IEc

Baseline Condition of Groundwater Resources in and around Los Alamos National Laboratory

Los Alamos National Laboratory Natural Resource Damage Assessment

DOE Contract DE-EM0003939

DOE Task Order DE-DT0011621

Final Report | June 2020

prepared for:

Los Alamos National Laboratory Natural Resource
Damage Assessment Trustee Council

prepared by:

Dr. Rita Cabral, Dr. A. Andrés Aguirre, Nadia Martin, Dr. Christopher Lewis, and Robert Unsworth

Industrial Economics, Incorporated
2067 Massachusetts Avenue
Cambridge, MA 02140

with assistance from:

Dr. Lee Wilson

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

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LIST OF EXHIBITS

LIST OF ACRONYMS

°F	degrees Fahrenheit
µg/L	micrograms per liter
BFR	basin-fill recharge
CDC	Centers for Disease Control and Prevention
C.F.R.	Code of Federal Regulations
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DAP	Damage Assessment Plan
DO	Dissolved Oxygen
DOE	Department of Energy
DOI	Department of the Interior
EIM	Environmental Information Management
EPA	United States Environmental Protection Agency
GBIR	Groundwater Background Investigation Report, Revision 5
GIS	geographic information system
GPM	gallons per minute
He	helium
HE	high explosive
HRMS	high resolution inductively coupled plasma mass spectrometry
IEc	Industrial Economics, Incorporated
LANL	Los Alamos National Laboratory
m	meters
Ma	mega annums
MBR	mountain-block recharge
MCL	Maximum Contaminant Level
mg/L	milligrams per liter
NMED	New Mexico Environment Department

NRDA	Natural Resource Damage Assessment
NRTC	Natural Resource Trustee Council
PCBs	polychlorinated biphenyls
pCi/L	picocuries per liter
ppm	parts per million
QA	quality assurance
QC	quality control
RDX	Royal Demolition Explosive
SOP	standard operating procedure
TA	technical area
TDS	Total Dissolved Solids
U.S.C.	United States Code
USGS	United States Geological Survey
UTL	upper tolerance limit

CHAPTER 1 | INTRODUCTION

1.1 REPORT BACKGROUND

The Los Alamos National Laboratory (LANL) Natural Resource Trustees (herein referred to as the "Trustees") are conducting a Natural Resource Damage Assessment (NRDA) to evaluate natural resource injuries and damages associated with the release of hazardous substances from the LANL facility. 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 (LANL NRTC 2014). The DAP presents the Trustees' understanding of the assessment work necessary to complete the NRDA. Specifically, it describes activities to identify and quantify injuries to natural resources and the services they provide, and to identify, scale, estimate the cost of, and implement compensatory restoration. Several activities outlined in the DAP relate to the assessment of groundwater.[1] Parts of these activities have been combined into this *Groundwater Data, Baseline, and Services* assessment activity, being completed under U.S. Department of Energy (DOE) Contract DE-EM0003939, Task Order DE-DT0011312, dated September 2016. As part of this assessment activity, Industrial Economics, Incorporated (IEc) prepared a work plan (IEc 2017). This report presents findings related to the second work plan objective, which is to "*Characterize the hydrological and chemical conditions of the groundwater in and around LANL under baseline.*"

1.1.1 GOALS AND OBJECTIVES OF THE ASSESSMENT ACTIVITY

As described in the work plan, the overarching goal of the groundwater activity is to compile and summarize available information on current and past groundwater conditions, baseline services, and potential impacts to groundwater services to support the NRDA, including injury and damages determination (IEc 2017). This report focuses on Task 2 (define baseline conditions for groundwater) and constitutes deliverable 3 of the work plan (report summarizing available data on the baseline condition of groundwater resources); that is, it describes the hydrological and chemical conditions of the groundwater in and around LANL under baseline. The services provided by groundwater under baseline (i.e., Task 3, deliverable 4) will be addressed under separate cover. A third, separate deliverable will focus on Task 1 of the work plan and will be a summary of existing information on current and past groundwater conditions in and around LANL, focusing on the characterization of plumes of released hazardous substances (IEc 2017).

The geographic scope of this assessment activity consists of areas within LANL property and the vicinity, including where LANL-related hazardous substances have come to be located (i.e., "*in and around*

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[1] 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"* (LANL NRTC 2014).

LANL”)[2] per section 101(9) of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and as described in the DAP (LANL NRTC 2014).[3]

1.1.2 BASELINE IN NATURAL RESOURCE DAMAGE ASSESSMENTS

The Department of the Interior (DOI) regulations pertaining to NRDA (DOI NRDA Regulations; 43 Code of Federal Regulations [C.F.R.] Part 11) discuss the concept of baseline in a number of instances and contexts. In particular, establishing the baseline condition of the resource is a key component of the injury quantification step. The baseline condition(s) of a resource is defined as “*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)). Further, restoration or rehabilitation of injured resources is defined as “*actions undertaken to return an injured resource to its baseline condition, as measured in terms of the injured resource's physical, chemical, or biological properties or the services it previously provided…*” (43 C.F.R. § 11.14(ll)).[4] Therefore although baseline is commonly understood to reflect the conditions that would have existed “but for” the release of contaminants; it is both the marker from which injury is measured, in a relative sense, and ultimately the target for measurement of the success of any restoration. Implicit in its definition; baseline can also change over time.

In order to define the baseline physical, chemical, or biological properties of groundwater, as well as baseline services, the DOI NRDA regulations provide guidance: they envision using either (1) information on the pre-release conditions of the resource (e.g., groundwater quality data from years prior to releases from LANL operations) (43 C.F.R. § 11.72(c)) or (2) information from control (sometimes referred to as background) areas (43 C.F.R. § 11.72(d)). Natural resource trustees, therefore, can consider information on resource conditions collected prior to the release of a hazardous substance and/or from geographic areas with attributes that are the same or similar to those of the injured resource, but that were not affected by the release.

The DOI NRDA regulations also provide resource-specific assessment guidance related to baseline determination (see 43 C.F.R. § 11.72(h)). While such guidance can be specific, the DOI NRDA regulations allow for flexibility. For instance, the Trustees may focus on subsets of releases, injuries, and/or services due to limitations on time and resources.

Anthropogenic versus Natural Sources of Contamination under Baseline

The DOI NRDA regulations state “*Baseline data should reflect conditions that would have been expected at the assessment area had the discharge of oil or release of hazardous substances not occurred, taking*

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[2] The specific geographic boundaries corresponding to “*in and around LANL*” will be defined during implementation of this assessment activity as the geographic dimensions of contaminated groundwater plumes resulting from releases from LANL operations (see "*Geographic Scope*" section of the LANL Damage Assessment Plan, LANL NRTC 2014).

[3] As described in the LANL Damage Assessment Plan (LANL NRTC 2014), the Trustees’ Memorandum of Agreement provides a framework for coordination among the parties in accordance with the authority established under CERCLA (42 United States Code [U.S.C.] §§ 9601 to 9675), the Clean Water Act (33 U.S.C. 1251 §§ *et seq.*), and the Oil Pollution Act (33 U.S.C. 2701).

[4] In the case of groundwater, the need to define the biological condition is rare - usually only reserved for circumstances where biota live in underground caves filled with groundwater or when exchange with the hyporheic zone is expected to be high. (The hyporheic zone is the area adjacent to a stream where shallow groundwater and surface water can mix.) Typically, once groundwater daylights in the form of a spring or as base flow to a stream, it is considered surface water and addressed as such.

into account both natural processes and those that are the result of human activities" (emphasis added; 43 C.F.R. § 11.72(b)(1)). Thus, understanding how natural processes and human activities can affect baseline is important. By acknowledging that natural processes affect baseline, the DOI NRDA regulations highlight the need to distinguish injuries caused by the hazardous substance release in question from other factors that can affect the type, quality, or quantity of services provided by a natural resource. For example, natural conditions and processes unrelated to a release of a hazardous substance can affect the chemical and physical conditions of groundwater, which can in turn affect the types of acceptable uses or values the public holds for a given groundwater resource. Such factors can include, for example, the natural minerals in the rock within which the groundwater resides (including naturally occurring radionuclides in ore deposits) or weather and other environmental conditions (including rainfall and infiltration). Additionally, contamination from non-LANL activities (i.e., from other entities) may exist given the long history of weapons testing and research activities in the region and globally (e.g., americium-241, cesium-137, strontium-90). However, it may be reasonable to assume that man-made radionuclides and anthropogenic organic compounds, such as trichloroethene, high explosive (HE) compounds, polychlorinated biphenyls (PCBs), and other volatile and semi-volatile compounds, would not have existed at measurable levels in groundwater near LANL absent releases from LANL operations.

In addition to natural processes, anthropogenic factors should be considered when determining baseline conditions. Emphasis on the use of historical or pre-release data is not meant to imply that baseline should reflect the condition of resources in a pre-development state. Rather, results of human activities that induce either adverse or beneficial changes to the environment should be reflected in the baseline determination. Over pumping, for example, can cause subsidence and compaction of an aquifer, which would affect the provision of drinking water.

Other Baseline Considerations

According to the DOI NRDA regulations, changes that are the result of remedial actions are not considered to be part of baseline. The regulations state that recoverable damages can be "*calculated based on injuries occurring from the onset of the release through the recovery period, less any mitigation of those injuries by response actions taken or anticipated, plus any increase in injuries that are reasonably unavoidable as a result of response actions taken or anticipated*" (43 C.F.R. § 11.15(a)(1)). Thus, injuries to groundwater resources that may be caused by remedial actions are accounted for directly within the injury quantification step of a NRDA and are not considered part of baseline. Similarly, the benefits of remediation should not be considered a component of baseline but should be accounted for in the injury quantification step.

The DOI NRDA regulations clearly indicate that care should be exercised when selecting and using data from control locations (see 43 C.F.R. § 11.72(d) *et seq.*). In particular, the Trustees should consider a number of factors to ensure that the control location is similar in its attributes to the release-affected area but that it has not itself been affected by the hazardous substance release. The regulations note also that "*Data collected at the control area should be compared to values reported in the scientific or management literature for similar resources to demonstrate that the data represent a normal range of conditions*" (43 C.F.R. § 11.72(d)(6)).[5]

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[5] Due to the existence of site-specific background data (LANL 2016a), we do not believe there are other values (i.e., values reported in the literature) that would be more applicable to this area.

1.2 TECHNICAL APPROACH AND FINDINGS

As described in the work plan (IEc 2017), the approach to this component of the assessment activity includes the following steps:

- Identify groundwater data and information relevant to the baseline condition of groundwater in and around LANL.
- Compile and summarize available information.
- Review assumptions and supporting evidence of the baseline condition of groundwater in and around LANL with resource managers.
- Develop a report summarizing findings.

Each of these steps and the information we relied upon are described in more detail in the subsequent chapters of this report.

- **Chapter 2** describes the approaches available for establishing baseline and the information sources that were relied upon for this report.
- **Chapter 3** summarizes and interprets control area (regional and site-specific) and pre-release data and information in the context of understanding baseline. This chapter includes a due diligence analysis and a discussion of broad-scale uncertainties related to groundwater baseline.
- Finally, **Chapter 4** provides our conclusions and recommendations.

Through this approach, we have found the following:

1. The background contaminant concentrations presented in the LANL *Groundwater Background Investigation Report*, *Revision 5* (GBIR) (LANL 2016a) appear to be sufficient for purposes of NRDA. However, in some cases values were not defined in the GBIR; some contaminants did not meet the GBIR's 50 percent non-detect criterion (e.g., americium-241, chromium in intermediate-depth groundwater) or were not evaluated in the GBIR since they are not naturally occurring (e.g., explosive compounds). Available information indicates that the hydrogeology of LANL is comparable to that of the surrounding areas that may be impacted by LANL discharges west of the Rio Grande. Therefore, the baseline concentrations from the GBIR can be applied to areas in and around LANL with similar hydrogeology.
2. In the case of chromium in intermediate groundwater, we recommend not affirmatively identifying a baseline concentration at this time, since a recommendation may come about as a result of the ongoing work to characterize groundwater contamination data (being conducted separately, see Section 1.1.1).
3. In the case of man-made contaminants (e.g., explosive compounds, solvents, and man-made radionuclides), we recommend assuming that they would not be present in groundwater under baseline conditions (i.e., their concentrations would be zero, absent releases from LANL).
4. Other compounds for which background values are not presented in the GBIR, however, such as tritium and uranium-235, could be present in the Española Basin due to the erosion and decay of natural deposits as well as from other releases. We include recommendations for compounds such as these in Chapter 4.

Overall, our findings suggest that groundwater in and around LANL would have chemical constituents at levels considered safe for drinking under baseline conditions and does not have undesirable characteristics (e.g., hardness). Although, some locations in the Española Basin suggest influence from anthropogenic activities (e.g., elevated chloride and nitrate) and geogenic metals (e.g., arsenic and uranium), these effects appear to be localized in areas distant from LANL and do not impact the baseline condition of groundwater in and around LANL. There is no evidence to suggest that the range of services provided by groundwater under baseline conditions would be limited in any way.[6]

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[6] As noted in Section 1.1.1, the suite of services provided by groundwater in and around LANL will be described under separate cover.

CHAPTER 2 | APPROACH AND INFORMATION SOURCES

2.1 APPROACHES TO ESTABLISHING BASELINE AT LANL

As noted in Chapter 1, there are two conventional approaches to establishing the baseline condition of a natural resource for NRDA purposes: utilizing (1) pre-release data, or (2) information from control areas. Below, we discuss the potential to use site-specific information to inform baseline at LANL according to these two approaches.

1. **Pre-release data**.

   Data related to the physical and chemical conditions of groundwater resources at LANL prior to the start of operations could be used as a basis for establishing baseline. This could include concentrations of anthropogenic and/or naturally occurring substances present in the groundwater prior to any hazardous substance release(s). At LANL, groundwater investigations began as early as 1949, and the United States Geological Survey (USGS) completed a technical report in 1964 on the geology and groundwater resources of the Los Alamos area (Griggs and Hem 1964). However, the underlying data from that time period are limited. The earliest available groundwater data obtained was from the LANL Environmental Information Management (EIM) Intellus New Mexico database (hereafter, Intellus) date back to the 1960s. It is possible that some pre-release data could be available for certain substances in certain locations, particularly if the original release dates are known. For example, data may be available from individual wells prior to their contamination by a given release. This concept is explored in greater detail in Chapter 3.

2. **Utilizing information from control areas**.

   In the absence of robust pre-release data, data collected from control areas can also be used to establish baseline. In the case of groundwater at LANL, regional data or data from areas within the vicinity that were not impacted by releases from LANL operations may be used.[7] When utilizing regional information to establish baseline, it is necessary to evaluate whether groundwater in the region is sufficiently homogenous whereby its characteristics can be used to represent the state of groundwater on the site-level. Regarding information from areas within the vicinity, LANL has undertaken numerous studies with the goal of characterizing groundwater conditions, including collecting data from sites designated as "background" locations (LANL 2016a). These data and information sources are also described in more detail in Chapter 3.

To the extent possible, our evaluation of baseline also considers factors other than the presence of hazardous substances that may have affected the condition of groundwater resources in and around LANL (e.g., population growth, climate change).

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[7] When relying on pre-release or regional information, it may be important to account for any other regional changes that may have occurred over time due to climate and other human influences.

2.2 INFORMATION SOURCES RELIED UPON

For the purpose of identifying and incorporating information from relevant sources, we identified geologic reports from USGS, LANL, and New Mexico state (or affiliated) agencies (e.g., the New Mexico Environment Department [NMED], the New Mexico Bureau of Geology & Mineral Resources). IEc also conducted several interviews with New Mexico groundwater resource experts and managers, which provided a broad understanding of the history of groundwater resources in New Mexico and at LANL. This included meetings with Pueblo de San Ildefonso staff and their attorney (5/9/17 and 6/14/17, respectively), representatives from the Los Alamos County Department of Public Utilities (7/14/17), and staff from the Utton Transboundary Resources Center (1/29/18).[8]

Groundwater in the Western United States is a precious resource. As a result, a great deal of effort is expended by a number of entities each year in studying and managing this resource. In the Española Basin specifically, major economic centers (e.g., Santa Fe) and federal facilities (e.g., LANL) drive the need to understand the quality and quantity of groundwater in this area. A number of reports exist, both related to Santa Fe's groundwater supply as well as groundwater in Los Alamos County. Site-specific information is typically more useful than regional information when attempting to establish baseline for an area. However, we provide an overview of the available regional information, at the scale of the Española Basin, to contextualize the data and information for groundwater in and around LANL.

We rely principally upon the following key reports:

- **Pre-release information:**
    - Geology and Ground-Water Resources of the Los Alamos Area, New Mexico, Geological Survey Water-Supply Paper 1753 (Griggs and Hem 1964).
- **Control area information:**
    - **Regional:**
        - Groundwater Major Elements, Trace Elements, Temperature, Noble Gas, and Carbon Isotope Data from the Española Basin, U.S. Geological Survey Scientific Investigations Report 2008-5200 (Manning 2009).
        - The impact of CO_2 on shallow groundwater chemistry: observations at a natural analog site and implications for carbon sequestration (Keating et al. 2010).
        - Water quality and hydrogeochemistry of a basin and range watershed in a semi-arid region of northern New Mexico (Linhoff et al. 2016).
    - **Site-specific:**
        - LANL Groundwater Background Investigation Report, Revision 5 (LANL 2016a).

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[8] The Utton Transboundary Resources Center at the University of New Mexico (http://uttoncenter.unm.edu/) researches and provides information to the public about water, natural resources, and environmental issues, with a particular focus on New Mexico and the Southwest. It also has expertise in water rights and adjudications.

We also rely upon groundwater data from the Intellus database. Specifically, we performed a due diligence analysis using data from background wells identified in the GBIR. This analysis is discussed in greater detail in Chapter 3.

CHAPTER 3 | BASELINE CONDITION

In this chapter, we summarize the baseline condition of groundwater in and around LANL, as interpreted from key documents and information sources. We do not attempt to reproduce a comprehensive discussion of the detailed geology present at LANL but discuss geology to the extent relevant for understanding the baseline condition of groundwater resources. We also point readers to original documents for further reading, as needed, and note that the Groundwater Characterization report (being produced under the same work plan as this report) will contain a more detailed overview of the geology in and around LANL.

3.1 REGIONAL INFORMATION

As noted in Chapter 2, pre-release information is preferred for establishing the baseline condition of a natural resource. However, to provide context for the discussion of baseline groundwater conditions in and around LANL, we first present our summary and evaluation of regional information for the Española Basin (within which LANL, Santa Fe, and Española reside). We also discuss baseline conditions of the various stratified groundwater resources found within LANL's geologic landscape, the Pajarito Plateau.

3.1.1 ESPAÑOLA BASIN

Hydrogeology of the Drainage Basin

The Española Basin is located within the central portion of the Rio Grande rift - a major continental rift zone extending from Colorado to Mexico (Exhibit 3-1). The crustal extension processes forming the Rio Grande rift began ~25 Ma (mega annums, or million years ago) (late Oligocene) and continue into the present (Manning 2009 and references therein). The Española Basin itself is bounded to the west by the Jemez Mountains and to the east by the Sangre de Cristo Mountains. These two mountain blocks originate from different geologic processes and are therefore composed of different rock types (Exhibit 3-2).[9] The Jemez Mountains are composed of Miocene to Quaternary age (23.03 - 0.012 Ma) intermediate to silicic volcanic rocks. The Sangre de Cristo Mountains are primarily composed of significantly older Proterozoic (2,500 - 541 Ma) metasedimentary rocks, such as schist and quartzite, as well as plutonic rocks, such as granites and granitic gneisses (Manning 2009). Miocene to Pliocene age (23.03 - 3.6 Ma) basin-fill sediments occur between these two mountain ranges and belong to the Santa Fe Group, a formation that spans multiple basins along the Rio Grande rift. In general, the thickness of the basin fill ranges from 0 meters (m) at the foot of the Sangre de Cristo Mountains to 2,000 - 3,000 m in the central and western part of the basin (Wilkins 1986).

The regional aquifer in the Española Basin lies predominantly in the Santa Fe Group. The Tesuque formation is a stratigraphic unit in the Santa Fe Group and is thickest at the Pajarito Plateau, where LANL is located (see text box below). The Tesuque formation is overlaid with riverine, volcanic, and pumice-

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[9] A mountain block includes all the mass composing the mountains, including vegetation, soil, bedrock (exposed and unexposed), and water (Wilson and Guan 2013).

rich units at the plateau. This interlayering of units with varying hydrogeologic characteristics results in the stratification of groundwater resources. The unsaturated (vadose) zone in the Pajarito Plateau can be up to 350 m thick compared to the rest of the basin, which ranges from 0 to 60 m (see Figure 4 of Broxton and Vaniman 2005). Within the vadose zone of the plateau and the greater Española Basin, groundwater has two modes of occurrence: (a) shallow (alluvial) groundwater (0.3 - 30 m), and (b) intermediate-depth groundwater (40 - 137 m). In the saturated zone, the regional groundwater can be found at 250 m depth (Robinson et al. 2005).

Groundwater residence time varies between aquifers and depends on the effective porosity of a given unit, which is a key determinant of groundwater flow. Groundwater dating techniques confirm that the deeper regional aquifer in the Española Basin is dominated by groundwater recharge that occurred thousands of years ago.[10]

Tesuque Formation

The Santa Fe Group contains the regional aquifer and includes the following units, in ascending order: the Tesuque Formation; older fanglomerate deposits of the Jemez volcanic field; the Totavi Lentil and older river gravels; pumice-rich volcaniclastic rocks; and the Puye Formation. On the Pajarito Plateau, these deposits interfinger with or are overlain by volcanic rocks from the nearby volcanic fields (e.g., Jemez and Cerros del Rio).

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[10] Dating techniques include evaluation of tritium and carbon-14 concentrations in groundwater. Tritium generated from cosmic rays in the atmosphere and tritium released during nuclear testing gives precipitation an elevated tritium concentration (19 picocuries per liter [pCi/L] or 6 tritium units) (Longmire et al. 2007; Manning 2009). Since tritium has a half-life of approximately 12 years, elevated tritium can suggest the presence of water with a mean age of less than 50 years. In regional aquifer wells analyzed by Manning (2009), tritium concentrations were at or below the limit of detection (0.05 tritium units) suggesting almost complete tritium decay. Additionally, carbon-14 analysis yielded mean groundwater ages of more than 5,000 years, confirming that the regional aquifer is dominated by very old water.

EXHIBIT 3-1 LOCATION OF THE ESPAÑOLA BASIN (FIGURE 1 FROM MANNING 2009)

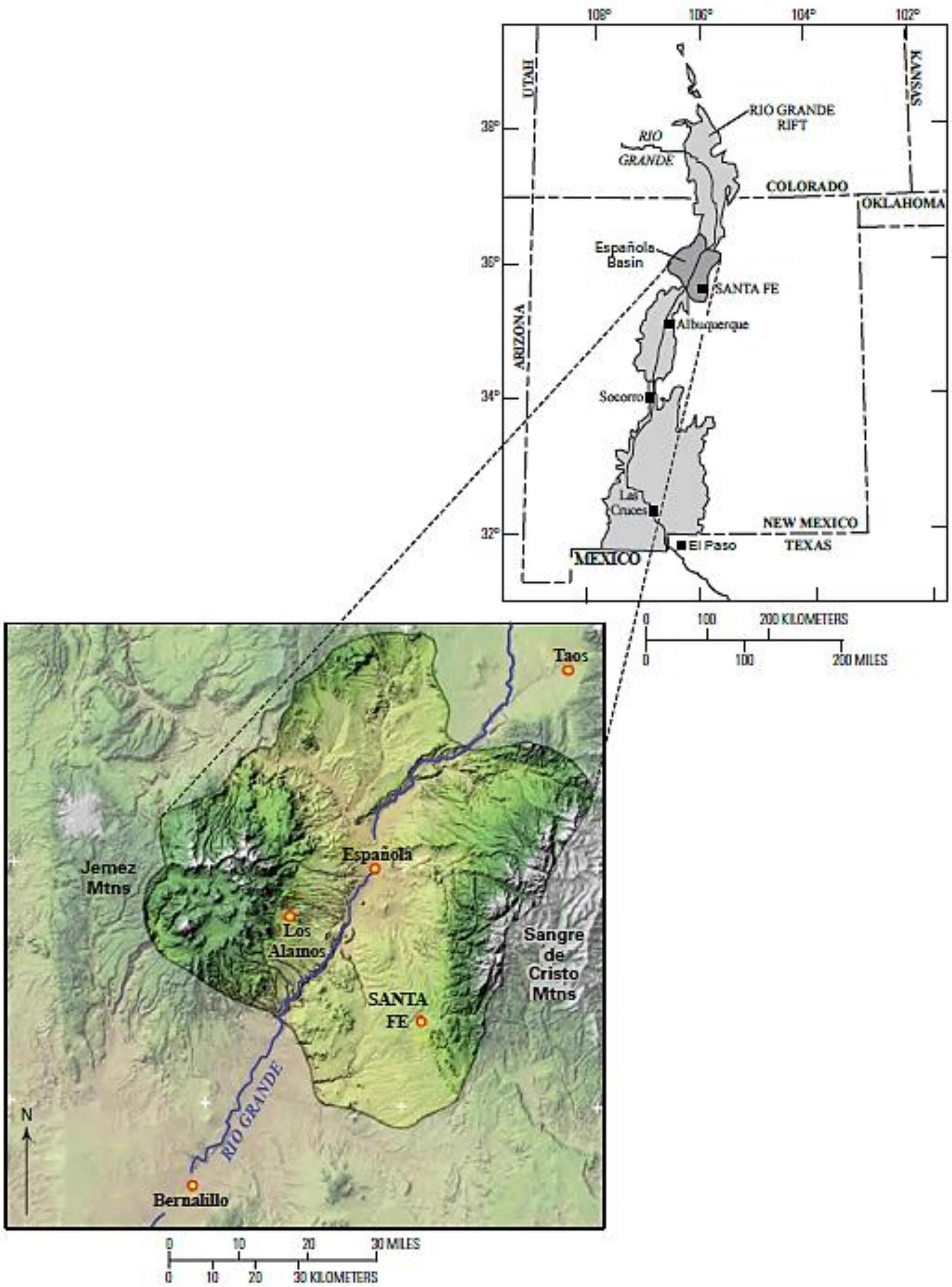
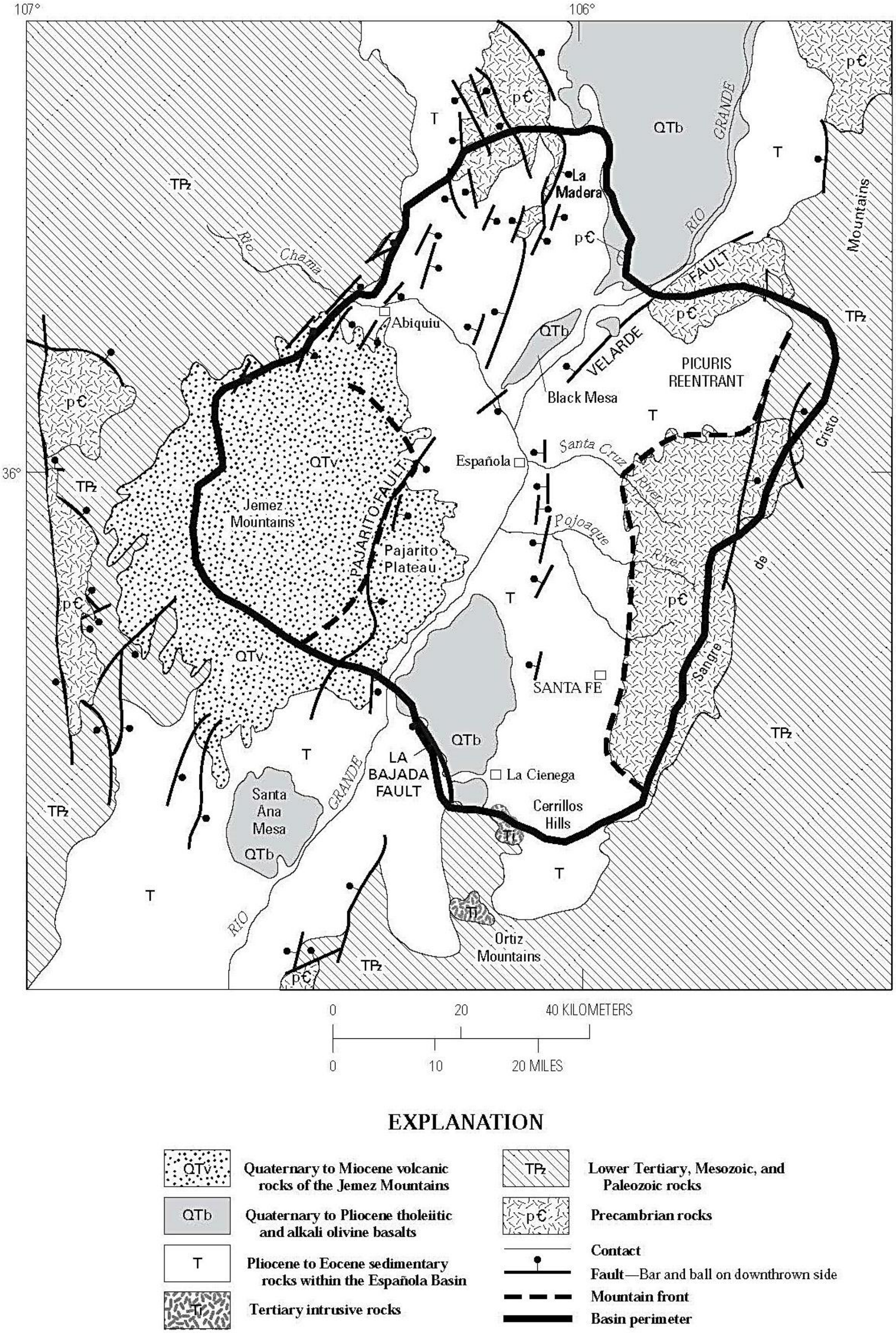


EXHIBIT 3-2 GENERALIZED GEOLOGIC MAP OF THE ESPAÑOLA BASIN AREA (FIGURE 2 OF MANNING 2009, FROM MANLEY 1979)



Groundwater Recharge in the Española Basin

Groundwater in the perimeter of the Española Basin generally flows from the mountains toward the Rio Grande, which bisects the Basin (Manning 2009) (Exhibit 3-3). Recharge occurs through mountain-front recharge, which has two components: mountain-block recharge (MBR) and stream loss recharge (Manning 2009). MBR occurs when water infiltrates in the mountain block, flows to lower elevations in the mountain-block groundwater system, and then enters the basin-fill aquifer in the subsurface. Stream loss recharge occurs when water exits the mountain block area as surface water and infiltrates near the mountain front through stream beds and arroyos cutting into the basin fill. Stream loss recharge can also occur farther from the mountain front. These two categories of stream loss (near the mountain front and far from the mountain front) can collectively be referred to as basin-fill recharge (BFR).

The proportion of groundwater recharge occurring through BFR versus MBR can influence the geochemistry of groundwater due to differences in flow paths. For example, BFR is generally more susceptible to anthropogenic impacts as compared to MBR, since the former is dependent on surface water infiltration. Understanding the relative contributions of these components in groundwater can also impact management of groundwater resources in the basin, especially decisions regarding sustainable extraction rates (Vesselinov and Keating 2002; Manning 2009). For example, MBR is usually a large component of regional groundwater in part because mountainous areas receive more precipitation than basin areas. Therefore, understanding changes in precipitation could inform recharge assumptions and influence management decisions.

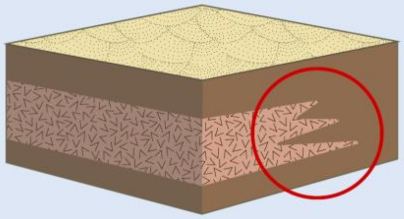
Hydrochemical Zones of the Española Basin

Based on the chemical and isotopic composition of the groundwater in the Española Basin, Manning (2009) divided the basin into four hydrochemical zones: West, Southeast, Northeast, and Central Deep (Exhibit 3-4). The Pajarito Plateau, and LANL, resides in the West zone. Differences in the chemical and isotopic composition of the groundwater in each zone most likely reflect differences in aquifer materials and associated water-rock interactions (Manning 2009). The boundaries also generally correspond with contacts between geologic units or lithosome transitions within the Tesuque Formation (see text box below). However, lateral boundaries between these zones are approximate, given the limited data coverage, and may be broad or gradational (Manning 2009).

In general, groundwater in the West zone appears to have the least water-rock interaction, as it exhibits low major ion concentrations. Southeast zone waters have intermediate concentrations of major ions, but have locally high chloride and nitrate levels that are probably due to mixing with septic effluent in Santa

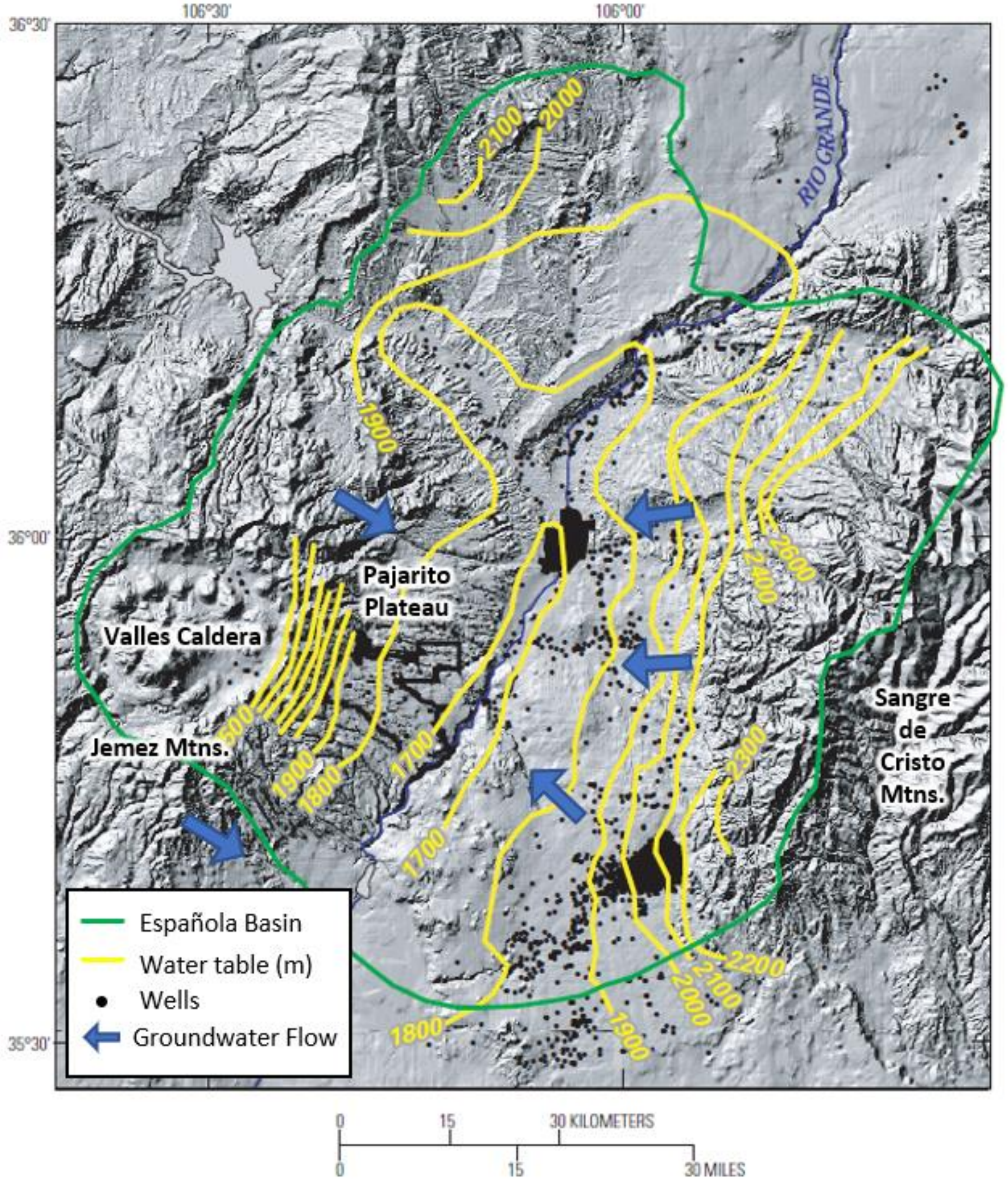
Lithosome

A lithosome is a rock mass of essentially uniform or uniformly heterogeneous lithologic character (i.e., physical characteristics), having intertonguing relationships (see illustration) in all directions with adjacent masses of different lithologic character.



Fe (Manning 2009; Linhoff et al. 2016).[11] Northeast zone waters also have intermediate ion concentrations, but high chloride and sulfate concentrations suggest the influence of upward leaking brines (Manning 2009; Keating et al. 2010). Mixing with brines is consistent with the presence of a brine-discharging well, Roberts Geyser, in the Northeast zone (Manning 2009). The chemical and isotopic composition of groundwater in the Central Deep zone suggests the most water-rock interaction among the four zones.

EXHIBIT 3-3 REGIONAL GROUNDWATER FLOW (MODIFIED FROM MANNING 2009)



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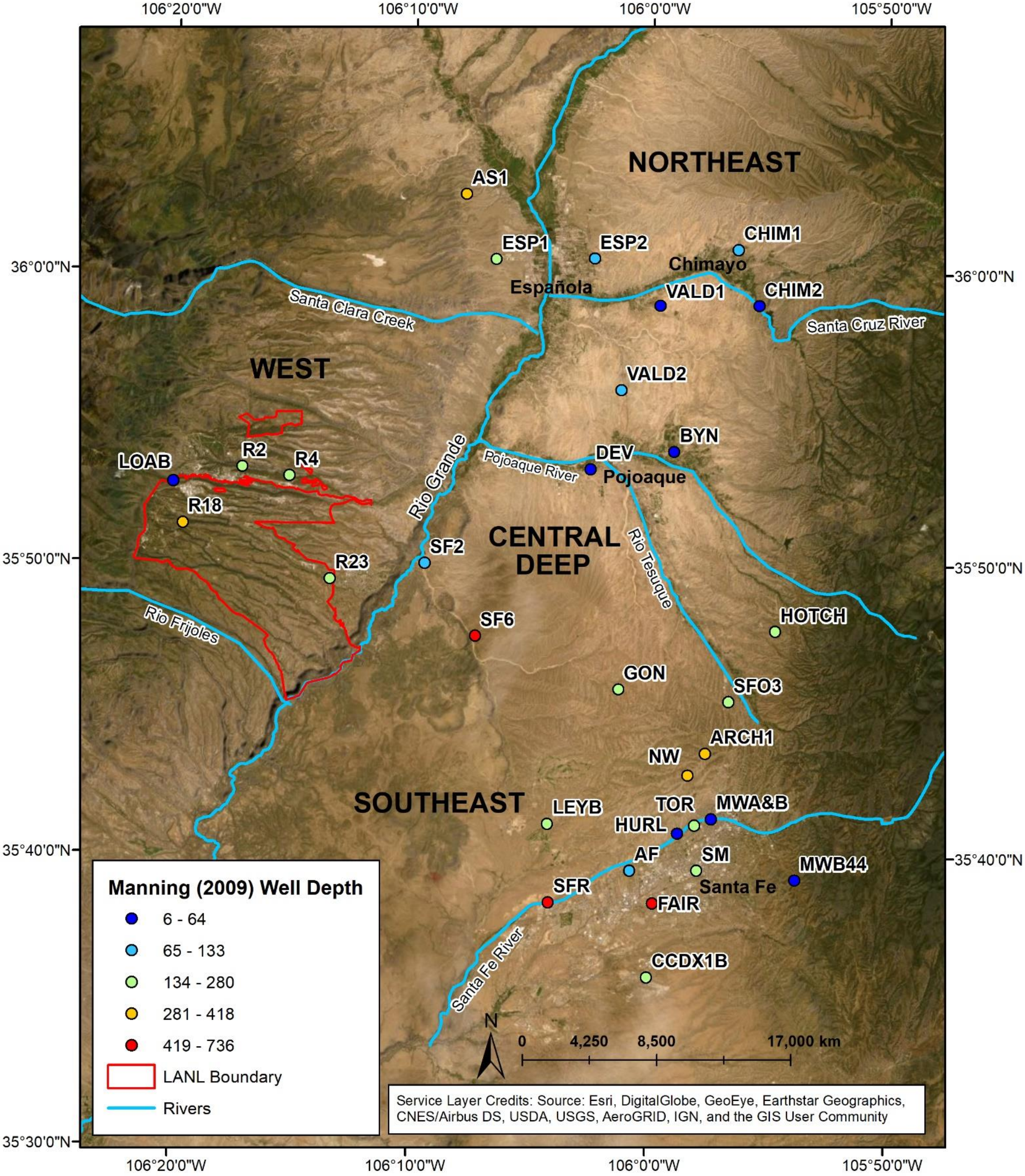
[11] "Intermediate" values are defined by the range of concentrations available in the data from this basin, as presented in Manning (2009). We refer readers to Manning (2009) for more specific concentrations of these and other compounds.

EXHIBIT 3-4 HYDROCHEMICAL ZONES (ADAPTED FROM FIGURE 38 OF MANNING 2009)



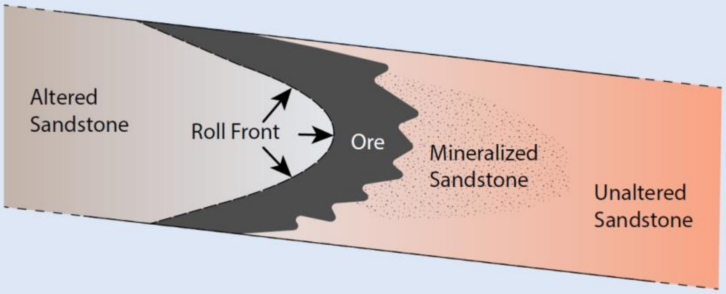
Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Uranium in the Regional Aquifer

Natural concentrations of uranium are elevated in the aerobic regional aquifer east of the Rio Grande within the Española Basin. For example, in the Northeast and Southeast zones, many wells exceed the drinking-water standard for uranium of 30 micrograms per liter (µg/L) and concentrations are as high as 1.82 milligrams per liter (mg/L) (Manning 2009; McQuillan et al. 2011; Linhoff et al. 2016). Elevated uranium in groundwater may be derived from roll-front precipitation of uranium minerals in a paleo-aquifer where reducing conditions dominated. This mineral precipitation resulted in a northwest-southeast trending belt of uranium in the basin-fill sediments (see text box below). Weathering of Precambrian rocks and ash with mineralized uranium release aqueous uranium(VI) to groundwater (McQuillan et al. 2011). Subsequently, the aqueous uranium(VI) migrates westward with the hydraulic gradient of the regional aquifer (Exhibit 3-3). Within the last 300,000 years, incision of the basin-fill sediment throughout the Española Basin by surface water flow has lowered the groundwater table and created oxidizing conditions, leaching uranium back into groundwater (McQuillan et al. 2011). Isotopic signatures of helium in the groundwater, however, suggest that uranium mineralization is not significant in the western and southern parts of the basin.[12] Additionally, low uranium concentrations (<1.0 µg/L) in regional wells of the Pajarito Plateau suggest that U mineralization in the vicinity of LANL is not significant (Manning 2009).

Roll-front deposits

Uranium "roll-front" deposits are found in some sedimentary sandstone rocks where an oxidation-reduction (redox) gradient between oxic and anoxic areas of the subsurface occurs, often as the result of groundwater mixing.



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[12] Uranium in aquifer host sediments can produce helium (He) as a result of radioactive decay (crustal helium). Additionally, He can diffuse to the aquifer from the mantle. Concentrations of He are high throughout the Española Basin and are probably caused by *in situ* production from locally high concentrations of uranium-bearing minerals within the Tesuque Formation or by upward transport of mantle-sourced He, possibly enhanced by basement piercing faults. In the western and southern part of the basin, $^{3}He/^{4}He$ isotopic signatures suggest mantle-sourced He (Manning 2009).

Drinking Water Quality of Groundwater in Española Basin

Regional groundwater wells in the Española Basin have chemical constituents that do not exceed United States Environmental Protection Agency (EPA) Maximum Contaminant Levels (MCLs) except for some with elevated arsenic and nitrate (EPA 2009a; Manning 2009). Those exceeding the arsenic MCL of 0.01 parts per million (ppm) were AS1, SF6 and SFR located in the Northeast, Central and Southeast geochemical zones respectively (Exhibit 3-4). Changes in pH, redox potential and weathering of volcanic sediments may be responsible for elevated arsenic at these sites (Linhoff et al. 2016). Nitrate concentrations were 24 ppm in ARCH1 and exceeded the MCL (10 ppm) by a factor of two. This was the only deep well in the dataset of Manning (2009) that showed some anomalies that may be attributed to anthropogenic sources.

The alluvial and intermediate wells of the Española Basin had chemical constituents below MCLs except for arsenic, nitrate, and uranium. Two wells (ESP1 and ESP2) located near the city of Española exceeded the arsenic MCL with concentrations ranging between 0.14 - 0.17 ppm. For nitrate, five wells exceeded the MCL and were located near the cities of Santa Fe, Pojoaque, and Chimayo. These wells may be influenced by septic effluent and sewage discharge into the shallow groundwater (Manning 2009). Lastly, three wells located in the south and Northeast zones had uranium concentrations ranging between 0.05 - 0.09 ppm, exceeding the uranium MCL of 0.03 ppm. This elevated uranium is consistent with weathering of roll front uranium deposits in the eastern section of the basin (Linhoff et al. 2016).

The tritium composition of alluvial and intermediate groundwater shows this is “modern water” (post-1950s; see footnote 10, above). These samples most likely reflect BFR in the basin. Most striking is the higher chloride concentration of alluvial and intermediate groundwater compared to the regional groundwater. In some cases, elevated chloride corresponded with elevated nitrate. Manning (2009) suggests that these shallower wells may have a non-trivial influence from anthropogenic contamination either from LANL or septic effluent.

The regional aquifer in the Santa Fe Group and specifically the Tesuque Formation, has been shown to be a suitable drinking water source and has served as the principal aquifer throughout the Española Basin. Local geochemical variations in groundwater occur due to the flow paths that are followed and the rock types encountered. Anthropogenic impacts to groundwater have been detected in major population areas (e.g., near Santa Fe and the Pojoaque River corridor) and occur through BFR. As noted above, regional groundwater may also be affected by an influx of brines and weathering of uranium-bearing minerals at some locations in the Northeast and Southeast zone (Keating et al. 2010; McQuillan et al. 2011; Linhoff et al. 2016). These processes have been shown to elevate toxic metal concentrations above EPA MCLs (Linhoff et al. 2016).

3.1.2 PAJARITO PLATEAU

The Pajarito Plateau is in north-central New Mexico between the Rio Grande and the Jemez Mountains (Exhibit 3-2). This area of about 225 square kilometers includes LANL, the city of White Rock, and Pueblo communities (Broxton and Vaniman 2005). The regional aquifer is hosted by the Tesuque formation of the Santa Fe group. The over layering of riverine and volcanic units above the Tesuque formation result in a division of groundwater resources among three primary modes; shallow (alluvial) groundwater (0.3 - 30 m), intermediate-depth groundwater (40 - 137 m), and regional groundwater at a depth greater than 250 m (Robinson et al. 2005). The groundwater in the unsaturated zone (alluvial and intermediate) is discontinuous and occurs as lenses above impermeable horizons in the stratigraphic profile. The thickness and spatial extent of these lenses is strongly dependent on seasonal variations in snowmelt and storm runoff (Broxton and Vaniman 2005).

Groundwater from the Pajarito Plateau follows the hydraulic gradient flowing eastward towards the Rio Grande (Exhibit 3-3). BFR is a significant recharge process for alluvial, intermediate, and the top 30 m of regional groundwater in the plateau (Manning 2009). This process dominates such that LANL contamination has been detected in some monitoring wells that extract water from alluvial and intermediate groundwaters (Rogers et al. 1996). However, MBR can dominate regional aquifer recharge at greater depths (Manning 2009; Kwicklis et al. 2005). Understanding the contribution to the regional aquifer made by infiltration in the Jemez Mountains west of LANL versus infiltration from streams in the canyons traversing LANL helps in determining the susceptibility of the regional aquifer to LANL-related contaminants (Kwicklis et al. 2005).

Tritium Contamination from LANL

As noted above, the Pajarito Plateau is in the West hydrochemical zone characterized by the lowest major ion concentrations resulting from limited mineral dissolution and the absence of naturally occurring uranium (Manning 2009). Nonetheless, LANL effluents enriched in tritium and other contaminants have affected some monitoring wells in the Pajarito Plateau (Longmire et al. 2007). For example, LANL released significant amounts of tritium or tritiated water to the environment through several long-term discharges starting in the mid-1940s and continuing to the mid-2000s. The primary release sites of tritium at LANL include technical area (TA) 01, TA-21, TA-50, and TA-45. Several hundred to several thousand pCi/L of LANL-derived tritium occur in intermediate groundwater throughout the laboratory (Longmire et al. 2007). However, only well MCOBT-4.4 in the intermediate groundwater of Mortandad Canyon exceeded the EPA MCL of 20,000 pCi/L (Intellus New Mexico - Los Alamos Area Environmental Data 2020).[13] MCOBT-4.4 is near the Ten Site Canyon confluence and the well is finished beneath the section of maximum contamination in the vadose zone (LA-UR-06-6752). The regional groundwater of the Pajarito Plateau has also exceeded the EPA MCL, but only in samples collected from four test wells that were analyzed from 1973 to 1982 (LANL Intellus Database 2020). However, the groundwater of the regional aquifer is primarily tritium dead and sub-modern (Longmire et al. 2007).

3.2 PRE-RELEASE DATA AND INFORMATION

Groundwater resources are influenced by lithology, as well as factors such as precipitation and climate. The USGS report by Griggs and Hem (1964) is the most significant early publication of groundwater conditions in the area surrounding LANL. It offers a summary of the geology in and around LANL based on exploration efforts in the West between 1850 and 1875 and several reports from the first half of the 20th century. Griggs and Hem (1964) details the layers of volcanic and sedimentary rock that underlie LANL, noting that the deeper sedimentary rock, and namely the Santa Fe Group, is the principal water-bearing aquifer in the region. Readers are referred to Griggs and Hem (1964) for a more detailed discussion of the various rock layers and groundwater resources contained within them.

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[13] The Intellus New Mexico - Los Alamos Area Environmental Data was accessed on June 3, 2020. https://www.intellusnm.com/

During World War II and the Manhattan Project, the residents of LANL relied on springs and perennial streams as sources of drinking water. The first six deep wells were completed at LANL after World War II, between 1946 and 1948. The USGS subsequently began studying groundwater resources, as well as the fate and transport of discharged wastes, by around 1949. Griggs and Hem (1964) present a table of the recorded wells considered for their study, which indicates a total of 38 wells that had been drilled in the area between 1946 and 1951 (see Appendix A).

The authors note at the outset of the report that "*The dissolved-solids content of ground and surface waters in the Valles Caldera area is less than 150 ppm (parts per million) and chemically the waters are suitable for most uses*," "*Wells in Los Alamos and Guaje Canyon tapping aquifers in the Santa Fe Group yield water containing less than 250 ppm of dissolved solids. The fluoride content of the water from most of these wells is less than 1.0 ppm*" (noting an exception of one well), and "*Chemically the water from these wells is suitable for a public water supply*" (Griggs and Hem 1964, p. 2). In comparison to current MCL standards, the fluoride and nitrate concentrations of these wells are below the MCLs of 4 and 10 ppm, respectively. The low to moderate concentrations of dissolved solids, coupled with the concentrations of other dissolved minerals, suggest that the water from the Los Alamos Canyon well field was within acceptable limits for domestic and most other uses[14]. Furthermore, the quality of water from wells sampled more than once over the investigation period changed little over time (i.e., no definite pattern was apparent). Water from the Buckman well was similar in quality to that of the Los Alamos Canyon well field, while groundwater from Guaje Canyon was slightly to moderately hard (37 - 66 ppm). More recent reports also corroborate the quality of groundwater in this area. For example, Broxton and Vaniman (2005) note that "*The Pajarito Plateau is an important source of abundant potable groundwater for Los Alamos National Laboratory (LANL) and the communities of Los Alamos and White Rock*" and "*Water quality is typically good, but the effects of LANL operations can be detected in parts of the groundwater system.*"

In summary, pre-release data like Griggs and Hem (1964) is not adequate for baseline determination because of the limited suite of elements measured. However, there is no indication that groundwater quality or quantity in or around LANL was infringed upon by naturally occurring constituents or regional groundwater issues. Groundwater (and surface water) sources have supplied the Los Alamos community for over 70 years (Griggs and Hem 1964, Broxton and Vaniman 2005, DBSA 2018). Since the regional analysis showed some heterogeneities among zones in the Española Basin, determining baseline based on information from the entire basin is inappropriate. Additionally, pre-release data do not supply a robust quantitative description of contaminants for the purposes of defining the baseline condition of groundwater in the vicinity of LANL. Therefore, we proceed with evaluating the site-specific control area approach.

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[14] Griggs and Hem (1964) mention that the high content of silica of some groundwater wells in their study was objectionable to some industrial uses, such as steam-power installation. They also note that, under some conditions, the water from this area may be corrosive to metal. Additionally, the wells had fluoride concentrations ranging between 0.2 and 3.6 mg/L. This range exceeds the recommended drinking water level of 0.7 mg/L (CDC 2019). However, groundwater wells do not exceed the EPA fluoride MCL of 4 mg/L. Despite high fluoride concentrations, groundwater wells reported in Griggs and Hem (1964) are adequate sources of drinking water and would not be limited for use.

3.3 CONTROL AREAS

Control (i.e., reference or background) areas are locations near LANL that have similar physical (i.e., relevant aquifer type/depth) and chemical conditions (i.e., water geochemistry), but which are unaffected by hazardous releases from LANL operations. Relevant to this, DOE and NMED have conducted background investigations at LANL to understand what groundwater conditions would exist absent contamination, which are described below.

3.3.1 LANL GROUNDWATER BACKGROUND INVESTIGATION

As part of groundwater monitoring at LANL, DOE has collected samples from background wells to establish background chemical levels. Though updated over time, DOE last summarized this information in the 2016 GBIR (LANL 2016a).[15]

The 2016 GBIR provides concentrations of naturally occurring constituents in the intermediate and regional groundwater systems underneath the Pajarito Plateau that are presented for use as background levels. The report defines background as "*natural groundwaters discharged by springs or penetrated by wells that have not been impacted by Laboratory [LANL] effluent or other municipal or industrial activities and that are representative of groundwater discharging from its respective aquifer material*" (LANL 2016a). As noted above, the DOI NRDA regulations define baseline as "*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*" (C.F.R. 43 § 11.14(e)). The GBIR's definition of background therefore is very similar to, but not exactly the same as, the NRDA definition of baseline.

The process for determining the groundwater background chemical levels presented in the GBIR included three steps, paraphrased below (LANL 2016a):

- **Phase I, Selection of Background Locations:** To identify background locations for the regional aquifer, LANL personnel followed a process outlined in the groundwater background implementation plan that relied on a review of well-water chemistry to identify LANL effluent impacted and non-impacted wells (LANL 2016b). Initial locations for intermediate groundwater were based on the Interim Plan monitoring network and agreed upon by NMED during project technical meetings. Chloride and tritium data, chemical tracers of anthropogenic contamination, from selected wells were then extracted from Intellus and compared to criteria (3 mg/L chloride and 2 pCi/L tritium) established in the groundwater background implementation plan (LANL 2016b). Wells with concentrations below these levels were understood to be unaffected by anthropogenic contamination. Based on the chloride and tritium data and other information, background wells were then agreed upon between LANL and NMED (Exhibit 3-5). Upon finalizing background locations, a larger dataset (i.e., a larger suite of analytes covering the period from January 2010 to December 2015) for these wells was extracted from Intellus.

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[15] Previous versions of this report exist and the need for an additional revision was identified by NMED in 2015. In short, past studies had used analytical methods appropriate for groundwater monitoring (as specified by a 2005 Consent Order), but that were not of sufficient resolution for establishing accurate and precise background concentrations. This is evidenced by a substantial number of reported data points having concentrations of some metals below detection limits. NMED conducted a study using high resolution inductively coupled plasma mass spectrometry (HRMS) to better quantify dissolved metals in groundwater. These results were presented to DOE and a series of technical discussions ensued, which resulted in a groundwater background implementation plan ("*Implementation Plan for the New Mexico Environment Department's New Groundwater Background Values for the Regional Aquifer*") and the resulting 2016 version of the GBIR (LANL 2016a and 2016b).

Consistent with the implementation plan (LANL 2016b), only samples collected by LANL were used (additional details provided in footnote 15). This was done to "capture the most recent data from background locations and also to incorporate recent improvements in analytical detection limits" (LANL 2016b, p. 2). Prior to analysis, a number of data-preparation/clean-up steps were performed (e.g., only validated data were used[16]; borehole data were removed; field duplicates, unmarked duplicates, and results from certain laboratories were removed; etc.), resulting in the removal of some data deemed inappropriate for use.

- **Phase II, Data Exploration and Analysis:** Temporal trends and outliers were specifically evaluated using plots and statistical tests. In collaboration with NMED, no temporal trends were identified. Outliers were analyzed using plots and statistical tests.[17]
- **Phase III, Statistical Calculation of upper tolerance limits (UTLs)[18]:** UTLs were calculated using EPA's ProUCL software, for constituents with at least 50 percent of results detected.[19] These constituent-specific calculated UTLs are the actual background values presented in the report.

Included in the GBIR are the statistical results for 59 constituents, including 29 metals, 14 general chemistry parameters, 13 radionuclides, and gross-alpha, -beta, and -gamma radiological measurements (Exhibit 3-6 provides the complete list of constituents). Regarding anthropogenic organic compounds (e.g., trichloroethene, HE compounds, PCBs, and other volatile and semivolatile compounds), the report

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[16] All sampling, data review, and data package validations conducted since 2000 have used standard operating procedures (SOPs) that are part of a quality assurance (QA) program. The program and procedures are available at the following location: http://www.lanl.gov/environment/plans-procedures.php. Data validation was conducted in two stages. The first was done by the analytical laboratory measuring the samples. The laboratory assigned qualifiers to the data to indicate the quality of the analytical results. The laboratory also submitted field quality control (QC) samples to test the sampling and analytical process and to spot-check for analytical problems. The second stage of data validation is known as "secondary validation" and was conducted by an independent contractor prior to March 2012. Since then, validation has been conducted by an automated process. The manual process included reviewing data quality and the documentation's correctness and completeness; verifying that holding times were met; and ensuring that analytical laboratory QC measures were applied, documented, and within contract requirements (LANL 2016a). The auto-validation process ensures that the electronic data deliverable from the laboratory contains all the required fields; verifies that the results of all QC checks and procedures are within criteria limits; and applies specific qualifiers and reason codes. Because the background locations have sufficient validated data under the current monitoring program, older data (i.e., pre-2010) were not used in the data evaluation.

[17] The statistical methods for outlier evaluation followed those described in Chapter 12 of the EPA Unified Guidance (EPA 2009b). This involved reviewing the distribution of detected analytes using probability plots and box plots as well as conducting statistical tests using ProUCL Version 5.1 (EPA 2015) (either Dixon's Test or Rosner's Test). Any outliers that were identified using these tests were removed from the dataset.

[18] The UTL is defined as a confidence limit on a percentile of the population (as opposed to a confidence limit on the mean). In the case of LANL, different UTLs were used depending on the underlying distribution of the data (i.e., normal, lognormal, etc.). Generally, the UTLs corresponded to 95 percent UTLs with 95 percent coverage, meaning that 95 percent of the population of data would be expected to be less than the selected UTL (with 95 percent confidence).

[19] UTLs were calculated following the EPA Unified Guidance (Chapter 17; EPA 2009b) as well as ProUCL technical guidance (see: https://www.epa.gov/sites/production/files/2016-05/documents/proucl_5.1_user-guide.pdf). ProUCL was used to calculate UTLs for constituents that were detected greater than or equal to 50 percent of the time with greater than or equal to ten sample results. The following descriptive statistics were also calculated for the data: count, detections (count, minimum, maximum), nondetections (count, minimum, maximum), 25th percentile, median, mean, 75th percentile, 95th percentile; along with the UTL.

clearly states that they are "*not included as part of this investigation because they are introduced and are not indicative of background or natural values.*" Analytical methods used to measure the constituents of interest are presented in Exhibit 3-7.

Recommended background values were ultimately developed for 22 constituents in intermediate groundwater and 23 constituents for the regional aquifer (Exhibit 3-8 and 3-9). The remaining 37 constituents in intermediate groundwater and 26 constituents in the regional aquifer had non-detected values at greater than 50 percent. Thus, UTLs were not calculated and no background values recommended for those constituents.

EXHIBIT 3-5 BACKGROUND WELL LOCATIONS IN AND NEAR LANL (FIGURE MODIFIED FROM LANL 2016a)

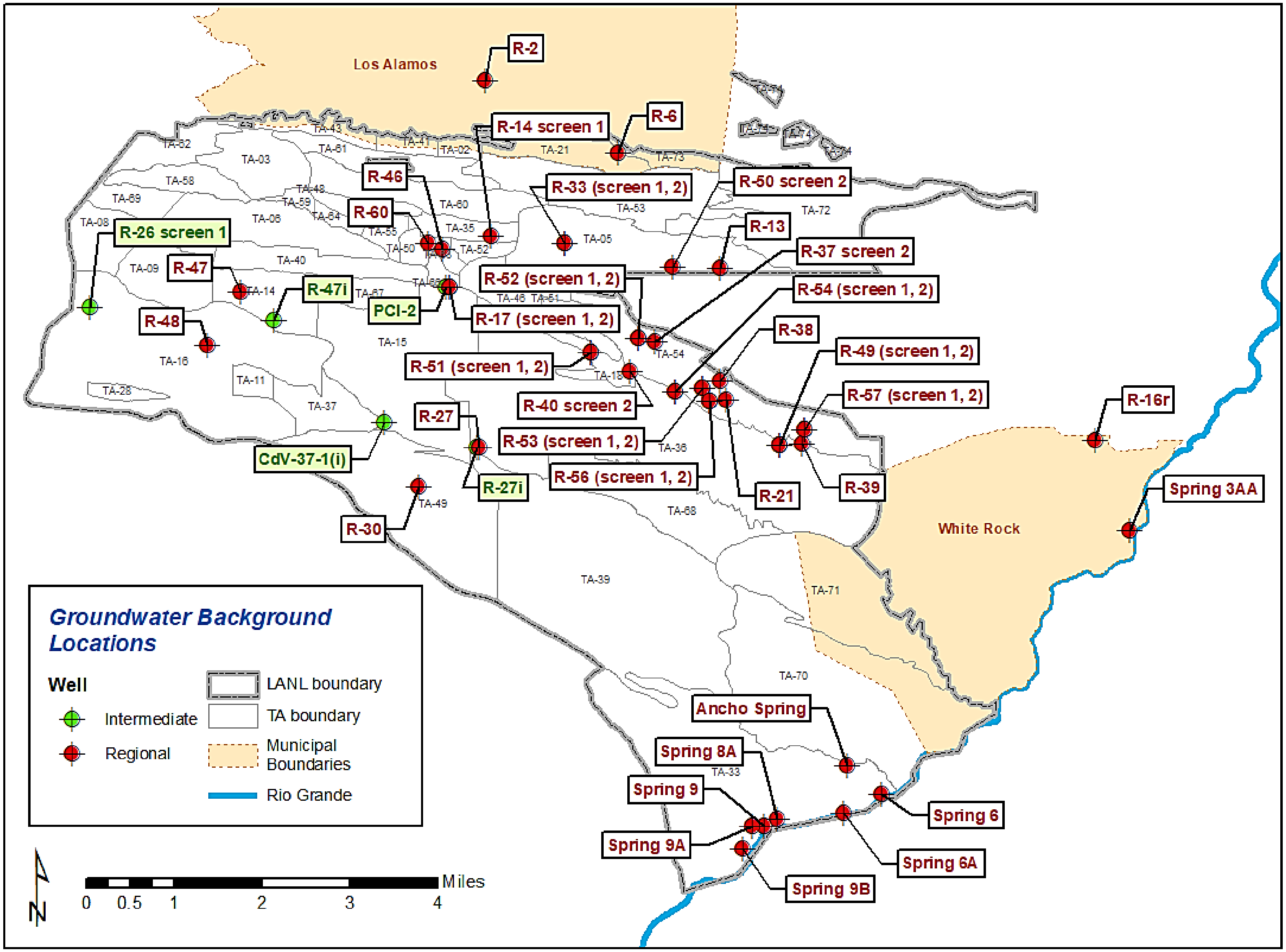

EXHIBIT 3-6 ANALYTES AND FIELD PARAMETERS (TABLE 3.4-1 FROM LANL 2016a)

METALS
Aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, calcium, chromium, cobalt, copper, iron, lead, magnesium, manganese, mercury, molybdenum, nickel, potassium, selenium, silicon dioxide, silver, sodium, strontium, thallium, tin, uranium, vanadium, zinc
RADIONUCLIDES
Americium-241, cesium-137, cobalt-60, gross-alpha radiation, gross-beta radiation, gross-gamma radiation, neptunium-237, plutonium-238, plutonium-239/240, potassium-40, sodium-22, strontium-90, tritium, uranium-234, uranium-235/236, uranium-238
GENERAL CHEMISTRY PARAMETERS
Alkalinity (CO3+HCO3), ammonia as N, bromide, chloride, cyanide (total), fluoride, hardness, nitrate-nitrite as N, perchlorate, sulfate, Total Dissolved Solids (TDS), total Kjeldahl nitrogen, total organic carbon, total phosphate as P
FIELD PARAMETERS
Dissolved Oxygen (DO), specific conductance, pH, temperature

EXHIBIT 3-7 ANALYTES, FIELD PREPARATION, AND ANALYTICAL METHODS USED BY CONTRACT LABORATORIES (TABLE 3.4-2 FROM LANL 2016a)

ANALYTICAL SUITE	ANALYTICAL GROUP	FIELD PREP	ANALYTICAL METHOD	ANALYTES
Metals	WSP-All Metals	Filtered	EPA:245.2	Mercury
Metals	WSP-All Metals	Filtered	SM:A2340B	Hardness
Metals	WSP-All Metals	Filtered	SW-846:6010C	Aluminum, barium, beryllium, calcium, cobalt, copper, iron, magnesium, manganese, potassium, silicon dioxide, sodium, strontium, tin, uranium, vanadium, zinc
Metals	WSP-All Metals	Filtered	SW-846:6020	Antimony, arsenic, boron, cadmium, chromium, lead, molybdenum, nickel, silver, thallium, uranium
Radionuclides	WSP-GrossA/B	Nonfiltered	EPA:900	Gross alpha, gross beta
Radionuclides	WSP-RAD	Nonfiltered	EPA:901.1	Cesium-137, cobalt-60, gross gamma, neptunium-237, potassium-40, sodium-22
Radionuclides	WSP-RAD	Nonfiltered	EPA:905.0	Stronium-90
Radionuclides	WSP-RAD	Nonfiltered	HASL-300:AM-241	Americium-241
Radionuclides	WSP-RAD	Nonfiltered	HASL-300:ISOPU	Plutonium-238, plutonium-239/240
Radionuclides	WSP-RAD	Nonfiltered	HASL-300:ISOU	Uranium-234, uranium-235/236, uranium-238
Tritium	WSP-H-3	Nonfiltered	EPA:906.0	Tritium
Low-Level Tritium	WSP-LL-H-3	Nonfiltered	Generic:Low_Level_Tritium	Tritium
General Inorganics	WSP-GENINORG+Perchlorate	Filtered	EPA:160.1	Total dissolved solids
General Inorganics	WSP-GENINORG+Perchlorate	Filtered	EPA:300.0	Bromide, chloride, fluoride, sulfate
General Inorganics	WSP-GENINORG+Perchlorate	Filtered	EPA:310.1	Alkalinity-CO3, alkalinity-CO3+HCO3
General Inorganics	WSP-GENINORG+Perchlorate	Filtered	SW-846:6010C	Silicon dioxide
General Inorganics	WSP-GENINORG+Perchlorate	Filtered	SW-846:6850	Perchlorate
General Inorganics	WSP-NH3+NO3/NO2+PO4	Filtered	EPA:350.1	Ammonia as nitrogen
General Inorganics	WSP-NH3+NO3/NO2+PO4	Filtered	EPA:353.2	Nitrate-nitrite as nitrogen
General Inorganics	WSP-NH3+NO3/NO2+PO4	Filtered	EPA:365.4	Total phosphate as phosphorus
General Inorganics	WSP-TKN+TOC	Nonfiltered	EPA:351.2	Total Kjeldahl nitrogen
General Inorganics	WSP-TKN+TOC	Nonfiltered	SW-846:9060	Total organic carbon
General Inorganics	WSP-CN(T)	Nonfiltered	EPA:335.4	Cyanide (Total)

EXHIBIT 3-8 SUMMARY OF UTLS FOR INTERMEDIATE GROUNDWATER (MODIFIED FROM TABLE 4.2-3 FROM LANL 2016a)

ANALYTE	UNIT	FILTRATION[†]	NUMBER OF OBSERVATIONS	NUMBER OF DETECTS	PERCENT DETECTS	NUMBER OF NON-DETECTS	DISTRIBUTION	UTL	UTL METHOD
Alkalinity-CO3+HCO3	mg/L	F	49	49	100	0	Normal	62.0	0.95 UTL with 0.95 Coverage
Barium	µg/L	F	49	48	97.96	1	Normal	13.5	0.95 KM UTL with 0.95 Coverage
Calcium	mg/L	F	50	50	100	0	Normal	10.7	0.95 UTL with 0.95 Coverage
Chloride	mg/L	F	50	50	100	0	Nonparametric	3.11	0.95 Percentile Bootstrap UTL with 0.95 Coverage
Fluoride	mg/L	F	51	51	100	0	Normal	0.234	0.95 UTL with 0.95 Coverage
Hardness	mg/L	F	50	50	100	0	Nonparametric	37.8	0.95 Percentile Bootstrap UTL with 0.95 Coverage
Magnesium	mg/L	F	50	50	100	0	Nonparametric	3.14	0.95 Percentile Bootstrap UTL with 0.95 Coverage
Molybdenum	µg/L	F	48	46	95.83	2	Nonparametric	2.9	0.95 UTL with 0.95 Coverage
Nickel	µg/L	F	48	37	77.08	11	Gamma	3.65	0.95 HW Approx. Gamma UTL with 0.95 Coverage (with KMb estimates)
Nitrate-Nitrite as Nitrogen	mg/L	F	50	47	94	3	Nonparametric	0.459	0.95 UTL with 0.95 Coverage
Perchlorate	µg/L	F	46	46	100	0	Nonparametric	0.27	0.95 Percentile Bootstrap UTL with 0.95 Coverage
Potassium	mg/L	F	50	49	98	1	Nonparametric	2.35	0.95 UTL with 0.95 Coverage
Silicon Dioxide	mg/L	F	51	51	100	0	Normal	75.0	0.95 UTL with 0.95 Coverage
Sodium	mg/L	F	49	49	100	0	Gamma	18.2	0.95 HW Approx. Gamma UTL with 0.95 Coverage
Strontium	µg/L	F	49	49	100	0	Nonparametric	59.6	0.95 Percentile Bootstrap UTL with 0.95 Coverage
Sulfate	mg/L	F	47	46	97.87	1	Nonparametric	7.1	0.95 UTL with 0.95 Coverage
Total Dissolved Solids	mg/L	F	51	51	100	0	Normal	152	0.95 UTL with 0.95 Coverage
Total Organic Carbon	mg/L	F	25	21	84	4	Normal	1.35	0.95 KM UTL with 0.95 Coverage
Uranium	µg/L	F	48	41	85.42	7	Gamma	0.992	0.95 HW Approx. Gamma UTL with 0.95 Coverage (with KM estimates)
Uranium-234	pCi/L	NF	17	17	100	0	Normal	0.477	0.95 UTL with 0.95 Coverage
Uranium-238	pCi/L	NF	17	17	100	0	Normal	0.201	0.95 UTL with 0.95 Coverage
Vanadium	µg/L	F	50	38	76	12	Nonparametric	9.29	0.95 UTL with 0.95 Coverage

F = Filtered; KM = Kaplan-Meier method; NF = Nonfiltered.

[†] It is currently unclear how the filtered concentrations compare to screening level values used by LANL in other contexts of their groundwater work.

EXHIBIT 3-9 SUMMARY OF UTLS FOR REGIONAL AQUIFER (MODIFIED FROM TABLE 4.2-4 FROM LANL 2016a)

ANALYTE	UNIT	FILTRATION†	NUMBER OF OBSERVATIONS	NUMBER OF DETECTS	PERCENT DETECTS	NUMBER OF NON-DETECTS	DISTRIBUTION	UTL	UTL METHOD
Alkalinity-CO3+HCO3	mg/L	F	418	416	99.52	2	Nonparametric	72.9	0.95 UTL with 0.95 Coverage
Barium	µg/L	F	410	409	99.76	1	Nonparametric	38.1	0.95 UTL with 0.95 Coverage
Calcium	mg/L	F	410	410	100	0	Nonparametric	17.03	0.95 Percentile Bootstrap UTL with 0.95 Coverage
Chloride	mg/L	F	424	424	100	0	Nonparametric	2.70	0.95 Percentile Bootstrap UTL with 0.95 Coverage
Chromium	µg/L	F	412	293	71.12	119	Nonparametric	7.48	0.95 UTL with 0.95 Coverage
Fluoride	mg/L	F	423	423	100	0	Normal	0.377	0.95 UTL with 0.95 Coverage
Hardness	mg/L	F	408	407	99.75	1	Lognormal	67.1	0.95 KM UTL (Lognormal) 0.95 Coverage
Magnesium	mg/L	F	410	410	100	0	Nonparametric	4.18	0.95 Percentile Bootstrap UTL with 0.95 Coverage
Molybdenum	µg/L	F	405	376	92.84	29	Nonparametric	2.5	0.95 UTL with 0.95 Coverage
Nickel	µg/L	F	405	249	61.48	156	Nonparametric	2.9	0.95 UTL with 0.95 Coverage
Nitrate-Nitrite as Nitrogen	mg/L	F	423	406	95.98	17	Nonparametric	0.769	0.95 UTL with 0.95 Coverage
Perchlorate	µg/L	F	398	396	99.5	2	Normal	0.414	0.95 KM UTL with 0.95 Coverage
Potassium	mg/L	F	410	410	100	0	Nonparametric	2.39	0.95 Percentile Bootstrap UTL with 0.95 Coverage
Silicon Dioxide	mg/L	F	422	419	99.29	3	Nonparametric	81.9	0.95 UTL with 0.95 Coverage
Sodium	mg/L	F	405	405	100	0	Nonparametric	16.0	0.95 Percentile Bootstrap UTL with 0.95 Coverage
Strontium	µg/L	F	410	410	100	0	Nonparametric	157	0.95 Percentile Bootstrap UTL with 0.95 Coverage
Sulfate	mg/L	F	420	420	100	0	Nonparametric	4.59	0.95 Percentile Bootstrap UTL with 0.95 Coverage
Total Dissolved Solids	mg/L	F	424	422	99.53	2	Nonparametric	161	0.95 UTL with 0.95 Coverage
Total Organic Carbon	mg/L	F	224	147	65.62	77	Nonparametric	1.08	0.95 UTL with 0.95 Coverage
Uranium	µg/L	F	408	390	95.59	18	Nonparametric	1.19	0.95 UTL with 0.95 Coverage
Uranium-234	pCi/L	NF	180	180	100	0	Nonparametric	0.715	0.95 Percentile Bootstrap UTL with 0.95 Coverage
Uranium-238	pCi/L	NF	178	171	96.07	7	Nonparametric	0.336	0.95 UTL with 0.95 Coverage
Vanadium	µg/L	F	407	398	97.79	9	Nonparametric	11.4	0.95 UTL with 0.95 Coverage

F = Filtered; KM = Kaplan-Meier method; NF = Nonfiltered.

† It is currently unclear how the filtered concentrations compare to screening level values used by LANL in other contexts of their groundwater work.

3.3.2 DUE DILIGENCE ANALYSIS OF THE GBIR

The methodological approach presented in the GBIR relies on data from the Intellus database and applies a filtering protocol that removes samples that may be affected by LANL releases, based on the concentrations of chloride and tritium. The background values presented appear consistent with values that could be considered baseline contaminant concentrations for purposes of NRDA. However, to independently evaluate the UTLs calculated in the GBIR we performed a due diligence analysis of the report and its underlying data (Exhibit 3-8 and Exhibit 3-9). The purpose of our analysis was to illustrate the variability in the raw data relative to the final calculated UTLs. Our approach, and the resulting figures provided in Appendix B, provide for visual evaluation of the underlying data by condensing the constituent data from each well into point measures that highlight variability. Our analysis does not provide a quantitative or statistical evaluation of the data.

Once the relevant Intellus data were identified and queried, we calculated quotients of the maximum and average concentrations for each constituent from each location by dividing each of these values by their respective UTLs.[20] We then plotted the quotients graphically, summarized them in tables, and mapped them in a geographic information system (GIS) software package (see Appendix B). The data collected from many of the background wells and for many of the measured constituents were not normally distributed (LANL 2016a). Since an arithmetic mean most accurately represents normally distributed datasets, and the majority of the well data are not normally distributed, our analysis can only be considered qualitative. However, its utility is that it highlights those individual wells for which arithmetic mean or maximum constituent concentrations were higher than the UTLs ultimately calculated based on all the wells used in the GBIR background analysis and allowed us to look for potential spatial trends.

The results of our analysis for intermediate groundwater did not reveal any concerning trends in either the average or maximum quotients. However, the GBIR only used five groundwater locations to calculate the UTLs for intermediate groundwater. Therefore, the small number of data points may not be sufficient to establish trends. A more robust analytical dataset would be required for a complete statistical evaluation of background concentrations in intermediate groundwater in and around LANL. Additional data may be collected over time, either by LANL or NMED, at which point more precise UTLs could be determined. Alternatively, or in the meantime, UTLs for the regional aquifer could be used when evaluating contaminant concentrations measured in intermediate groundwater.

Finally, the average and maximum quotients for the regional aquifer do exhibit some features worth highlighting:

- Data from locations R-16r and Spring 3AA consistently exceed UTLs for several constituents (e.g., calcium, strontium, uranium, vanadium). These two locations had less than 3 ppm chloride and exhibited nearly complete tritium decay, eliminating the possibility that they are impacted by anthropogenic activity. However, both of these locations discharge from the Puye formation which overlies the Tesuque formation. Therefore, concentrations of specific constituents may be reflecting unique water/rock interactions.

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[20] The statistical analysis of outliers conducted in the GBIR was not replicated for the purposes of this due diligence analysis in order to evaluate the observed variability in the underlying, raw data.

- Locations R-50 S2 and R-13 also exceed UTLs for a number of constituents (e.g., sodium, total dissolved solids, nitrate), but not as frequently as the wells closer to White Rock.[21] Wells R-50 S2 and R-13 are located northwest of White Rock (approximately equidistant between White Rock and Los Alamos). R-50 S2 is located within the chromium plume but no other contributor (anthropogenic or naturally occurring) to observed constituent concentrations has been identified. Location R-13 discharges from a unique formation of interbedded pumice and volcanic gravel deposits (LANL 2016a). The unique geology at R-13 may explain some of the UTL exceedances.
- It is important to note that the GBIR conducted a statistical analysis of the background well data to remove outliers, which we did not replicate. Therefore, some of the observations we highlight may have been reduced or eliminated through that process and not used to calculate UTLs.
- Aside from the observations noted here, exceedances of UTLs for other contaminants of concern appear to be infrequent and random throughout the regional aquifer sampling locations. There is no systematic trend in the well data that would suggest contamination from LANL activities.

Overall, the GBIR analysis appears to be well-developed and represents the most extensive set of site-specific contaminant concentrations for groundwater background that is readily available. The due diligence analysis increased our confidence in the GBIR's methodology for deriving the UTLs. Further, the UTLs were peer reviewed by NMED, which also supports the integrity of the work that has been conducted. Of the analytes that have EPA MCLs or State criteria available, none of the UTLs exceeded the respective promulgated thresholds. Based on this information, as described in more detail in Chapter 4, we are generally supportive of using the published UTL background values to represent baseline chemical concentrations in intermediate and regional aquifer groundwater.

3.4 BROAD-SCALE UNCERTAINTIES

As noted in Chapter 1, the baseline condition of groundwater need not be static, in that it may vary over time. Major factors with the potential to cause baseline to shift over time include but are not limited to (1) climate change, (2) changes in groundwater use (e.g., coincident with population growth), and (3) radionuclide contamination from atmospheric nuclear fallout. Though the baseline condition of groundwater in the past can be reasonably estimated based on available information, these forces represent broad-scale uncertainties in the future baseline condition of groundwater. Each is discussed below.

1. Climate Change

The wintertime average temperature in New Mexico has increased by approximately 1.5 degrees Fahrenheit (°F) since the 1950s, with predictions that temperatures will increase by 5°F to 10°F by the end of the century (DBSA 2018 and references therein). These trends will likely culminate in increased water demand for agriculture, lower rates of groundwater recharge, and decreased reservoir storage due to increased evaporation, for example. Using water level data for the period between 1949 and 1993, an analysis implied that recharge to the regional aquifer was negligible

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[21] Note, "S2" in well "R-50 S2" refers to screen interval number two. Some background wells were designed to have multiple screen intervals. Specific intervals may have been selected over others if they met the chloride and tritium background criteria and if they were representative of the appropriate depth interval (e.g., intermediate groundwater or the regional aquifer).

during this time and that production well pumping was essentially mining the aquifer (DBSA 2018). However, even if net recharge is negligible, the saturated thickness is at least 1,900 feet (penetrated by well PM-5) and there is potentially 10,000 feet of Santa Fe Group sediments underlying the Pajarito Plateau, so a continuation of the observed rates of decline does not represent a substantial imminent or foreseeable risk to the water supply (DBSA 2018).

2. Changes in Groundwater Use

In general, population growth increases the likelihood of anthropogenic impacts on groundwater due to concomitant increases in septic effluent, the use of road salt, and improper disposal of household or commercial wastes, for example. In areas of the Pajarito Plateau, this type of contamination could impact the use of groundwater for reasons unrelated to LANL releases. However, there is no currently foreseeable risk to the quality of the Los Alamos County water supply due to population growth. In fact, the population of Los Alamos County has decreased by approximately 2 percent since 2000, and the 2018 Long-Range Water Supply Plan for the County of Los Alamos does not note concerns due to population growth (DBSA 2018).

If not carefully managed, increased groundwater use and/or drier conditions in the future (i.e., diminished recharge) could impact the groundwater table and the chemical condition of the groundwater. However, there is currently no reason to expect climate change or changes in groundwater use to impact groundwater baseline conditions in the near future such that estimates of groundwater injuries or damages would be impacted.

3. Radionuclide Contamination from Atmospheric Nuclear Fallout

Another broad-scale uncertainty to consider for baseline is radionuclide contributions to groundwater due to global nuclear fallout. For radionuclides to reach groundwater, they must be at least partially mobile. Otherwise, a given radionuclide would sorb to soil particles at the surface and not reach subsurface waters.[22] In addition to the characteristics of the radionuclides, themselves, adsorption/desorption processes are strongly influenced by the soil type (e.g., clay content, calcite concentrations, ferrihydrite or ferric (oxy)hydroxide), pH, and contaminant valence states (e.g., uranium(VI) versus uranium(IV)) (EPA 1999a, 1999b). While it is known that contaminants such as tritium and uranium can be mobile, can be present in liquid effluents from LANL, and are detected in groundwater downgradient from outfalls, other radionuclides, such as cesium-137, strontium-90, plutonium-238,239,240, and americium-241, are less mobile and adsorb onto solids (Longmire et al. 2007 and references therein). Stable isotope measurements show that regional aquifer groundwater at background wells is submodern (i.e., older than 1943) and does not contain tritium (Longmire et al. 2007). Background intermediate groundwater is mixed (modern and submodern), but only contains atmospheric/cosmogenic

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[22] One of the most important parameters used in estimating the migration potential of contaminants in aqueous solutions in contact with surface, subsurface, and suspended solids is the partition ratio, or K_d value (PAC 1993, EPA 1999a). These contaminant-specific values are used in formulating retardation factors, R_f, which describe the rate of contaminant transport relative to groundwater (EPA 1999a). For example, K_d values for uranium can vary over six orders of magnitude depending on the composition of the aqueous and solid phase chemistries (EPA 1999a, 1999b). For these reasons, it is known that generic or default partition ratios found in the literature can result in errors when used to predict the impacts of contaminant migration; therefore, it is essential to measure site-specific partition ratios (EPA 1999a).

tritium, as opposed to LANL-generated tritium (Longmire et al. 2007). Further, the man-made radionuclides included in the GBIR (e.g., americium-241, cesium-137, plutonium-238, etc.) were nearly all non-detect, indicating low activities in groundwater (LANL 2016a). Therefore, we do not expect global nuclear fallout in groundwater to be a large source of uncertainty in this assessment activity.

CHAPTER 4 | CONCLUSIONS AND RECOMMENDATIONS

Given the history of contamination at LANL and the importance of groundwater resources in New Mexico, a large volume of data and information about groundwater in and around LANL are available. This includes the GBIR, which was developed by LANL and NMED, and represents a readily available source of site-specific groundwater background chemical concentrations (LANL 2016a). This groundwater baseline report compiles and summarizes available information relevant to the LANL site and conducts a due diligence analysis of the data used in the GBIR. Our findings are summarized below and in Exhibits 4-1 and 4-2.

1. The background chemical concentrations presented in the GBIR appear to be sufficient for purposes of NRDA. However, in some cases values were not defined in the GBIR; analytes either did not meet the GBIR's 50 percent non-detect criterion (e.g., americium, chromium in intermediate groundwater) or were not evaluated in the GBIR since they are not naturally occurring (e.g., explosive compounds). For example, the dataset for chromium in intermediate groundwater only contained eight detects out of 47 total observations (LANL 2016a).
2. As mentioned above, a background value was not defined in the GBIR for chromium in intermediate groundwater. Indeed, most site reports focus on chromium in the regional aquifer and appear to consider intermediate groundwater as a pathway to the regional aquifer. Since the intermediate groundwater UTLs were calculated based on data from five wells and a substantial regional groundwater chromium plume has been identified, we recommend addressing this gap at a later date, as NRDA needs require. Further, as progress continues to be made characterizing existing groundwater data, we may identify an appropriate concentration to recommend for chromium in intermediate groundwater. In the absence of additional information, one option may be utilizing the chromium UTL calculated for the regional aquifer.
3. In the case of man-made explosive compounds, solvents and organic contaminants, we recommend assuming that they would not be present in groundwater under baseline conditions (i.e., their concentrations would be zero, absent releases from LANL). This is consistent with the GBIR's opinion regarding such compounds (LANL 2016a, p. 3). No evidence suggests that significant volumes of explosive compounds, solvents, and other organic contaminants would have been released to groundwater in the absence of LANL-related releases.
4. In the case of man-made radionuclides (e.g., americium-241, plutonium-238, and others), we also recommend assuming for NRDA purposes that they would not be present in groundwater under baseline conditions. Stable isotope measurements show that intermediate and regional aquifer groundwater from background wells only contain atmospheric/cosmogenic tritium, if any tritium at all, so these locations are not influenced by LANL-related wastes. The frequency of non-detected results presented in the GBIR also supports this position.

5. Other compounds of potential concern were identified in the work plan for this effort but did not have UTLs calculated in the GBIR (IEc 2017). Specifically, background values were not defined for tritium or uranium-235, which could both be present in the Pajarito Plateau due to the erosion and decay of natural deposits as well as from other releases. However, uranium-235 is exceedingly rare in nature, having an isotopic abundance of 0.72 percent of all naturally occurring U isotopes, and the regional aquifer background locations have tritium activities less than detection (2 to 3 pCi/L). Further, the 2017 Annual Drinking Water Quality Report for the Los Alamos Department of Public Utilities suggests that radioactive contaminants are not an issue in the regional aquifer of the Pajarito Plateau, which indicates that these compounds would not affect the baseline services that groundwater could provide absent releases from LANL (LACDPU 2017). This conclusion is further supported by the frequency of non-detected results in the GBIR for these compounds. We recommend (1) utilizing NMED’s screening criterion of 2 pCi/L tritium as the baseline concentration for tritium, and (2) not developing a background value for uranium-235 unless it becomes clear during the NRDA that this compound poses a concern.[23]
6. Consistent with regional information, it appears that uranium deposits and leaking brines are not groundwater issues in or around LANL.
7. Anthropogenic impacts from the Los Alamos townsite and White Rock (e.g., septic effluent and fertilizer) could play a role in diminishing water quality in this area. These anthropogenic sources of nitrate could also coincide geographically with explosive compounds originally released by LANL. However, based on laboratory studies conducted by LANL, there is very little abiotic and biotic degradation of Royal Demolition Explosive (RDX) to nitrate under the aerobic groundwater conditions occurring in and around LANL (Longmire 2019). Therefore, this co-location of septic effluent, fertilizer, and RDX contamination should not obscure nitrogen sources in groundwater. We do not expect significant anthropogenic contributions of contaminants but would expect impacts, to the extent they occur, to be localized to areas in and around population centers (e.g., Los Alamos townsite or White Rock). We recommend carefully evaluating this baseline factor when reviewing nitrate or RDX concentrations in groundwater during the assessment.
8. Overall, our findings suggest that groundwater in and around LANL is in ample supply, would have chemical constituents at levels considered safe for drinking and does not have undesirable characteristics (e.g., hardness). There is no evidence to suggest that the range of services provided by groundwater under baseline conditions would be limited in any way.[24]

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[23] As noted by one technical peer reviewer, “Developing a UTL for uranium-235 in intermediate-depth and regional aquifer groundwater would be very expensive and requires numerous groundwater samples (n > 400) using TIMS [Thermal Ionization Mass Spectrometry] as the analytical method of choice” (Longmire 2019).

[24] As noted in Section 1.1.1, the suite of services provided by groundwater in and around LANL will be described under separate cover.

EXHIBIT 4-1 SUMMARY OF RECOMMENDATIONS FOR BACKGROUND VALUES IN INTERMEDIATE GROUNDWATER

CONTAMINANT OF CONCERN	GBIR VALUE	IEC RECOMMENDATION	UNIT	NOTES
GENERAL CHEMISTRY PARAMETERS				
Alkalinity-CO3+HCO3	62.0	62.0	mg/L	Source: GBIR (LANL 2016a).
Hardness	37.8	37.8	mg/L	Source: GBIR (LANL 2016a).
Total Dissolved Solids	152.0	152.0	mg/L	Source: GBIR (LANL 2016a).
Total Organic Carbon	1.35	1.35	mg/L	Source: GBIR (LANL 2016a).
POTENTIAL CONTAMINANTS				
Americium-241	NA	0.0	µg/L	Man-made compound.
Barium	13.5	13.5	µg/L	Source: GBIR (LANL 2016a).
Calcium	10.7	10.7	mg/L	Source: GBIR (LANL 2016a).
Cesium-137	NA	0.0	µg/L	Man-made compound.
Chloride	3.11	3.11	mg/L	Source: GBIR (LANL 2016a).
Chromium	NA	NA	NA	Develop at a later date.
Fluoride	0.234	0.234	mg/L	Source: GBIR (LANL 2016a).
HMX	NA	0.0	µg/L	Man-made compound.
Magnesium	3.14	3.14	mg/L	Source: GBIR (LANL 2016a).
Molybdenum	2.9	2.9	µg/L	Source: GBIR (LANL 2016a).
Nickel	3.65	3.65	µg/L	Source: GBIR (LANL 2016a).
Nitrate-Nitrite as Nitrogen	0.459	0.459	mg/L	Source: GBIR (LANL 2016a).
Perchlorate	0.27	0.27	µg/L	Source: GBIR (LANL 2016a).
Plutonium-238	NA	0.0	µg/L	Man-made compound.
Plutonium-239/240 *	NA	0.0	µg/L	Man-made compound.
Potassium	2.35	2.35	mg/L	Source: GBIR (LANL 2016a).
RDX	NA	0.0	µg/L	Man-made compound.
Silicon Dioxide	75.0	75.0	mg/L	Source: GBIR (LANL 2016a).
Sodium	18.2	18.2	mg/L	Source: GBIR (LANL 2016a).
Strontium	59.6	59.6	µg/L	Source: GBIR (LANL 2016a).
Strontium-90	NA	0.0	µg/L	Man-made compound.
Sulfate	7.1	7.1	mg/L	Source: GBIR (LANL 2016a).
Technetium-99 *	NA	0.0	µg/L	Man-made compound.
Tritium	NA	2.0	pCi/L	Source: LANL 2016b.
Uranium	0.992	0.992	µg/L	Source: GBIR (LANL 2016a).
Uranium-234	0.477	0.477	pCi/L	Source: GBIR (LANL 2016a).
Uranium-235	NA	NA	NA	Develop at a later date.
Uranium-238	0.201	0.201	pCi/L	Source: GBIR (LANL 2016a).
Vanadium	9.29	9.29	µg/L	Source: GBIR (LANL 2016a).

* Trace quantities of this radionuclide exist naturally, but it is primarily man-made.

EXHIBIT 4-2 SUMMARY OF RECOMMENDATIONS FOR BACKGROUND VALUES IN THE REGIONAL AQUIFER

CONTAMINANT OF CONCERN	GBIR VALUE	IEC RECOMMENDATION	UNIT	NOTES
GENERAL CHEMISTRY PARAMETERS				
Alkalinity-CO3+HCO3	72.9	72.9	mg/L	Source: GBIR (LANL 2016a).
Hardness	67.1	67.1	mg/L	Source: GBIR (LANL 2016a).
Total Dissolved Solids	161	161	mg/L	Source: GBIR (LANL 2016a).
Total Organic Carbon	1.08	1.08	mg/L	Source: GBIR (LANL 2016a).
POTENTIAL CONTAMINANTS				
Americium-241	NA	0.0	μg/L	Man-made compound.
Barium	38.1	38.1	μg/L	Source: GBIR (LANL 2016a).
Calcium	17.03	17.03	mg/L	Source: GBIR (LANL 2016a).
Cesium-137	NA	0.0	μg/L	Man-made compound.
Chloride	2.70	2.70	mg/L	Source: GBIR (LANL 2016a).
Chromium	7.48	7.48	μg/L	Source: GBIR (LANL 2016a).
Fluoride	0.377	0.377	mg/L	Source: GBIR (LANL 2016a).
HMX	NA	0.0	μg/L	Man-made compound.
Magnesium	4.18	4.18	mg/L	Source: GBIR (LANL 2016a).
Molybdenum	2.5	2.5	μg/L	Source: GBIR (LANL 2016a).
Nickel	2.9	2.9	μg/L	Source: GBIR (LANL 2016a).
Nitrate-Nitrite as Nitrogen	0.769	0.769	mg/L	Source: GBIR (LANL 2016a).
Perchlorate	0.414	0.414	μg/L	Source: GBIR (LANL 2016a).
Plutonium-238	NA	0.0	μg/L	Man-made compound.
Plutonium-239/240 *	NA	0.0	μg/L	Man-made compound.
Potassium	2.39	2.39	mg/L	Source: GBIR (LANL 2016a).
RDX	NA	0.0	μg/L	Man-made compound.
Silicon Dioxide	81.9	81.9	mg/L	Source: GBIR (LANL 2016a).
Sodium	16.0	16.0	mg/L	Source: GBIR (LANL 2016a).
Strontium	157.0	157.0	μg/L	Source: GBIR (LANL 2016a).
Strontium-90	NA	0.0	μg/L	Man-made compound.
Sulfate	4.59	4.59	mg/L	Source: GBIR (LANL 2016a).
Technetium-99 *	NA	0.0	μg/L	Man-made compound.
Tritium	NA	2.0	pCi/L	Source: LANL 2016b.
Uranium	1.19	1.19	μg/L	Source: GBIR (LANL 2016a).
Uranium-234	0.715	0.715	pCi/L	Source: GBIR (LANL 2016a).
Uranium-235	NA	NA	NA	Develop at a later date.
Uranium-238	0.336	0.336	pCi/L	Source: GBIR (LANL 2016a).
Vanadium	11.4	11.4	μg/L	Source: GBIR (LANL 2016a).
* Trace quantities of this radionuclide exist naturally, but it is primarily man-made.				

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APPENDIX A | EARLY WELLS AND TEST HOLES IN THE LANL AREA

EXHIBIT A-1 RECORDS OF WELLS AND TEST HOLES IN THE LANL AREA (MODIFIED FROM TABLE 2 IN GRIGGS AND HEM 1964)

LOCALE[1]	DATE COMPLETED	DEPTH OF WELL (FEET)	PRINCIPAL WATER-BEARING UNIT	SPECIFIC CAPACITY (GPM PER FOOT)	USE OF WATER
VALLES CALDERA AREA					
Valle Grande	November 1949	630	Caldera fill	-	N
	November 1949	589	Caldera fill	-	N
Divide between Valle Grande and Valle de los Posos	October 1949	420	Caldera fill	-	N
Valle Grande	October 1949	600	Caldera fill	-	N
	November 1949	595	Caldera fill	-	N
	November 1949	1,185	Caldera fill	10	N
	November 1949	595	Caldera fill	-	N
	November 1949	634	Caldera fill	-	N
Valle Toledo	October 1949	530	Caldera fill	-	N
	October 1949	285	Caldera fill	-	N
	October 1949	405	Caldera fill	-	N
	October 1949	410	Caldera fill	-	N
	July 1949	652	Caldera fill	50	N
	July 1949	444	Caldera fill	-	N
Valle de los Posos	July 1949	800	Caldera fill	-	N
East rim of caldera	1949	1,269	Tschicoma Formation	-	N
RIO GRANDE AREA					
Ancho Canyon	April 1950	55	Tschicoma Formation	-	N
Rim of Pueblo Canyon	March 1950	1,205	Tschicoma Formation	0.6	Ws

LOCALE[1]	DATE COMPLETED	DEPTH OF WELL (FEET)	PRINCIPAL WATER-BEARING UNIT	SPECIFIC CAPACITY (GPM PER FOOT)	USE OF WATER
Los Alamos Canyon	November 1949	815	Puye Conglomerate	0.5	Ws
Pueblo Canyon	November 1949	789	Puye Conglomerate	1	Ws
	November 1949	133	Puye Conglomerate	-	Ws
Los Alamos Canyon	September 1949	2,000	Tschicoma Formation	-	-
Pajarito Canyon	March 1950	300	Tschicoma Formation	-	-
Guaje Canyon	July 1951	1,800	Santa Fe Group undifferentiated unit	6	Ps
	August 1951	1,990	Santa Fe Group undifferentiated unit	7	Ps
	July 1950	2,000	Santa Fe Group undifferentiated unit	4.8	Ps
	May 1951	1,850	Santa Fe Group undifferentiated unit	5.4	Ps
	May 1951	1,940	Santa Fe Group undifferentiated unit	4	Ps
Los Alamos Canyon	November 1946	870	Santa Fe Group undifferentiated unit	-	Ps
	May 1947	870	Santa Fe Group undifferentiated unit	1.4	Ps
	December 1946	870	Santa Fe Group undifferentiated unit	-	Ps
	December 1948	1,790	Santa Fe Group undifferentiated unit	6.9	Ps
	September 1949	1,750	Santa Fe Group undifferentiated unit	3.2	Ps
Pueblo Canyon	January 1950	642	Puye Conglomerate	0.2	N
	January 1950	225	Basalt of chino mesa, unit 2	-	Ws
Los Alamos Canyon	July 1948	1,965	Santa Fe Group undifferentiated unit	6.3	Ps
Pajarito Canyon	March 1950	263	-	-	-
Canada Ancha	-	-	Santa Fe Group undifferentiated unit	-	S

Use of water: N, not used; Ws, nuclear waste study; Ps, public supply; S, stock.

GPM: gallons per minute.

[1] Griggs and Hem (1964) do not provide a map of well locations. Rather, they describe a location identification approach that relies upon New Mexico state divisions of public lands. Translating this information into a GIS-ready format would be time-consuming and we do not expect the mapped locations to impact the recommendations presented in this report. Therefore, such an effort has not been completed at this time.

APPENDIX B | DUE DILIGENCE ANALYSIS RESULTS

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