latitude and longitudes associated with the Location ID, LANL locations were assigned.
4. For LANL samples that did not have latitude and longitudes associated with the Location ID, NMED locations were assigned.
5. In instances where the NMED and LANL location fields differed in regard to the latitude and longitude values for the same Location ID, these were reviewed individually to determine the location most likely to be accurate. There were 71 instances of Location IDs with different latitude and longitude values between NMED and LANL location fields.
6. We then identified locations outside of LANL and by visual inspection, identified 1,702 LANL location IDs that had distant coordinates. These were checked for accuracy using Google, Intellus, and LANL documents (via EPRR). 153 location IDs were corrected and 1,389 were assigned to Technical Areas, canyons, or watershed centroids. Of the remaining 160 location IDs, 44 are likely background samples and the others could not be corrected or confirmed. These 160 were not addressed further as part of this SOP since subsequent analysis steps will begin with an ArcGIS-based selection of data (and hence, these locations would likely be excluded as outside of the area of interest).

[81] NA is "Not Applicable", REG is "Regular Investigative Sample", SS is "Special sampling event, data unique", and UA is "Unassaigned".

STEP THREE: ASSESS MULTIPLE RESULTS FOR SAMPLE DATES, MEDIA, AND PARAMETERS

Multiple results for a single environmental sample within a dataset can occur for reasons including, but not limited to, samples being sent to multiple labs for QA/QC purposes, reanalysis due to a lab or equipment error, or due to transcription errors (i.e., duplicate records). The objective of this step was to identify decision rules for identifying and selecting the preferred record among multiple results for a given environmental sample. This was an iterative process, in which the suite of multiple records were reviewed, and decision rules were created and applied. If, after the implementation of the decision rules, there were still multiple results, the data fields were further evaluated and additional decision rules were created and applied. A field was added to the databased called IEc_Good_Result_Flag and populated with a "Y" or "N" to indicate the preferred record. Although this SOP is capable of automatically processing multiple results, some records must be reviewed manually post-processing to ensure the best result selection. For example, some record sets appear to be waste extracts, though they are not labeled accordingly. These manual selections will be documented post-processing.

1. Due to the fact that different measurements can be reasonably made on a single environmental sample to attain different types of information on the sample, we identified **multiple sample results** initially only if all of the following fields were identical across two or more records:
    a. **Field_Sample_ID** is the unique identifier for all samples taken in the field. Despite being a unique identifier, samples may be analyzed for multiple parameters; therefore the *Field_Sample_Result* table contains multiple results per Field_Sample_ID.
    b. **Parameter_Code**[82] is the ID/code assigned to a given analytical parameter. This number is most often the CAS Number unless the parameter does not have one. As described above it is expected that Field_Sample_ID would be associated with multiple Parameter_Codes. However querying for exact matches on Field_Sample_ID + Parameter_Code alone still produces multiple reasonable results.
    c. **Filtered_Flag** is a binary (Y/N) field indicating whether the sample was filtered. If a water sample was filtered it may produce two sample results with two different acceptable results and units.
    d. **Lab_Matrix** is the matrix of the lab sample (such as water, solid, etc.). If a water sample was filtered in the lab it may produce a sample with a matrix of water, and an additional sample with a matrix of sediment. Both of these samples produce acceptable results.
    e. **Report_Units** is a field that displays the units for the result. The units for a given parameter may be different (e.g., radionuclides in pCi/L or mg/L), but they are two separate measurements using different analytical methods.
2. If the data quality category assigned to multiple results records differed, the record categorized as UU was selected as the preferred value. If no record was categorized as UU, each of the multiple records was retained and the remaining steps in this section applied for selection of the preferred value. If

[82] On September 1, 2017 IEc submitted a question to LANL regarding some inconsistencies identified between the Parameter_Code and Parameter_Name fields in the LANL data. LANL responded on September 14, 2017 stating that the Parameter_Code is the more accurate field for identifying the contaminant analyzed for a given sample.

each of the multiple results were categorized as NAFU, the multiple records were assigned "N" in the IEc_Good_Result_Flag field.

3. Remaining multiple results[83] were then screened based on the Best_Value_Flag field. As part of LANL's data validation process, a Best_Value_Flag is assigned, in Intellus, to field sample results based on a standard evaluation process for multiple analytical results (see the *Automated Verification & Validation Process for Chemistry Data* (LA-UR-12-26702) 2012). Samples may be assigned a "Y," or "N," in this field or the field may be blank (i.e., "Null").[84] To identify preferred records among the remaining multiple records we applied the following decision rules.
    a. If a record(s) had Best_Value_Flag = "N" with one sibling record that had a BEST_VALUE_FLAG = "Y" the record with the Best_Value_Flag= "Y" was selected as the preferred record.
    b. If a record had Best_Value_Flag = "N" with more than one sibling record that had a Best_Value_Flag = "Y" all of the records with the Best_Value_Flag= "Y" were carried through the remaining selection process to identify the preferred record.
    c. If records had a Best_Value_Flag of "N" and did not have a sibling record(s) with Best_Value_Flag = "Y" all multiple records (with Best_Value_Flag =N) were carried through the remaining selection process to identify the preferred record[85].
    d. If a record had a Best_Value_Flag = "Null," it never had a sibling record with Best_Value_Flag = "Y" or "N"; it only had sibling records with Best_Value_Flag = "Null." Multiple result records that had a Best_Value_Flag of "Null" were carried through the remaining selection process to identify the preferred record[86].
4. Preferred records were then selected based on detection status in accordance with the best value selection methods in the *Automated Verification & Validation Process for Chemistry Data* (LA-UR-12-26702; 2012). Records were selected using the following decision rules.
    a. If one result associated with a sample was detected, and the other results associated with the same sample was not detected (based on a "Y" or "N" in the Detect_Flag field), we chose the sample that was detected (Based on LANL 2012).
    b. If multiple results associated with the sample were detected (based on a "Y" in the Detect_Flag field), we followed these steps:
        i. Chose the result (Report_Result field) that had a lower value[87].

[83] Not every record has just one multiple record, there are up to four records with the same sample ID, parameter code, analytical method, lab matrix, and filtered flag.

[84] Best_Value_Flag was not consistently applied across all multiple results in Intellus, as such, there are still multiple results which need decision rules to select a preferred value.

[85] All records with a Best_Value_Flag of "N" and no sibling sample with "Null" or "Y" were evaluated as a group to determine that there were no major data quality violations resulting in their "Best_Value_Flag" determination of "N" based on Validation_Qualifier and Validation_Reason_Code.

[86] The only sample types where multiple records had a Best_Value_Flag = "Null," were AIR (Air) and F (Filter).

[87] Based on LANL 2012, the highest value should be selected as the best value, which makes sense for screening purposes, however, for NRDA purposes we prefer to bias the results low instead of high. As such, we selected the lower value.

ii. If one or more of the multiple results associated with the sample were diluted, we chose the result from the original undiluted sample (based on LANL 2012).

iii. If results were the same, but had different Validation_Qualifiers, the preferred value was selected using the following hierarchy, with the codes higher on the list preferred over codes lower on the list.[88]

1. NQ
2. J

iv. If one result did not list any limit of detection or a zero limit of detection and the other did list a limit of detection, we selected the one with a detection limit, or chose the result with the lower detection limit for:

1. Report_Method_Detection_Limit
2. Instrument_Detection_Limit

c. If results associated with the sample were not detected (based on a "N" in the Detect_Flag field), we followed these steps:

i. If one result did not list any limit of detection or a zero limit of detection and the other did list a limit of detection, we selected the one with a detection limit, or chose the result with the lower detection limit for:

1. Report_Method_Detection_Limit
2. Instrument_Detection_Limit

ii. If the detection limits were the same, but the sample was diluted, the non-diluted sample (Dilution_Factor is "Null" or "1") was selected.

1. If all records were diluted and none had the same dilution factor, the data were carried through to the next step.

iii. If there were different Validation_Qualifiers, the preferred result was selected by using the more reliable Validation_Qualifier with the following hierarchy[89]:

1. NQ
2. J
3. U

iv. If the sample results were different, the lower sample result (Report_Result field) was selected (unless the lower value was "0").

1. If the lower sample result was "0," the non-zero result was selected as the preferred record.

[88] Only Validation_Qualifier codes in the database that were relevant to multiple results with a Detect_Flag = Y were ranked in this step.

[89] Only Validation_Qualifier codes in the database that were relevant to multiple results with a Detect_Flag = N were ranked in this step. Some of these Validation_Qualifiers are not common for non-detect results, they are still present in the database and, as such, are ranked here.

d. For remaining records with multiple values, the preferred value was selected using the following set of decision rules:

   i. We selected the first sample analyzed (based on temporal order). This was based on the following hierarchy:

      1. Analysis_Date: first in the sequence was assigned as preferred, or
      2. Analysis_Time: first in the sequence was assigned as preferred, or
      3. Analysis_Type_Code: "INIT" means initial analysis and is the first analyses, so it was assigned as preferred.

   ii. Lab_Qualifiers were the next determinant of preferred record based on the following hierarchy[90]:

      1. J
      2. U
      3. B,J

   iii. Where an order of analysis could be determined using QC_Batch_Sequence_Num with a similar code but lower number (e.g., 1, 2) or letter (e.g., a, b, c), the lower value was assigned as the preferred result.

   iv. If no prior decision factor selected a preferred value, the preferred result was selected based on the one with the longer Sample_Result_Comments.

   v. If no prior decision factor selected a preferred value, then the preferred result was selected as the one with a smaller Lab_Sample_ID (in dictionary order).

   vi. If no prior decision factor selected a preferred value, then the preferred result was selected as the one with the smaller value for the Field_Sample_Result_Recno field.

   vii. If all the aforementioned were the same, the preferred value was randomly selected.

STEP FOUR: SAMPLE TYPE AND UNITS FILTERING

Once data were assigned quality codes and good result flags, sample types relevant to the NRDA were identified and selected for watershed-specific exports by populating the IEc_For_Export field with "Y" (Table 5). However, some records from these sample types were excluded from the watershed-specific exports based on their report units or parameter (i.e., some records had "N" populated in the IEc_For_Export field). For example, units of "XYZ" are not valid for either solid or liquid sample types; solid units are generally not valid for water samples (e.g., "pCi/g", "µg/kg"); liquid units are not valid for soil or sediment samples (e.g., "pCi/L", "µg/L"), unless density assumptions are made; and physical and biological parameters (e.g., "TOTAL SAND", "Eisenia fetida end weight") are not relevant to the current effort.[91] The full set of unit decisions are contained in the spreadsheets

[90] Only Lab_Qualifier codes in the database that were remaining at this step were ranked.

[91] Information on soil or sediment bulk density was not available in the database, so no unit conversions could be performed on sediment samples with liquid units. Due to the small number of water samples with solid units, we assumed these units represented errors in the database and excluded these data rather than attempting a conversion (e.g., based on the mass of water).

"tbl_UnitDecisions_sed_working_12182019.xlsx", "tbl_UnitDecisions_water_working_12182019.xlsx", and "tbl_UnitDecisions_NASH_12312019.xlsx".[92] No order-of-magnitude unit conversions (e.g., 0.001 ppm to 1 ppb) were conducted at this time; unit conversions will be considered on a case-by-case basis when performing analyses using the data.

Some records were also excluded from watershed-specific exports based on inconsistencies in the use of the Lab_Matrix field. The Lab_Matrix field was included in the sample identification key to capture valid pairs of matrices, such as "LIQ" and "SD" for the same Field_Sample_ID (see *Step Three: Assess Multiple Results for Sample Dates, Media, and Parameters*). However, inconsistencies in the use of the Lab_Matrix field caused multiple results to continue to exist. For example, a single Field_Sample_ID might have one result with "SD" reported in the Lab_Matrix field and another result with "SED" reported in the Lab_Matrix_Field. Such samples were therefore not identified as multiple results prior to this point due to such differences, but undoubtedly represent multiple results. Therefore, such multiple results were subsequently flagged so they would not be exported based on the following steps. In these cases, the IEc_For_Export field was populated with "1" (yes) following these decisions for data tracking and filtering purposes (the remaining, paired record was assigned "0", no). Specifically, the following records were selected as the preferred records:

1. If one record had a Best_Value_Flag of "Y" that record was selected for export.
2. If one record had an Analytical_Method of "HASL-300:Am-241" when the other record noted an EPA method. Otherwise, records with any Analytical_Method field populated were selected over "LEGACY."
3. Records with a Report_Detection_Limit_Updated value of "Y" were selected as the preferred record.[93]

[92] The unit decisions were based on the raw data, not the data resulting from Step 3 (i.e., not just data with IEc_Good_Result_Flag = "Y").

[93] Four records were valid Lab_Matrix pairs of LIQ and SD for Field_Sample_ID = AAA1285 and AAA6679. These were left as-is.

TABLE 5. SAMPLE TYPE, DESCRIPTION, AND ASSIGNED MEDIA GROUP

SAMPLE TYPE AND DESCRIPTION					
SAMPLE TYPE	DESCRIPTION	MEDIA GROUP	SAMPLE TYPE	DESCRIPTION	MEDIA GROUP
A	Animal	Animal	OIL	Oil	N/A
AIR	Air Samples for AirNet	N/A	OTH	Other	N/A
APP	Apples	Vegetation	PA	Filter Particulates and/or adsorbates	N/A
ASH	Volcanic Ash	N/A	PLM	Plum	Vegetation
D	Debris	N/A	R	Rock	N/A
DRYDEP	Dry Atmospheric Deposition	N/A	**RAIN**	**Rain**	**Water**
EM	Engineered Material	N/A	**S**	**Soil**	**Soil**
F	Filter, total	N/A	S_FTB	soil for FTB, used for replacement W->S for FTB	N/A
FBC	Bullhead Catfish	Animal	**SED**	**Geologic Sediment**	**Sediment**
FBG	Blue Gill	Animal	SLD	Sludge, Dry	N/A
FCC	Channel Catfish	Animal	SLW	Sludge, Wet	N/A
FCP	Carp	Animal	**SNOW**	**Snow**	**Water**
FCS	Carp Sucker	Animal	SWP	Wipe (Including Swipes)	N/A
FNP	Northern Pike	Animal	UA	Unassigned	N/A
FRT	Rainbow Trout	Animal	UNK	Unknown	N/A
FSMB	Smallmouth Bass	Animal	V	Vegetation	Vegetation
FWB	White Bass	Animal	**W**	**Water**	**Water**
FWC	White Crappie	Animal	W_FTB	Water for FTB, used for replacement S->W in FTB	N/A
FWLY	Walleye	Animal	WD	Drinking Water from Fountain or Tap	N/A
FWS	White Sucker	Animal	**WE**	**Effluent**	**Water**
GAS	Gas	N/A	**WG**	**Groundwater**	**Water**
LET	Lettuce	Vegetation	**WI**	**Influent**	**Water**
LIQ	Liquids other than water or oil	N/A	**WIP**	**Industrial Process Water**	**Water**
MOSS	Moss	Vegetation	**WM**	**Snowmelt**	**Water**
NA	Not Applicable	N/A	**WO**	**Outfall**	**Water**
NASH	**Nongeologic Ash**	**Sediment**	**WOE**	**Outfall Effluent**	**Water**
NSED	**Nongeologic Sediment**	**Sediment**	**WP**	**Persistent Flow**	**Water**
			WS	**Base Flow**	**Water**
			WT	**Storm Runoff**	**Water**

Note: Step four of this SOP applies to the media types highlighted grey and formatted bold in this table.

REFERENCES

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APPENDIX B | SCREENING LEVEL VALUE ANALYSIS METHODOLOGY

SCREENING LEVEL VALUE (SLV) ANALYSIS

This appendix describes the steps conducted and considerations made for the screening level value (SLV) analysis described in Chapter 4. This methodology applies to analysis of the groundwater database constructed according to the procedures described in the Appendix A standard operating procedure (SOP). The goal of the SLV analysis is to identify the most widespread contaminants of potential concern for subsequent spatial and temporal evaluation and characterization steps.

STEP ONE: DATA EXPLORATION

The availability, spatial coverage, and attributes of environmental sampling data available for each contaminant identified in the work plan (Exhibit B-1) are explored by documenting the following:

1. Geographic distribution (i.e., sampling locations in which a given contaminant has been detected).
2. Proportion of detect and non-detect samples for the given contaminant.[94]
3. Maximum and minimum contaminant concentrations (in detected samples).

STEP TWO: DATA PREPARATION

Several data fields were filtered to ensure the correct comparison of data to the SLVs:

a. **Qualified Results:** Only results with an "IEc_Data_Quality_Category" of universal use ("UU") are used for this step.

b. **Sample Matrix, Lab Matrix, and Sample Type:** At this time, only groundwater data are included. Thus, the sample matrix and lab matrix should be "W" (water). The sample type should be "WG" (groundwater). Samples with other matrices are excluded from further analysis.

c. **Sample Purpose:** The field "SAMPLE_PURPOSE" was filtered to include only "REG" (regular investigative sample) samples.

d. **Result Type Code:** The field "RESULT_TYPE_CODE" are filtered to include only "TRG" (target) samples.

e. **Parameter Code:** Discrepancies between the fields "PARAMETER_NAME" and "PARAMETER_CODE" exist in the raw data. For example, in some instances, the Parameter Name of "Titanium" has a Parameter Code of "Sr" (strontium). Los Alamos National Laboratory (LANL) confirmed that "PARAMETER_CODE," is the most accurate field to rely upon and is used for this analysis; therefore, this field is relied on.

f. **IEc Good Result Flag and IEc For Export:** "IEc_Good_Result_Flag" value of "Y" and "IEc_For_Export" flags of "Y" and "1" are relied on. These quality indicators are determined through implementation of the Appendix A Standard Operating Procedure.

[94] Results flagged as non-detect in the "VALIDATION_QUALIFIER" field were included in this analysis but tracked throughout.

STEP THREE: EXCEEDANCE ANALYSIS

To identify the most widespread contaminants of groundwater from among those listed in the work plan, contaminant concentration data for each contaminant are compared to their respective SLVs. Where promulgated, federal- or state-promulgated Maximum Contaminant Level (MCL) are prioritized as SLVs. In the absence of an MCL, alternative SLVs are used from the following sources:

- **Interim Facility-Wide Groundwater Monitoring Plan for the 2018 Monitoring Year, October 2017-September 2018 (IFGMP 2017) –** Groundwater data collected by LANL are reviewed monthly and are compared against screening criteria provided in Section XXVI of the 2016 Consent Order (2016 Consent Order).
- **Screening Levels Spreadsheet Provided by LANL ("Screening Levels_8-16-17.xlsx")** – Due to differences in SLVs across documents and through time, the most recent SLVs from LANL were requested. These values were provided in an Excel spreadsheet on August 18, 2017.[95]
- **Federal and state promulgated criteria** – The United States Environmental Protection Agency (USEPA) has promulgated criteria under National Primary Drinking Water Regulations (EPA 2009). Similarly, the State of New Mexico has also promulgated standards for ground and surface water protection (New Mexico Administrative Code [NMAC] 20.6.2 *et seq*.).
- **A screening level value of 20 picocuries per liter (pCi/L) for uranium-235** – This is based on an assumption that this value is generally consistent with the USEPA Maximum Contaminant Level of 30 micrograms per liter (µg/L), taking into consideration likely proportions of naturally occurring isotopes, but would also be protective if proportions of man-made uranium isotopes were higher (J. Mauro, *personal communication*, 2017).

As a general rule, the most stringent (i.e., lowest) SLVs from these sources are selected for use in the exceedance analysis (Exhibit B-1). This approach results in the identification of more exceedances relative to using less stringent (i.e., higher) SLVs, and was employed to bias the analysis toward the inclusion, as opposed to the exclusion, of samples with contaminant concentrations of potential concern. The results of this analysis are summarized in Section 4.4.

[95] Several outstanding questions remained. For example, certain parameters appeared to have SLVs used in Site reports but not included in the provided spreadsheet (e.g., americium-241, cesium-137, plutonium-238, plutonium-239/240). As a specific example, americium-241 was compared to a value of 1.2 pCi/L in IFGMP (2017), but this value did not appear in the provided spreadsheet.

EXHIBIT B-1. GROUNDWATER SCREENING LEVEL VALUES (SLVS)

PARAMETER	SLV VALUE	SLV UNIT	DESCRIPTION	SOURCE
Americium-241	1.2	pCi/L	DOE DW DCG	IFGMP 2017
Chromium	50	µg/L	NM GW STD	NMAC 20.6.2.3103 A.(4)
Hexavalent chromium	50	µg/L	NM GW STD	Screening Levels_8-16-17.xlsx (from LANL)
Cesium-137	120	pCi/L	DOE DW DCG	IFGMP 2017
High Melting eXplosive	780	µg/L	EPA TAP SCRN LVL	IFGMP 2017
Perchlorate	13.8	µg/L	NMED A1 TAP SCRN LVL	Screening Levels_8-16-17.xlsx (from LANL)
Plutonium-238	1.6	pCi/L	DOE DW DCG	IFGMP 2017
Plutonium-239/240	1.2	pCi/L	DOE DW DCG	IFGMP 2017
Royal Demolition eXplosive	6.1	µg/L	EPA TAP SCRN LVL	IFGMP 2017
Strontium-90	8	pCi/L	EPA MCL	Screening Levels_8-16-17.xlsx (from LANL)
Technicium-99	1,760	pCi/L	DOE DW DCS	Screening Levels_8-16-17.xlsx (from LANL)
2,4,6-trinitrotoluene (TNT)	9.8	µg/L	NMED A1 TAP SCRN LVL	Screening Levels_8-16-17.xlsx (from LANL)
Tritium	20,000	pCi/L	EPA MCL	Screening Levels_8-16-17.xlsx (from LANL)
Uranium	30	µg/L	EPA MCL	EPA 2009
Uranium-234	20	pCi/L	DOE DW DCG	IFGMP 2017
Uranium-235	20	pCi/L	Assumption	Screening assumption (per John Mauro, SC&A)
Uranium-238	24	pCi/L	DOE DW DCG	IFGMP 2017

EPA MCL = EPA maximum contaminant level
EPA TAP SCRN LVL = EPA tap water screening level
NM GW STD = New Mexico groundwater standard
NMED A1 TAP SCRN LVL = New Mexico Environment Department tap water screening level
DOE DW DCG = Department of Energy drinking water–derived concentration guide
DOE DW DCS = Department of Energy-derived concentration standard
LANL BG LVL = LANL-derived groundwater background level

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APPENDIX C | PLUME EVALUATION DATA PROCESSING APPROACH

CHROMIUM PLUME PROCEDURES

This section describes the process Lee Wilson & Associates (LWA) used to acquire and process data from Intellus online in support of their chromium plume evaluation for the Los Alamos National Laboratory (LANL) Natural Resource Damage Assessment (NRDA).

DATA ACQUISITION

This processing uses data from Intellus online, the online data repository for LANL. The data is obtained by visiting the Intellus data web portal at https://www.intellusnm.com/reporting/quick-search/quick-search.cfm. These directions start from there and follow the numbering of the website.

1. Select **Los Alamos National Laboratory** and **NMED DOE Oversight Bureau** as the *data providers*.
2. Select **Analytical results** as the *type of data*.
3. Select **Water** as the *type of sample* you are interested in. Then select **Ground Water** as the *type of water*.
4. Change the *time period* to **1/1/1980** to **6/18/2020**. Click the *Continue* or *Save Changes* button.
5. Select **Everywhere in the Los Alamos area** for *Where do you want to look.*
6. For *What analytical parameter are in interested in*, click **Select parameter(s) from a list**. Then select **Individual parameter** in *Select parameters by:* and search for **Chromium** and add all five entries with the >> button. Click the *Continue* or *Save Changes* button.
7. For *What data columns do you want to see*, search for

   Analysis Date
   Analysis Time
   Analysis Type Code
   Best Value
   Best Value Status Code
   Dilution Factor
   Field Sample Result Record ID
   Instrument Detection Limit
   Lab Result
   Lab Sample ID
   Method Detection Limit
   Parameter Code
   QC Batch Sequence #
   Report Method Detection Limit
   Result Type
   Sample Result Comments
   Validation Qualifier
   Validation Reason Codes

   and add them to the selected fields with the single > button. Click the *Continue* or *Save Changes* button.
8. In *Results*, click the **Download results** button then choose *Export type:* **CSV**, *Enclosure:* **with “quotes”** and click **Export**.

The data should be saved as a .csv file to a local folder.

Location Information

1. Visit Intellus online at https://gis.locusfocus.com/arcgisservice/?app=intellus&uid=0a5807b7-3448-4cf8-8dc2-efd68fb8ac06.
2. On the options bar on the right, expand **Locations**, expand **Location Type**, select **Monitoring Well**.
3. Expand **Map Layer**, select the icon 2nd from the right, **export visible layers to ArcGIS Online**. This requires being signed into ArcGIS Online.
4. This opens a dialogue where you enter the **Feature Layer Name** to export and then click **Export Layer** to view in ArcGIS Online.
5. A new window will open to ArcGIS Online. Click on **Home** then on the **Content** tab. The file you downloaded should be at the top of the list or the only file. Click on it. On the right under Details, there should be **Feature Collection**. Click on this and you will have the data displayed in .json format. Save this as **Intellus Monitoring Wells.json**.

DATA PRE-PROCESSING

The data were subjected to the Data Review and Cleanup Standard Operating Procedure (Appendix A). The process was slightly modified by LWA in order to accommodate the different data structure from Intellus online versus the SQL Server database backup that had been used originally.

1. Create a new **Chromium** database in SQL Server Management Studio (SSMS).
2. Setup the database by running **DB setup.py**. This imports the data downloaded from Intellus online to the SQL Server *Chromium* database.
3. Open SSMS and navigate to the Raw table in the Chromium database. Open up the columns and rename VALIDATION_REASON_CODES by deleting the trailing "space".
4. Run **Cleanup_Step1_QualCat.py**.
5. Run **Cleanup_Step2_DupResults.py**.
6. Run **Cleanup_Step3_Mark_IEcForExport.sql** in SSMS. This step applies all of the IEc flagging protocol to produce the *Chromium_Flagged* database.
7. Run **Phase II Processing.py**.

TABLES AND PLOTS FOR LOCATION CROSS-CHECK PROCESS

This section outlines the processing used to develop figures and tables for the location cross check process, described in Section 5.2.

1. Run **activeLocations.py**. This will query the database and produce figures and an Excel spreadsheet identified with *Active* as the first word in the title.
2. Run **ESDLocations.py**. This will query the database and produce figures and an Excel spreadsheet identified with *ESD* (exceedance & substantial data) as the first word in the title.

3. Run **excludedLocations.py**. This will query the database and produce figures and an Excel spreadsheet identified with E*xcluded* as the first word in the title.
4. Run **TablesOutExcluded.py**. This will query the database and produce .txt files.
5. Run **tablesToExcelExcluded.py**. This will use the .txt files produced in the previous step to create formatted Excel spreadsheets from the data for final tables.

EXCLUDED LOCATIONS

This section describes the process LWA used to determine which wells to include in the chromium plume evaluation.

LWA needed to create GIS location files for **Well Info- 2019-01-09- Areas & Watersheds.**

1. Query out **Well Info- 2019-01-09- Areas & Watersheds** table from **IEc** database. The SQL is "USE IEc; SELECT * FROM [Well Info- 2019-01-09- Areas & Watersheds];". Save as *Text (Tab delimited) (*.txt)* with name **Well Info- Areas & Watersheds.ascii**.

LWA needed to create GIS location files for **Intellus Monitoring Wells.**

2. Download the monitoring well location information from Intellus online. See instructions in the **Location Information** section of **Directions for Intellus Query.docx** to acquire the data. You should end up with the file **Intellus Monitoring Wells.json**. Also do **Springs.json** and **Watercourses.json**.
3. Extract the .json data from Springs and Watercourses with **Intellus Locations Upacker.py**. This creates **Springs.ascii** and **Watercourses.ascii**.
4. Run **Intellus Monitoring Wells Upacker.py**. This reads in the **Intellus Monitoring Wells.json** and outputs **Intellus Monitoring Wells.ascii**.

LWA needed to create GIS location files from **Intellus Chromium Data.**

1. Query the Chromium table out of the Chromium database in SQL Server. The SQL is "SELECT * FROM chromium;". Save as a tab separated file **EIM_EXPORT_06_18_2020.txt**. Note, this is the same as the Intellus online query but we query it out of the database so as to have tab separated formatting.
2. Copy the header from **EIM_EXPORT_06_18_2020.csv** into **EIM_EXPORT_06_18_2020.txt.**
3. Run **Intellus Chromium Data Wells Compiler.py** which reads in **EIM_EXPORT_06_18_2020.txt** and creates the files **Intellus Chromium Data Locations- All.ascii, Intellus Chromium Data Locations- Discrepencies.ascii** and **Intellus Chromium Data Locations- Report.ascii** (*This is currently blank*) in the same location.

GIS Processing

4. Create **Extended Chromium Examination Area.shp** as a way to limit the wells initially examined.
5. Run **asciiToSHP.py** to create .shp files for **Well Info- Areas & Watersheds.ascii, Intellus Chromium Data Locations- All.ascii** and **Intellus Monitoring Wells.ascii**.

6. Run **getPointsInPolygon.py** to create .shp files that have been spatially limited to the extent of the **Extended Chromium Examination Area** polygon.
7. Run **dbfTotxt.py** to create .txt files from the .dbf files created in the previous step.

Python Processing

8. Run **wellTableCompiler.py** with the parameter option set to *Chromium* and the type option set to *Narrowed*. This uses **Well Info** as a base then adds any locations from **Intellus Monitoring Wells** and **Intellus Chromium Data** that are not included in **Well Info.** Additionally, it compares multiple values for a single location and builds a discrepancy table when not in agreement. The steps taken are outlined as follows:

    a. Read in the location information from the file **Watercourses.ascii**. These will be used to exclude locations.

    <u>**Well Info**</u>

    b. Read in the well information from the file **Narrowed- Well Info.txt** to determine which wells are to be included.

    c. Read in the well information from the file **Well Info- Areas & Watersheds.txt** as **wellInfoIn**.

    d. Loop through **wellInfoIn**.

        i. If the location is in **Watercourses**, skip the location.

        ii. If the location has an excluded type, skip the location.

        iii. If the location is in the **Narrowed- Well Info.txt, s**ave selected columns from **Well Info- 2019-01-09- Areas & Watersheds** to a *wellInfo* dictionary.

    <u>**Intellus Monitoring Wells**</u>

    e. Read in **Narrowed- Intellus Monitoring Wells.txt**.

    f. Read in **Intellus Monitoring Wells.ascii**.

    g. Loop through the **Intellus Monitoring Wells.ascii** data. If the location is in the **Narrowed- Intellus Monitoring Wells.txt**:

        i. If it **is not** in *wellInfo* dictionary**, s**ave selected columns to *wellInfo* dictionary.

        ii. If it **is** in *wellInfo* dictionary, compare it to the columns in *wellInfo* dictionary and build discrepancy dictionary if they do not agree.

    <u>**Intellus Chromium Data**</u>

    h. Read in **Narrowed- Intellus Chromium Data.txt**.

    i. Read in **EIM_EXPORT_03_31_2020.txt**.

    j. Loop through the **EIM_EXPORT_03_31_2020.txt** data. If the location is in the **Narrowed- Intellus Chromium Data.txt**:

        i. If it **is not** in *wellInfo* dictionary**, s**ave selected columns to *wellInfo* dictionary.

ii. If it **is** in *wellInfo* dictionary, compare it to the columns in *wellInfo* dictionary and build discrepancy dictionary if they do not agree.

k. Write the *wellInfo* and *discrepancy* dictionaries to .txt files; **Compiled- Narrowed.txt** and **Discrepancy- Compiled- Narrowed.txt**.

9. Run **SummaryStats.py**. This queries the database for total chromium data for the locations in **Compiled- Narrowed.txt** and produces files that identify the active locations (**Active- Compiled- Narrowed.txt**), the locations with exceedances (**Exceedance- Compiled- Narrowed.txt**), the locations with substantial data (**Substantial Data- Compiled- Narrowed.txt**) and it summarizes the maximum values observed (**Maxes- Compiled- Narrowed.txt**). It stores all of these files in Outputs. Note that this process excludes non-detect data.
10. Run **addStatus.py**. This reads in **Compiled- Narrowed.txt** and adds fields to document the results of **SummaryStats.py** and outputs **Compiled- Narrowed- For Watersheds.txt**.
11. Run **getWatershed.py**. This reads in **Compiled- Narrowed- For Watersheds.txt** and updates the watershed field based on the **Watersheds- Revised.shp** file. It outputs **Compiled- Narrowed- For DB.txt**.

Import to Database

12. Run **Chromium Locations DB Setup.py**. This reads in the **Watershed- Final- Compiled- Narrowed.txt** file and creates the *chromium_locations* table in the SQL Server Chromium database.
13. Run **TablesOut.py**. This queries the *chromium_locations* table in the SQL Server database and produces the appropriate .txt files.
14. Run **tablesToExcel.py**. This reads in the info from the .txt files created in the previous step and writes them to formatted tables for final products.

Plotting

15. Run **Chromium_Flagged Plotter.py**. This will read in all the wells from **Compiled- Narrowed.txt,** query the database for each location's data, plot it and produce the file **Active- Well Info- Narrowed- Final.txt**.

Remove db.ini*

RDX PLUME PROCEDURES

This section describes the process Lee Wilson & Associates (LWA) used to acquire and process data from Intellus online in support of their Royal Demolition eXplosive (RDX) plume evaluation for the Los Alamos National Laboratory (LANL) Natural Resource Damage Assessment (NRDA).

DATA ACQUISITION

This processing uses data from Intellus online, the online data repository for LANL. The data is obtained by visiting the Intellus data web portal at https://www.intellusnm.com/reporting/quick-search/quick-search.cfm. These directions start from there and follow the numbering of the website.

1. Select **Los Alamos National Laboratory** and **NMED DOE Oversight Bureau** as the *data providers*.

2. Select **Analytical results** as the *type of data*.

3. Select **Water** as the *type of sample* you are interested in. Then select **Ground Water** as the *type of water*.

4. Change the *time period* to **1/1/1990** to **8/3/2020**. Click the *Continue* or *Save Changes* button.

5. Select **Everywhere in the Los Alamos area** for *Where do you want to look.*

6. For *What analytical parameter are in interested in*, click **Select parameter(s) from a list**. Then select **Individual parameter** in *Select parameters by:* and search for **RDX** and add it with the > button. Click the *Continue* or *Save Changes* button.

7. For *What data columns do you want to see*, search for

   Analysis Date
   Analysis Time
   Analysis Type Code
   Best Value
   Best Value Status Code
   Dilution Factor
   Field Sample Result Record ID
   Instrument Detection Limit
   Lab Result
   Lab Sample ID
   Method Detection Limit
   Parameter Code
   QC Batch Sequence #
   Report Method Detection Limit
   Result Type
   Sample Result Comments
   Validation Qualifier
   Validation Reason Codes

   and add them to the selected fields with the single > button. Click the *Continue* or *Save Changes* button.

8. In *Results*, click the **Download results** button then choose *Export type:* **CSV**, *Enclosure:* **with "quotes"** and click **Export**.

The data should be saved as a .csv file to a local folder.

Location Information

6. Visit Intellus online at https://gis.locusfocus.com/arcgisservice/?app=intellus&uid=0a5807b7-3448-4cf8-8dc2-efd68fb8ac06.

7. On the options bar on the right, expand **Locations**, expand **Location Type**, select **Monitoring Well**.

8. Expand **Map Layer**, select the icon 2nd from the right, **export visible layers to ArcGIS Online**. This requires being signed into ArcGIS Online.

9. This opens a dialogue where you enter the **Feature Layer Name** to export and then click **Export Layer** to view in ArcGIS Online.

10. A new window will open to ArcGIS Online. Click on **Home** then on the **Content** tab. The file you downloaded should be at the top of the list or the only file. Click on it. On the right under Details, there should be **Feature Collection**. Click on this and you will have the data displayed in .json format. Save this as **Intellus Monitoring Wells.json**.

DATA PRE-PROCESSING

The data were subjected to the Data Review and Cleanup Standard Operating Procedure (Appendix A). The process was slightly modified by LWA in order to accommodate the different data structure from Intellus online versus the SQL Server database backup that had been used originally.

1. Create a new **RDX** database in SQL Server Management Studio (SSMS).
2. Setup the database by running **DB setup.py**. This imports the data downloaded from Intellus online to the SQL Server *RDX* database.
3. Open SSMS and navigate to the Raw table in the RDX database. Open up the columns and rename VALIDATION_REASON_CODES by deleting the trailing "space".
4. Run **Cleanup_Step1_QualCat.py**.
5. Run **Cleanup_Step2_DupResults.py**.
6. Run **Cleanup_Step3_Mark_IEcForExport.sql** in the SQL Server Management Studio. Note: the Python file doing the same was not executing properly.
7. Run **Phase II Processing.py**.

TABLES AND PLOTS FOR LOCATION CROSS-CHECK PROCESS

This section outlines the processing used to develop figures and tables for the location cross check process, described in Section 5.2.

1. Run **activeLocations.py**. This will query the database and produce figures and an excel spreadsheet identified with *Active* as the first word in the title. (~Share to IEc\Python\Excluded Locations\Outputs).
2. Run **ESDLocations.py**. This will query the database and produce figures and an excel spreadsheet identified with *ESD* (exceedance & substantial data) as the first word in the title.
3. Run **excludedLocations.py**. This will query the database and produce figures and an excel spreadsheet identified with E*xcluded* as the first word in the title.
4. Run **TablesOutExcluded.py**. This will query the database and produce .txt files.
5. Run **tablesToExcelExcluded.py**. This will use the .txt files produced in the previous step to create formatted excel spreadsheets from the data for final tables.

EXCLUDED LOCATIONS

This section describes the process LWA used to determine which wells to include in the RDX plume evaluation.

LWA needed to create GIS location files for **Well Info- 2019-01-09- Areas & Watersheds.**

1. Query out **Well Info- 2019-01-09- Areas & Watersheds** table from **IEc** database. The SQL is "USE IEc; SELECT * FROM [Well Info- 2019-01-09- Areas & Watersheds];". Save as *Text (Tab delimited) (*.txt)* with name **Well Info- Areas & Watersheds.ascii**.

LWA needed to create GIS location files for **Intellus Monitoring Wells.**

2. Download the monitoring well location information from Intellus online. See instructions in the **Location Information** section of **Directions for Intellus Query.docx** to acquire the data. You should end up with the file **Intellus Monitoring Wells.json**. Also do **Springs.json** and **Watercourses.json**.
3. Extract the .json data from Springs and Watercourses with **Intellus Locations Upacker.py**. This creates **Springs.ascii** and **Watercourses.ascii**.
4. Run **Intellus Monitoring Wells Upacker.py**. This reads in the **Intellus Monitoring Wells.json** and outputs **Intellus Monitoring Wells.ascii**.

LWA needed to create GIS location files from **Intellus RDX Data.**

1. Query the RDX table out of the RDX database in SQL Server. The SQL is "SELECT * FROM RDX;". Save as a tab separated file **EIM_EXPORT_06_18_2020.txt**. Note, this is the same as the Intellus online query but we query it out of the database so as to have tab separated formatting.
2. Copy the header from **EIM_EXPORT_06_18_2020.csv** into **EIM_EXPORT_06_18_2020.txt.**
3. Run **Intellus RDX Data Wells Compiler.py** which reads in **EIM_EXPORT_06_18_2020.txt** and creates the files **Intellus RDX Data Locations- All.ascii, Intellus RDX Data Locations- Discrepencies.ascii** and **Intellus RDX Data Locations- Report.ascii** (*This is currently blank*) in the same location.

GIS processing

4. Create **Extended RDX Examination Area.shp** as a way to limit the wells initially examined.
5. Run **asciiToSHP.py** to create .shp files for **Well Info- Areas & Watersheds.ascii, Intellus RDX Data Locations- All.ascii** and **Intellus Monitoring Wells.ascii**.
6. Run **getPointsInPolygon.py** to create .shp files that have been spatially limited to the extent of the **Extended RDX Examination Area** polygon.
7. Run **dbfTotxt.py** to create .txt files from the .dbf files created in the previous step.

Python processing

8. Run **wellTableCompiler.py** with the parameter option set to *RDX* and the type option set to *Narrowed*. This uses **Well Info** as a base then adds any locations from **Intellus Monitoring Wells** and **Intellus RDX Data** that are not included in **Well Info.** Additionally, it compares multiple values for a single location and builds a discrepancy table when not in agreement. The steps taken are outlined as follows:
    a. Read in the location information from the file **Watercourses.ascii**. These will be used to exclude locations.

Well Info

b. Read in the well information from the file **Narrowed- Well Info.txt** to determine which wells are to be included.

c. Read in the well information from the file **Well Info- Areas & Watersheds.txt** as **wellInfoIn**.

d. Loop through **wellInfoIn**.

    i. If the location is in **Watercourses**, skip the location.

    ii. If the location has an excluded type, skip the location.

    iii. If the location is in the **Narrowed- Well Info.txt, s**ave selected columns from **Well Info- 2019-01-09- Areas & Watersheds** to a *wellInfo* dictionary.

Intellus Monitoring Wells

e. Read in **Narrowed- Intellus Monitoring Wells.txt**.

f. Read in **Intellus Monitoring Wells.ascii**.

g. Loop through the **Intellus Monitoring Wells.ascii** data. If the location is in the **Narrowed- Intellus Monitoring Wells.txt**:

    i. If it **is not** in *wellInfo* dictionary**, s**ave selected columns to *wellInfo* dictionary.

    ii. If it **is** in *wellInfo* dictionary, compare it to the columns in *wellInfo* dictionary and build discrepancy dictionary if they do not agree.

Intellus RDX Data

h. Read in **Narrowed- Intellus RDX Data.txt**.

i. Read in **EIM_EXPORT_03_31_2020.txt**.

j. Loop through the **EIM_EXPORT_03_31_2020.txt** data. If the location is in the **Narrowed- Intellus RDX Data.txt**:

    i. If it **is not** in *wellInfo* dictionary**, s**ave selected columns to *wellInfo* dictionary.

    ii. If it **is** in *wellInfo* dictionary, compare it to the columns in *wellInfo* dictionary and build discrepancy dictionary if they do not agree.

k. Write the *wellInfo* and *discrepancy* dictionaries to .txt files; **Compiled- Narrowed.txt** and **Discrepancy- Compiled- Narrowed.txt**.

9. Run **SummaryStats.py**. This queries the database for total RDX data for the locations in **Compiled- Narrowed.txt** and produces files that identify the active locations (**Active-Compiled- Narrowed.txt**), the locations with exceedances (**Exceedance- Compiled-Narrowed.txt**), the locations with substantial data (**Substantial Data- Compiled- Narrowed.txt**) and it summarizes the maximum values observed (**Maxes- Compiled- Narrowed.txt**). It stores all of these files in Outputs. Note that this process excludes non-detect data.

10. Run **addStatus.py**. This reads in **Compiled- Narrowed.txt** and adds fields to document the results of **SummaryStats.py** and outputs **Compiled- Narrowed- For Watersheds.txt**.

11. Run **getWatershed.py**. This reads in **Compiled- Narrowed- For Watersheds.txt** and updates the watershed field based on the **Watersheds- Revised.shp** file. It outputs **Compiled- Narrowed- For DB.txt**.

Import to database

12. Run **RDX Locations DB Setup.py**. This reads in the **Watershed- Final- Compiled- Narrowed.txt** file and creates the *RDX_locations* table in the SQL Server RDX database.
13. Run **TablesOut.py**. This queries the *RDX_locations* table in the SQL Server database and produces the appropriate .txt files.
14. Run **tablesToExcel.py**. This reads in the info from the .txt files created in the previous step and writes them to formatted tables for final products.

Plotting

15. Run **RDX_Flagged Plotter.py**. This will read in all the wells from **Compiled- Narrowed.txt,** query the database for each location's data, plot it and produce the file **Active- Well Info- Narrowed- Final.txt**.

Remove db.ini*