HOMESTAKE MINING COMPANY OF CALIFORNIA

Grants Reclamation Project

ALTERNATE CONCENTRATION LIMIT APPLICATION

For the Groundwater Corrective Action Program

Revision 1

Radioactive Materials License SUA-1471

Submitted:

June 30, 2026

Submitted To:

United States Nuclear Regulatory Commission

Submitted By:

Homestake Mining Company of California

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LIST OF ACRONYMS

3-D	three-dimensional
ACHP	Advisory Council on Historic Preservation
ACL	Alternate Concentration Limit
AEC	United States Atomic Energy Commission
ALARA	As Low As Reasonably Achievable
amsl	above mean sea level
ARARs	applicable or reasonable and appropriate requirements
ATSDR	Agency for Toxic Substances and Disease Registry
ASTM	ASTM International
BCG	Biota Concentration Guide
CAP	Corrective Action Program
CEC	cation exchange capacity
CFR	Code of Federal Regulation
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CGM	conceptual geochemical model
cmol+/kg	centimoles of positive charge per kilogram
CO	Confirmatory Order
COC	Constituents of Concern
COPC	Constituents of Potential Concern
ºC	Degrees Celsius
DCGL	Derived Concentration Guideline Level
DDM	Drain Down Model
DOE	Department of Energy
DO	dissolved oxygen
DP	Discharge Permit
EC	Engineered Controls
ECP	East Collection Pond
Eh	redox potential
EPA	United States Environmental Protection Agency
EP1	Evaporation Pond 1
EP2	Evaporation Pond 2
EP3	Evaporation Pond 3
ER	Environmental Report
°F	Degrees Fahrenheit
FS	Feasibility Study
ft	foot
GHBs	General head boundaries
gpd	gallons per day
gpm	gallons per minute
GRA	general response actions
GRP	Grants Reclamation Project including areas of corrective action
GWQB	Ground Water Quality Bureau
HDPE	high density polyethylene

HFB	Horizontal Flow Barrier
HHS	Health and Human Services
HMC	Homestake Mining Company
HPRO-1	High Pressure No. 1
IARC	International Agency for Research on Cancer
IC	Institutional Controls
ID	Identification
IX	Ion Exchange
K_f	empirical partition coefficient
kg/L	kilogram per Liter
kg/yr	kilogram per year
km^2	square kilometer
kg/m^2	kilograms per square meter
License	NRC License SUA-1471
L	Liter
LM	Legacy Management
LPRO-1	Low Pressure No. 1
LPRO-2	Low Pressure No. 2
LPRO-3	Low Pressure No. 3
LTCB	Long-term Care Boundary
LTSP	Long-term Surveillance Plan
MCLs	Maximum Concentration Limits
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
mrem	millirem
MRL	minimal risk level
nCi/kg/day	Nano Curies per kilogram per day
NCP	National Contingency Plan
NESHAP	National Emission Standards For Hazardous Air Pollutants
NHPA	National Historic Preservation Act of 1966
NMAC	New Mexico Administrative Code
NMED	New Mexico Environment Department
NMEID	New Mexico Environmental Improvement Division
NMSA	New Mexico Statutes and Authorities
OSE	New Mexico Office of State Engineer
NPL	National Priority List
NRC	United States Nuclear Regulatory Commission
pCi/g	picocuries per gram
PCB	Prescribed Concentration Boundary
POC	Point of Compliance
POE	Point of Exposure
PPE	Personal Protective Equipment
ppm	parts per million
PRISM	Parameter-Elevation Regressions on Independent Slopes Model

PTT	post treatment tank
R_f	retardation factor values
RfD	reference dose
RDA	Recommended daily allowance
RCH	MODFLOW Recharge
RMM	reformulated mixing model
RO	Reverse Osmosis
ROD	Record of Decision
RMSE	root mean squared error
SAG	San Andres-Glorieta
SCM	surface complexation models
SCMM	geochemical surface complexation and mixing model
SEM	Scanning Electron Microscope
SERP	Safety and Environmental Review Panel
SI	Saturation Index
SMC	San Mateo Creek
SOP	Standard Operating Procedure
TDS	Total Dissolved Solids
TEDE	Total Effective Dose Equivalent
Tri-State	Tri-State Generation & Transmission Escalante Generation Station
TVD	total variation diminishing
TI Wavier	Technical Impracticability Waiver
USACE	United States Army Corps of Engineers
WCP	West Collection Pond
XRD	X-ray Diffraction

1 GENERAL INFORMATION

1.1 Introduction

Homestake Mining Company of California (HMC) requests amendment of U.S. Nuclear Regulatory Commission (NRC) Radioactive Materials License SUA-1471 (License) Conditions 15, 35 and 36, which address groundwater compliance, groundwater corrective action, and reporting for the former uranium mill located at the Grants Reclamation Project (GRP; Figure 1.1-1). Specifically, this Alternate Concentration Limit (ACL) Application requests approval of the following amendments to the License.

- Modification of License Condition 15 to reflect the proposed changes to the environmental monitoring and reporting frequency, which are identified in License Condition 35.
- Modifications to the License Condition 35A to address proposed updates to the Groundwater Compliance Monitoring Plan in scope, monitoring frequency and reporting frequency.
- Modifications to License Condition 35B by approving the proposed Alternate Concentration Limits (ACLs) for the identified constituents.
- Removal of License Condition 35C for implementation of groundwater corrective action.
- Removal of License Condition 35E for operation of a zeolite water treatment system associated with the groundwater corrective action.
- Removal of License Condition 35F for annual reporting of corrective action program performance.
- Removal of License Condition 36B(2) to delete reference to a completion date for groundwater corrective actions.
- Modification of License Condition 42 to remove reference to corrective action program report

Specific language changes to the current License are proposed in Section 5.2 of this submittal. The bases supporting the requested amendments are presented herein. This License amendment request is accompanied by an Environmental Report (ER) that addresses the expected environmental impacts of the Proposed Action and evaluates alternatives for mitigating these impacts per 10 Code of Federal Regulations (CFR) Part 40, Appendix A Criterion 9, and is intended to support NRC in meeting its obligations under 10 CFR Part 51. Amendment of License Condition 28 to reflect proposed changes to the surety basis of estimate and amount will be provided under separate cover at later date once technical review of this ACL Application is further advanced and closer to approval.

More than 40 years of groundwater corrective action has mitigated a significant portion of the groundwater constituents by removing and treating more than 12 billion gallons of affected groundwater. Constituent impacted fluid may continue to emanate from the Large Tailings Pile and diffuse from fine-grained silt and clay, located along the path of the groundwater plume from the GRP, back into the groundwater transport regime. The concentrations of these constituents in groundwater, however, have been reduced to levels that are as low as reasonably achievable (ALARA), considering practicable corrective actions. Further groundwater restoration, including to background or current License groundwater protection standards, is not technically feasible. Analytical data and modeling provided with this ACL Application demonstrate that the proposed ACLs, along with restrictions to access and use of groundwater, will ensure protectiveness of human health, safety, and the environment at the points of exposure (POE).

Therefore, approval of ACLs, removal of the requirements for groundwater corrective actions, and modification to the groundwater monitoring program and reporting frequency is requested. Upon approval,

these License amendments will result in modifications of the surety amount. Upon License termination, which will be the subject of a separate future License amendment request, the GRP will be transferred to the U.S. Department of Energy, Office of Legacy Management (DOE-LM) as long-term custodian. Approval of these ACLs, in conjunction with final site decommissioning and reclamation and DOE-LM ownership and/or control of these lands will provide reasonable assurance of protection of public health, safety, and the environment for 1,000 years, to the extent reasonably achievable, and, in any case, for at least 200 years.

This ACL Application is one component of an integrated closure strategy that addresses not only NRC requirements identified in the License and 10 CFR Part 40 Appendix A but also U.S. Environmental Protection Agency (EPA) requirements under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and requirements under New Mexico State law. In addition, HMC is engaged in discussions with the New Mexico Environment Department (NMED) regarding the appropriate methods by which HMC may terminate its groundwater discharge permit for the GRP. HMC's intent and objectives are to fulfill all its regulatory obligations for all appropriate regulatory agencies and transfer the site and associated licensed 11e.(2) Byproduct Material to the long-term custodian.

The former uranium mill at the GRP was initially regulated by the NRC from 1958 through 1974. The State of New Mexico assumed regulatory authority for these licensed materials in 1974 through the Agreement State Program identified in Section 274 of the Atomic Energy Act of 1954. The state of New Mexico returned regulatory authority for licensed 11e.(2) Byproduct Material back to the NRC in 1986. The former uranium mill at the GRP processed ore from local mines in the Ambrosia Lake and Mount Taylor districts from 1958 to 1990 and deposited the mill tailings in licensed unlined impoundments from which constituents have migrated into underlying water-yielding units. Groundwater impacts from milling operations were first discovered in 1961 (Chavez, 1961), further investigated by the EPA in 1974 (EPA, 1975), and groundwater corrective action and restoration were initiated in 1977.

The GRP was added to the National Priorities List (NPL) under CERCLA at the request of the State of New Mexico in 1983. The GRP is currently regulated by the NRC, the EPA, and NMED.

A groundwater corrective action program is ongoing at the GRP, in accordance with License Condition 35, to remediate groundwater constituents to the License groundwater protection standards identified in License Condition 35B for each hydrostratigraphic unit beneath the GRP (Table 1.1-1). The Groundwater Corrective Action Program, initially approved by NRC in 1990 (License Amendment 5), is implemented using an adaptive strategy that includes source control, groundwater plume control, evaporation, and water treatment. Four subsequent groundwater corrective action program documents have been submitted to the NRC since 1989; the first in 2006, the second in 2012, the third in 2019, and a fourth in 2020. The 2006 and 2012 submittals were accepted for technical review but were never approved. The December 19, 2019, Groundwater Corrective Action Program submittal (HMC, 2019) and the associated February 28, 2020, submittal of an Environmental Report (HMC, 2020a) responded to an NRC Confirmatory Order (CO) issued by NRC on March 28, 2017 (NRC, 2017a), which has since been relaxed in its entirety and administratively removed from the GRP license. The NRC subsequently provided a Request for Supplemental Information (RSI) on June 18, 2020 (NRC, 2020). HMC submitted an updated Groundwater Corrective Action Program and an updated Environmental Report on November 20, 2020 (HMC, 2020e) in response to the Request for Supplemental Information. As part of this response submittal, HMC identified its intent to submit a License amendment application for approval of ACLs, which, if approved,

would eliminate the requirement for a Groundwater Corrective Action Program. Consequently, the NRC suspended its review of the Groundwater Corrective Action Program in anticipation of an ACL application submittal (NRC, 2021b).

HMC has conducted extensive site characterizations including engineering, geologic, hydrologic, geochemical, and ecological studies. Based on analysis of water samples in the tailings and the uppermost aquifer, HMC has identified 10 constituents, as defined in Criterion 5B(2) of Appendix A to 10 CFR Part 40, many which are not extensively spatially distributed across the GRP area and are not currently included in the License groundwater monitoring requirements. The identified constituents to be addressed in this ACL Application include metals: arsenic, cadmium, molybdenum, selenium, vanadium; as well as radionuclides: uranium, combined radium-226 and radium-228, and thorium-230. Fluoride and nitrate have also been identified as constituents to be addressed at the GRP. These 10 constituents are the focus of the analyses in this ACL Application.

No organic compounds, polychlorinated biphenyls (PCBs), or pesticides have been used at the GRP or identified in samples from the tailings. Thus, no ACL is required for these substances.

Although chloride, sulfate, and total dissolved solids (TDS) are identified in GRP License Condition 35B and in the State of New Mexico Discharge Permit DP-200 (NMED, 2014), these parameters are not considered hazardous and are not listed as hazardous constituents in Appendix A to 10 CFR Part 40, and thus do not require an ACL. HMC therefore proposes to remove them from the GRP License Condition 35B upon NRC approval of the ACLs for the ten identified constituents. Chloride, sulfate, and TDS are retained as monitoring parameters in the proposed monitoring program and are discussed in this application for this reason.

In addition, while boron has been identified at the site above the State of New Mexico irrigation standard, it is not listed as a hazardous constituent in Appendix A to 10 CFR Part 40 and thus does not require an ACL. Boron is discussed in this document because of the State of New Mexico standards, but will not be retained as a water quality monitoring constituent.

A review of historical groundwater corrective action performance and modeling of the long-term sources of groundwater contaminants (Large Tailings Pile seepage and diffusion of constituents from the immobile transport domain associated with fine-grained silt and clay) demonstrates that groundwater remediation to the levels currently set as standards cannot reasonably be achieved. This is demonstrated through assessment and modeling of past and potential future sources of contamination and past and potential future corrective actions.

In this ACL Application, a range of groundwater corrective action alternatives has been developed to address the identified constituents addressed in this ACL Application. These corrective action alternatives are based on extensive site characterization data, over 40 years of groundwater corrective action experience and testing, and screening of a broad range of technologies and process options for groundwater restoration and treatment. The alternatives address source control, groundwater remediation, water treatment and disposal, as well as control of access to and use of groundwater. The alternatives consider both active and passive technological approaches as well as *in situ* and *ex situ* technologies. The three corrective action alternatives evaluated include a) containment and removal of groundwater contaminants using the existing approved groundwater corrective action plan (No Action alternative, assumes this ACL Application is denied and corrective action measures continue); b) continued containment and removal of groundwater

contaminants for a shorter period followed by passive *in situ* treatment using a permeable reactive barrier (PRB); and c) ACLs with control over access to and use of groundwater through property ownership within the proposed control boundary and a revised groundwater monitoring program.

Based on site-specific data, HMC has developed a calibrated groundwater flow and contaminant transport model to assess the efficacy of the groundwater corrective action alternatives and to support selection of an appropriate long-term groundwater corrective action. Based on the analysis of alternatives, ACLs and modified groundwater monitoring are identified as the Proposed Action. A cost/benefit analysis is provided to support the demonstration that the past several decades of corrective actions and the Proposed Action have reduced groundwater constituent concentrations to levels that are ALARA. Long-term control of access to and use of groundwater will be provided by property ownership within the proposed control boundary, which will be transferred to the long-term custodian upon License termination and site transfer, and institutional controls. The control boundary circumscribes the area over which long-term control of access to and use of groundwater would be required under the Proposed Action. As detailed in Section 5.1.5 of this application, HMC has obtained ownership of approximately 86% of the surface estate and 77% of the subsurface estate within the proposed long-term control boundary (i.e., a substantial majority of the estates), continues its good faith and serious efforts to obtain all such estates, and intends to comply with regulatory requirements governing acquisition and transfer of property within the control boundary. Documentation demonstrating HMC's serious and good faith efforts being made to acquire the remaining surface and subsurface estates is available for NRC staff review onsite.

ACLs are groundwater constituent concentrations to be met at the points of compliance (POC). ACLs are established at concentrations that will ensure that groundwater meets protective standards at the POE, which is the control boundary at the GRP.

In order to predict contaminant transport, calibrated groundwater flow and contaminant transport models for uranium and molybdenum were developed as they are the two constituents with the highest concentrations respective to their protective standards identified at the site. Two groundwater model types were developed, a set of calibrated base-case models were developed to assess corrective action alternative performance, and a set of bounding-case models were developed by modifying the base-case models to conservatively assess groundwater concentrations at the POE for the proposed ACL values. The calibrated models, referred to as the base-case models, were developed to assess the relative performance of the corrective action alternatives presented in this ACL Application. To address potential uncertainties associated with future contaminant sources, contaminant transport properties, long-term groundwater use demand, and long-term hydrologic inputs when calculating ACLs for the Proposed Action, bounding-case models were developed. The bounding-case models simultaneously apply values for multiple key input parameters at endpoints of their reasonable ranges that promote constituent transport. Accordingly, the bounding-case models generate highly conservative estimates of predicted contaminant concentrations at the POE, providing an additional protective margin beyond the concentrations predicted by the calibrated base-case model. Calculation of ACL values from the conservative bounding-case model simulations is intended to address potential uncertainties associated with long-term site conditions and modeling of the Proposed Action. Proposed modifications to the groundwater monitoring program take into consideration the results of the bounding-case model simulations and are commensurate with protection afforded by the Proposed Action.

This ACL Application is structured to generally follow the outline presented in Appendix K of NUREG-1620 (NRC, 2003a) and provides the information identified in Section 4 of NUREG-1620 regarding groundwater protection, as well as the information identified in Staff Technical Position: Alternate Concentration Limits for Title II Uranium Mills (NRC, 1996). The Environmental Report, accompanying this ACL Application, has been developed considering the guidance presented in NUREG-1748 (NRC, 2003b). NRC Form 313 is included as Appendix 1.1-A to this submittal.

Section 1 of this submittal presents the GRP description and historical background, summarizes the current extent of groundwater constituents identified in the License, the current groundwater protection standards and the proposed ACLs and control over access to and use of groundwater through property ownership.

Section 2 presents the Hazard Assessment, which identifies constituents to be addressed in this ACL Application, characterizes their sources, and addresses the potential health and environmental risks associated with these constituents.

Section 3 presents the Exposure Assessment. The Exposure Assessment includes presentation of a calibrated, three-dimensional, groundwater flow and reactive transport model, which was developed to support assessment of current and potential future exposure pathways. It also includes an assessment of exposure consequences.

Section 4 presents the Corrective Action Assessment, which summarizes the previous and current groundwater corrective action programs and assesses potential corrective action alternatives. The Corrective Action Assessment also analyzes costs and benefits associated with corrective action alternatives and demonstrates that the preferred alternative reduces concentrations to ALARA.

Section 5 identifies the proposed ACLs, the proposed monitoring program, and the decommissioning of the groundwater corrective action program components, consistent with the approved Decommissioning and Reclamation Plan (HMC, 2013).

1.2 Facility History and Description

The GRP is located 5.5 miles north of Milan, New Mexico, in Cibola County (Figure 1.1-1) and is owned and operated by HMC. In this ACL Application, the area of the GRP includes the License boundary and the areas where corrective actions have occurred (Figure 1.2-1). The former Homestake mill at the GRP processed uranium ore from local mines in the Ambrosia Lake and Mt. Taylor districts from 1958 to 1990 and deposited mill tailings in licensed unlined impoundments. The Homestake Mill consisted of two mills. The southern mill, built in 1957, was known as the Homestake-New Mexico Partners mill and was closed in 1962 (Chenoweth, 1989; McLemore and Chenoweth, 2003). It had a nominal milling capacity of 750 tons per day. The Homestake-Sapin Partners, a partnership between Homestake and Sabre Pinon Corporation, in 1957 built a second, larger mill, with a nominal milling capacity of 1,750 tons per day, north of the first mill. The two mills initially operated independently but were subsequently combined and expanded in 1961 under Homestake-Sapin Partners. The nominal milling capacity of the combined mills was 3,400 tons per day (McLemore, 2007).

Uranium production ceased at the Homestake mill in 1981 but resumed in 1988 to process ore from the Section 23 mine and Chevron's Mount Taylor mine (McLemore, 2007). The Homestake mill closed soon after and was decommissioned in 1990. Reclamation of the Homestake mill and some areas of surface soil

contamination was completed in 1994. Groundwater restoration and tailings reclamation activities continue at the GRP.

The total quantity of tailings generated under milling contracts with the United States Government under the Atomic Energy Commission (AEC) was 13.45 million tons. In addition, another 7.6 million tons of commercial tailings were generated (AK Geoconsult and Jenkins, 1993). The tailings were discharged to and contained within two unlined impoundments with earthen embankments: the Large Tailings Pile and the Small Tailings Pile (Figure 1.2-1). The Large Tailings Pile has residual saturation, and the Small Tailings Pile does not have residual saturation. Constituents from the GRP tailings facilities have migrated into underlying groundwater. Groundwater impacts from former mill operations were first discovered in 1961 (Chavez, 1961), further investigated by the EPA in 1974 (EPA, 1975), and groundwater corrective action efforts, initiated in 1977, have continually expanded in scope and volume to the present day.

The following sections identify the current License, permit and other regulatory requirements, and describe the operating background and history of the former Homestake Mill at the GRP. Further, the following sections summarize the current extent of groundwater contamination, the current groundwater protection standards, and the proposed ACLs and control over access to and use of groundwater through property ownership within the proposed control boundary.

1.2.1 Licenses, Permits, and Other Environmental Requirements

1.2.1.1 NRC Source Materials License SUA-1471

The GRP operates under NRC Source Materials License SUA-1471, issued on November 10, 1986, and subsequent amendments. The License authorizes HMC to possess, incidental to decommissioning, residual uranium and 11e.(2) Byproduct Material in the form of uranium mill tailings and other byproduct wastes generated by the past milling operations in accordance with the License.

Groundwater restoration is regulated under License Condition 35. Requirements specified in License Amendment 63 Condition 35 include 1) implementation of groundwater monitoring; 2) establishing the License groundwater protection standards (Table 1.1-1) and identifying that constituents listed for the alluvial aquifer must not exceed the specified concentration limit at compliance monitoring wells; 3) authorizing operation of evaporation ponds (EP1, EP2 and EP3), and enhanced evaporation systems; 4) authorize operation of the zeolite water treatment systems located on the Large Tailings Pile; 5) submit by March 31 of each year, a performance review of the corrective action program that details the progress towards attaining License groundwater protection standards.

License Conditions 15, 16, and 43 also apply to the groundwater corrective action program. License Condition 15 requires that the results of all effluent and environmental monitoring required by this license and regulation shall be reported semiannually, by March 31 and September 30. All groundwater monitoring data shall be reported according to the requirements in License Condition 35.

License Condition 16 specifies that before engaging in any change in facility operations, systems, equipment, infrastructure or procedures not previously assessed by the NRC, or authorized under current License conditions, including any related tests or experiments not described in current License conditions, the licensee shall convene a Safety and Environmental Review Panel (SERP). This panel would determine whether the proposed change, test or experiment would impact the operational design or performance

specifications previously reviewed and approved by NRC by means of a Safety Evaluation Report (SER), Technical Evaluation Report (TER), Environmental Impact Statement (EIS) or Environmental Assessment (EA). If, based on the criteria identified in License Condition 16, the SERP concludes that the proposed change, test or experiment would not compromise the operational performance, health, safety or environmental protection requirements afforded by the current License conditions, the licensee may implement the proposed change, test or experiment without a License amendment. Otherwise, the licensee shall obtain prior approval from the NRC in the form of a License amendment.

License Condition 43 indicates that before engaging in any developmental activity not previously assessed by the NRC, the licensee shall administer a cultural resource inventory. All disturbances associated with the proposed development will be completed in compliance with the National Historic Preservation Act (as amended) and its implementing regulations (36 CFR 800), and the Archaeological Resources Protection Act (as amended) and its implementing regulations (43 CFR 7). To ensure that no unapproved disturbance of cultural resources occurs, any work resulting in the discovery of previously unknown cultural artifacts shall cease. The artifacts shall be inventoried and evaluated in accordance with 36 CFR Part 800, and no disturbance of the area shall occur until the licensee has received authorization from the NRC to proceed.

The Proposed Action updates the licensed infrastructure and operations in License Condition 35C.

1.2.1.2 Other Consultations and Requirements

The NRC will perform an evaluation of the environmental impacts associated with reclamation activities to comply with the National Environmental Policy Act and NRC's regulations. The evaluation will describe the affected environment, evaluate the potential environmental impacts of the proposed reclamation actions, and consider potential mitigation measures. The NRC will undertake any required compliance with wildlife and cultural resource protection requirements, including those under the Endangered Species Act, the Migratory Bird Treaty Act, and the National Historic Preservation Act (NHPA).

The online United States Fish and Wildlife Service project review process was accessed and a survey was conducted in 2018 with a one-mile buffer around the GRP (ERM, 2018). The threatened and endangered species that may occur are discussed in Section 1.2.2.4. None of the threatened and endangered species were identified as having critical habitat within the boundary identified. No critical habitats under the jurisdiction of the United States Fish and Wildlife Service were indicated within the area identified. Several migratory birds were identified as potentially using the area.

HMC has documented relevant surveys of historical and cultural resources in the Environmental Report associated with this ACL Application. Consultation with the State Historic Preservation Officer and the relevant Native American Tribes is performed by the NRC under Section 106 of the NHPA.

1.2.2 Location and Setting

The GRP is located within the Grants Mineral Belt in New Mexico. The Grants Mineral Belt produced more uranium than any other district in the world during the period of 1951-1980 (McLemore and Chenoweth, 1989). Situated within the San Mateo Creek Basin (SMC), more than 85 legacy uranium mines with recorded production are located upgradient of the GRP (Weston, 2016). Locations of some of the mines in relation to the GRP are presented in Figure 1.2-2. Several legacy uranium mines generated liquid wastes that included water produced from mine dewatering operations that were discharged to the surface.

The GRP is located in a semi-circular valley ringed by a series of mesas that are approximately 7,000 to 8,000 feet above mean sea level (amsl). The GRP elevation is approximately 6,600 feet amsl. Local topography in the valley is generally flat with some low, rolling hills and shallow arroyos (Figure 1.2-3). The GRP is located near the confluence of the ephemeral Lobo Creek and San Mateo Creek drainages, both tributaries of the Rio San Jose.

1.2.2.1 Land Use/Land Cover

When the HMC mills were built, the surrounding area was generally remote ranch land with some irrigated land. In the 1960s and 1970s, several subdivisions were constructed in the vicinity of the mill, primarily occupied by families working at the mill or in the area mines. The area vegetation, which influences local land use, is characterized by Inter-Mountain Basins Semi-Desert Grassland, which comprises approximately 46 percent of the land use within five miles of the GRP, and Colorado Plateau Pinyon-Juniper Shrubland, which comprises approximately 25 percent of the land cover (Table 1.2-1). Inter-Mountain Basins Semi-Desert Grassland includes dry grasslands and occurs on xeric sites within an elevation range of approximately 4750 to 7610 feet on varied landforms that include plains, swales, mesas, alluvial flats, and playas (NatureServe Explorer, 2021). This widespread ecological system often occurs on well-drained sandy or loam soil. The dominant shrubs and bunchgrasses are drought resistant (NatureServe Explorer, 2021).

Colorado Plateau Pinyon-Juniper Shrubland is dominated by less than nine-foot-tall trees on tops of rocky mesas and side slopes (NatureServe Explorer, 2021). Inter-Mountain Basins Mat Saltbush Shrubland comprises the next largest percentage, approximately 10 percent, of land cover within five miles of the GRP. Inter-Mountain Basins Mat Saltbush Shrubland is a dwarf shrub ecosystem in gentle slopes, basins, and plains (NatureServe Explorer, 2021). The herbaceous layer is sparse but can include perennial forbs and annual grasses.

Land use within five miles of the GRP License Boundary is predominantly undeveloped shrubland (Table 1.2-2). Shrubland comprises approximately 87 percent of the land use within five miles of the GRP (Figure 1.2-4). Developed land comprises approximately six percent of the land use within five miles of the GRP. A combination of pasture, open water associated with the GRP and other former mills, and evergreen forest comprise the remaining seven percent of land use.

Some land owned by HMC is used for livestock grazing through a lessor/lessee tenant arrangement. Portions of the GRP containing the evaporation ponds, RO Plant, tailings piles, and office/shop compound are excluded from livestock grazing and other land uses except those related to the ongoing groundwater restoration activities (Figure 1.2-5).

HMC owns several parcels within the GRP License boundary, which are not used except in limited locations where treated and/or fresh groundwater injection and groundwater collection occurs as part of the ongoing groundwater restoration program (Figure 1.2-5). A past land use involved land application on HMC land in Township 12 North, Range l0 West Sections 28, 33, and 34, as discussed above and in Section 4.1.

Major use of land not controlled by HMC and immediately proximal to the GRP consists of residential development located in the Pleasant Valley Estates, Murray Acres, Broadview Acres and Felice Acres

residential subdivisions. The most recent land use survey conducted pursuant to License Condition 42 is provided in the 2024 Annual Monitoring Report (HMC and Hydro-Engineering, 2025). An assessment of current land use in these four subdivisions was undertaken in January 2025 to provide an annual review of the present uses, occupancy and status for the various lots within these subdivisions. Over the years, permanent residential homes, modular homes and mobile homes have been established in the subdivisions, and adjacent areas, as would typify a rural residential neighborhood. Several lots remain vacant, or are used for horse barns, corrals, equipment storage, etc. In some cases, dwellings that are in various states of disrepair are present on several lots that are currently vacant or have been permanently abandoned.

The 2024 land use survey consisted of first obtaining the records and customer database from the Village of Milan water district. This information was reviewed to prepare a separate residential customer database for the subdivisions that would reflect the lot number, customer, water meter customer identification number and whether the customer utilized Milan water during 2024 (HMC and Hydro-Engineering, 2025). The lot-by-lot reconnaissance was made in each of the subdivisions to determine whether each lot was occupied or vacant, contained a residence(s), and which residences are currently occupied. This information was then checked against the database to determine whether each occupied residence is supplied and metered through the Village of Milan water supply system. Results of this reconnaissance effort are summarized on the subdivision plat maps (HMC and Hydro-Engineering, 2025) and Table 1.2-3. Field review of the subdivision areas, along with follow-up inquiries as required to confirm the status of water use at each property, indicates that occupied residential sites in, or immediately adjacent to the Felice Acres, Broadview Acres, Murray Acres, Pleasant Valley and Valle Verde subdivisions are on metered water service with the Village of Milan.

1.2.2.2 Population and Demographics

The population of New Mexico in 2020 was 2,117,522 (Census, 2020). This population represents an overall density of 17 persons per square mile or 8.9 persons per square kilometer (km^2). The average household population in New Mexico is 2.5 persons (https://www.census.gov/quickfacts/NM).

Cibola County was formed in 1981 from part of Valencia County. The overall annual growth rate of Valencia County from 1900 through 2020 is 4.57 percent. Cibola County is approximately 4,542 square miles in size and the population was estimated to be 27,172 in 2020 (Census, 2020) or approximately six people per square mile. The population of Cibola County declined 0.15 percent between 2010 and 2020 (Census, 2020). Cibola County population has declined an average of 0.29 percent per year since its creation in 1981.

The median household income for New Mexico for 2019 to 2024 was $67,816 with approximately 13.2 percent of the population living in poverty. The median household income for 2019 to 2024 in Cibola County was $50,759 with approximately 26 percent of the population living below the poverty threshold. Although Cibola County has a lower median income and higher rate of poverty than New Mexico as a whole, median income and poverty rate are similar to other counties in New Mexico. McKinley County, immediately to the north of the GRP, includes portions of the Navajo and Zuni Nations. McKinley County has a median income of approximately $45,307 and a poverty rate of 23.4 percent. Of the 33 counties in New Mexico, McKinley, Socorro and Cibola counties have the highest poverty rates in New Mexico. Socorro County is southeast of Cibola County. Available information for Milan, Grants, and San Rafael, in Cibola County is provided in Table 1.2-4.

1.2.2.3 Meteorology, Climatology and Air Quality

1.2.2.3.1 Regional Climate

The climate of western New Mexico is generally a mild, arid to semi-arid, continental climate characterized by low precipitation, abundant sunshine, low relative humidity, and a large annual and diurnal (day and night) temperature range. Temperature and precipitation are largely controlled by elevation and slope aspect. Summer rains fall almost entirely during brief, but frequently intense thunderstorms. The general southeasterly circulation from the Gulf of Mexico brings moisture for these storms into New Mexico, and strong surface heating combined with orographic lifting as the air moves over higher terrain causes air currents and condensation. July and August are typically the rainiest months, with between 30 and 40 percent of the year's total moisture falling during those months. Winter precipitation is caused mainly by frontal activity associated with the general movement of Pacific Ocean storms from west to east. As these storms move inland, much of the moisture is precipitated over the coastal and inland mountain ranges of California, Nevada, Arizona, and Utah. Winter is the driest season in New Mexico. Much of the winter precipitation falls as snow in the mountain areas, but it may occur as either rain or snow in the valleys (NMSU, 2019).

1.2.2.3.2 Local Meteorology and Climate

The GRP has an arid to semi-arid, temperate climate typical of a high desert. Table 1.2-5 summarizes the average maximum and minimum temperature and mean total precipitation at the Grants Airport located about 5.5 miles south of the GRP. Mean average temperatures range from a low of approximately 14 degrees Fahrenheit (°F) in January to a high of 89°F in July. The average annual total precipitation at the Grants-Milan Municipal Airport from 1953 through 2012 is approximately 10.29 inches per year (WRCC, 2019). Most of the precipitation, about 60 percent, falls in late summer and early fall. Average precipitation for the remainder of the year is about 0.5 inches per month.

HMC maintains a meteorological station at the GRP that is equipped to measure horizontal wind speed and direction at 10 meters above ground level, temperature, solar radiation and relative humidity at 9.5 meters above ground level, barometric pressure at 8.8 meters above ground level, and precipitation at 0.4 meters above ground level. A summary of the GRP meteorological data for 2024 is provided as Table 1.2-6.

The minimum and maximum temperatures measured at the GRP in 2020 ranged from 4.8° F to 91.4° F (-15.1^{o} C to 33.0^{o} C). The annual precipitation measured at the GRP in 2024 was 9.65 inches. The average pan evaporation at Laguna, New Mexico, about 30 miles southeast, for the period 1914-2005 (WRCC, 2019) is approximately 63 inches per year, resulting in an annual moisture deficit for the region. Evaporation is highest in June and July as shown in Figure 1.2-6.

Wind speed and direction are measured hourly at the GRP meteorological station. Wind roses for daytime and nighttime from 2009-2012 are shown on Figures 1.2-7 and 1.2-8, respectively. The hourly average wind speed exceeded 8.8 meters per second (m/sec) and 11.1 m/sec, which are 4.25 percent and 1.34 percent of the time, respectively (HMC, 2013). Prevailing winds faster than 2.1 meters per second are from the west and northwest, consistent with regional prevailing northwesterly winds reported at the Grants Airport, located 5.5 miles south of the GRP.

Surface wind speeds at the Grants Airport are highest in the spring, with a maximum monthly average of 14 miles per hour during April (NMCC, 2013). Historic data indicate that dominant (strongest) winds are

from the west and southwest and are associated with frontal systems moving from the Pacific Ocean. High spring winds in the area are known to create periods of dusty conditions, which may occur for several days during the months of March, April, and May. Moderate winds from the south-southeast are common and typically associated with summer storms sourced in the Gulf of Mexico. Most of the light northeasterly breezes occur at night. Nighttime is relatively calm compared to daytime hours (HMC, 2013).

1.2.2.3.3 Air Quality

No known monitoring stations are near the GRP. The nearest monitoring stations are outside of Albuquerque in Los Lunas and Bernalillo (NMED, 2019). Local sources of total suspended particulates are windblown dust, windblown water particles from the aeration systems on the evaporation ponds and vehicles on unpaved roads. HMC does not have any air permits for the GRP.

1.2.2.4 Ecology

When the Homestake mill and tailings piles were constructed in 1956 to 1958, no ecological surveys were performed before disturbance. The GRP is located within the Semiarid Tablelands ecoregion of the Arizona and New Mexico plateau that contains areas of high relief and some low relief plains (EPA, 2010a). The Semiarid Tablelands ecoregion is characterized by canyons, valleys, mesas, and plateaus formed primarily from flat to gently sloping sedimentary rocks, and areas of Tertiary and Quaternary volcanic fields. Bedrock exposures are common features in this ecoregion. The tablelands are vegetated with woodland, shrubs, and grass.

Shallow, stony soils supporting scattered to dense stands of junipers (*Juniperus species [spp.]*), and pinyon-juniper woodland is common in some areas. Other characteristic vegetation includes saltbush (*Atriplex spp.*), alkali sacaton (*Sporobolus airoides*), sand dropseed (*Sporobolus cryptandrus*), and mixed grama grasses (*Bouteloua spp.*). Vegetation is not as sparse as in the San Juan/Chaco Tablelands and Mesas ecoregion to the north or the Albuquerque Basin ecoregion to the east. The Semiarid Tablelands ecoregion lacks the dense pine forests typical of the higher- elevation Arizona and New Mexico Mountains ecoregion (EPA, 2010a).

A survey was conducted in 2018 with a one-mile buffer around the GRP as shown in Figure 1.2-9 (ERM, 2018).

1.2.2.4.1 Terrestrial Ecology

The vegetation communities near the GRP are Inter-Mountain Basins Mixed Salt Desert Shrub and Inter-Mountain Basins Semi-Desert Grasslands with minor areas of Inter-Mountain Basins Semi-Desert Shrub Steppe (ERM, 2018). Developed and disturbed areas and cultivated cropland are also present at and in the vicinity of the GRP. The vegetation communities are shown on Figure 1.2-10. Aquatic or diverse riparian habitat was not present and therefore the associated aquatic and riparian species would not be present in the one-mile buffer around the GRP (ERM, 2018).

Vegetation types within the GRP and immediate vicinity consist largely of semi-desert grassland, mixed salt desert scrub, and greasewood flat (Southwest Regional Gap Analysis Project, 2004). The GRP has been subject to human disturbance for more than 50 years. In 1995, much of the GRP was bladed and reseeded with a seed mixture consisting of western wheatgrass (*Pascopyrum s*mithii), blue grama (*Bouteloua gracilis*), sand dropseed (*Sporobolus cryptandrus*), Indian ricegrass (*Achnatherum hymenoides*), alkali

sacaton (*Sporobolus airoides*), and fourwing saltbush (*Atriplex canescens*) (NRC, 1993). Groundcover varies from 79 percent to 99 percent.

Other common plant species found within the GRP include kochia (Kochia spp.), bottlebrush squirreltail (*Elymus elymoides*), Russian thistle (*Salsola tragus*), broom snakeweed (*Gutierrezia sarothrae*), three-awn (*Aristida spp*.), spike dropseed (*Sporobolus contractus*), galleta grasses (*Pleuraphis spp*.), greasewood (*Sarcobatus vermiculatus*), sand sage (*Artemisia filifolia*), and narrowleaf yucca (*Yucca angustissima*). Limited areas of saltcedar (*Tamarix ramosissima*) are present along the ephemeral San Mateo Creek (HMC, 1982; Bridges and Meyer, 2007; NRC, 2008).

Characteristic animal species include desert cottontails, jack rabbits, pocket gophers, meadowlarks, and western rattlesnakes. Table 1.2-7 lists the species of wildlife known to occur in the vicinity of the GRP.

The survey (ERM, 2018) identified several plant and wildlife species of interest (Tables 1.2-8 and 1.2-9). No federal or state threatened or endangered species were observed at the GRP. However, suitable habitat exists within one mile of the GRP for the peregrine falcon and the gray vireo, federal threatened and state threatened species, respectively. The loggerhead shrike, a New Mexico sensitive and federal bird of conservation concern was observed during the survey. Habitat for other federal birds of conservation concern and New Mexico sensitive species and crucial habitat for elk, cougar, turkey, and mule deer were identified within the one-mile buffer around the GRP (Figures 1.2-11 through 1.2-14).

No species currently listed as endangered by the federal government or the State of New Mexico are expected near the GRP. The majority of listed species and species of concern have no potential to occur in the GRP due to a lack of suitable habitat. A survey confirmed the lack of suitable habitat for listed plant and animal species (Bridges and Meyer, 2007). The exceptions are American peregrine falcons, arctic peregrine falcons, and bald eagles, which may occasionally pass through the area during migration; cinder phacelia, mountain plovers, and western burrowing owls, which can inhabit disturbed areas and areas near people; and spotted bats, which may occasionally forage at the GRP (HMC, 2013).

The United States Fish and Wildlife Service online threatened and endangered species list identified no critical habitat within the area near the GRP (Appendix 1.2-B).

1.2.2.4.2 Aquatic Ecology

The ephemeral San Mateo Creek within GRP the flows infrequently and only after heavy precipitation events or snowmelt. There is no distinct channel for this drainage within the GRP (Bridges and Meyer, 2007).

The evaporation ponds are anthropogenic, engineered structures designed to contain and evaporate GRP water. Therefore, they do not have a natural aquatic ecosystem, and are not suitable for aquatic habitats for community-level receptor groups such as fish or invertebrates.

The significant aquatic habitat nearest to the GRP is Bluewater Lake, an anthropogenic impoundment of Bluewater Creek, located about fourteen miles to the west. No studies of surface water aquatic organisms were conducted.

1.2.2.5 Soil

The Natural Resource Conservation Service Soil Map was reviewed and 21 soil map units were identified within the one-mile buffer around the GRP (ERM, 2018). The Sparank-San Mateo complex was identified as the predominant soil type (Figure 1.2-15). Sparank and San Mateo soils are moderately alkaline and well drained loams. Sparank soil is clay loam overlying a silty clay loam. San Mateo soil is a loam (ERM, 2018).

1.2.2.6 Geology

1.2.2.6.1 Regional Geology and Hydrogeology

The GRP is located in the San Mateo Creek Basin in the southeastern portion of the Colorado Plateau physiographic province on the south flank of the San Juan Basin (Figure 1.2-16). Figure 1.2-17 presents a geologic cross-section illustrating the principal stratigraphic units of the San Juan Basin. The region experienced structural deformation (regional folding and block uplift) associated with formation of the Zuni Uplift from the Late Cretaceous through the Eocene during the Laramide Orogeny (HDR, 2020). This uplift formed the Zuni Mountains, which consist of a northwest-trending monoclinal fold approximately 75 miles long and 30 miles wide located southwest of the GRP. This fold is composed of Precambrian crystalline basement rocks overlain by Permian to Jurassic sedimentary rocks (Langman, et al., 2012). Figure 1.2-18 presents a geologic cross section through the central portion of the San Mateo Creek Basin illustrating the water-yielding units.

Bedrock units at the GRP consist of the Glorieta Sandstone (Early Permian), San Andres Limestone (Early Permian), and the Chinle Formation Group (Late Triassic). The Chinle Formation is composed of laterally continuous sandstone units separated by thick sections of low permeability shale. The GRP is located on the eastern flank of the fold, where bedrock dips approximately 3 to 10 degrees to the north-northeast into the San Juan Basin (Kelley, 1967). Figure 1.2-19 presents a generalized surficial geologic map.

More recent faulting associated with the Rio Grande Rift resulted in the large northeast-striking San Mateo normal fault located northeast of the GRP and two small-scale normal faults near the GRP referred to as the West Fault and the East Fault (Figures 1.2-19 and 1.2-20). The dip of these two faults is nearly vertical and offset in the Chinle Formation results in the juxtaposition of permeable sandstones with impermeable mudstones and siltstones across the two faults near the GRP. Displacement along the East Fault is minimal immediately south of the Felice Acres subdivision, and sandstone units are not vertically offset (HMC and Hydro-Engineering, 2010b). The magnitude of structural offset of the underlying San Andres-Glorieta regional aquifer is much lower than the vertical thickness of the unit and does not appear to significantly affect groundwater flow.

During the Tertiary (Neogene) Period, volcanic activity associated with the Mount Taylor volcanic field resulted in widely scattered andesite and basalt flows (HDR, 2020). An erosional period followed the volcanism and created the valley forms observed in the San Mateo Creek Basin, eroding the surface up to 150 to 200 feet below the current land surface (Langman, et al., 2012). This erosional period exposed Cretaceous and Permian bedrock formations outcrop in progressively older northeast to southwest trending bands to the west of the GRP. Erosion of the dipping formations produced a pronounced angular unconformity between bedrock strata and Quaternary valley fill, resulting in sandstone units within the underlying Chinle Formation abruptly truncating at the base of the alluvium.

Quaternary deposits consist of localized andesite and basalt flows and widespread alluvium, which is composed of locally eroded bedrock materials, some of which were ore-bearing rock. As a result, the alluvium contains significant concentrations of naturally occurring uranium, as well as selenium and molybdenum, which are typically present in uranium deposits (HMC, 2012). The lithology types and stratigraphic placement observed in the borehole logs (primarily clays and sands with varying silt and/or gravel) are consistent with a fluvial depositional environment (e.g., meandering stream and flood overbank deposits). Clay and silt beds typically range from two to ten feet in thickness, with combined thickness up to 20 feet. Sand beds generally range from five to 20 feet. Clasts range from rounded to some angular grains, though the majority are sub-rounded, indicating that sediments were transported a moderate distance from their source (Novak-Szabo et al., 2018). This type of depositional environment results in the presence of preferential pathways of a higher permeability channel and channel lag deposits positioned directly adjacent to fine-grained, low permeability overbank deposits.

High resolution characterization techniques were used in two supplemental studies at the GRP; a study of background concentrations in alluvial groundwater and a tripolyphosphate pilot study (Arcadis, 2016; Arcadis, 2019). Two geologic cross sections from these studies have been reproduced in this report to show the degree of heterogeneity in the alluvium at the GRP. One cross section is located immediately upgradient of the Large Tailings Pile (Figure 1.2-21) and the other is located downgradient of the Large Tailings Pile (Figure 1.2-22). Both cross sections illustrate the scale and degree to which the sediments vary, both aerially and with depth.

Widespread Quaternary andesite and basalt flows are interbedded with alluvial deposits. These localized volcanic flows were encountered during drilling investigations to the west of the Large Tailings Pile and are limited to the area west of the Pleasant Valley Estates neighborhood in both the San Mateo Creek and Rio San Jose alluviums. The thickness of the basalt encountered during drilling has a maximum thickness of 109 feet (average 49 feet). Depictions of the three-dimensional geology and hydrogeology of the area around the GRP are illustrated on Figure 1.2-23.

1.2.2.6.2 Local Geology and Hydrogeology

The hydrogeological framework of the GRP area consists of a hydraulically unconfined, buried valley alluvial water-yielding unit overlying, and in hydraulic connection with, discrete bedrock aquifer units within the Chinle Formation and the San Andres-Glorieta regional aquifer (Figures 1.2-24 through 1.2-27). Although the Chinle Formation is largely composed of shale, there are three water-bearing units within the Chinle: the Upper, Middle, and Lower Chinle. The Upper and Middle Chinle are both largely composed of sandstone. The Lower Chinle consists of a zone of enhanced water yield within the shale formation. The Chinle water-yielding units are under partially confined conditions where they subcrop beneath the alluvial aquifer. The units are under confined conditions further downdip. A regional aquifer, the Permian-age San Andres Formation sandstone, exists at depth below the GRP, and predominantly consists of limestone with subsidiary sandstones and shale.

Bedrock units are tilted and faulted near the GRP. As a result, all three Chinle water-yielding units subcrop with the overlying alluvial aquifer. Water exchange occurs between the alluvial aquifer and the Chinle units creating mixing zones. In these mixing zones, hydraulic communication exists between the alluvium and the Chinle units (USACE, 2010).

1.2.2.6.2.1 Alluvial Aquifer System

The unconfined alluvial aquifer in the area of the GRP is laterally bound by areas of higher bedrock elevation. The saturated extent of the aquifer is shown on Figure 1.2-28. As a result of these bedrock highs, the alluvial aquifer has been subdivided into three distinct but connected alluvial systems, referred to as the San Mateo, Rio Lobo, and Rio San Jose alluvial systems. The San Mateo alluvial system covers the majority of the GRP area, extending northeast, south and southwest of the GRP, eventually joining with the Rio Lobo and more extensive Rio San Jose alluvial systems.

San Mateo Alluvial System

The San Mateo alluvial aquifer occurs as a north-south trending buried valley extending through the GRP. Groundwater flow in the San Mateo alluvial aquifer is generally north to the south, upgradient of the Large Tailings Pile, and to the southwest of the Large Tailings Pile (Figure 1.2-29). An artificial hydraulic barrier that is part of the current remediation system creates a zone on the southern and western sides of the Large Tailings Pile area where the natural gradient is artificially interrupted by a combination of collection and injection operations.

An area of high bedrock southwest and downgradient of the Large Tailings Pile results in a local branching of the San Mateo alluvial aquifer downgradient of the Large Tailings Pile. A branch extends to the west to a confluence with the Rio San Jose alluvial aquifer, and a branch extends to the south to a confluence with the Lobo alluvium, which eventually leads to a confluence with the Rio San Jose alluvial aquifer.

From the inception of monitoring by HMC through 2016, saturation of the San Mateo alluvium has increased both upgradient and downgradient of the Large Tailings Pile. Increased saturation upgradient of the Large Tailings Pile is attributable to recharge from upgradient conditions unrelated to the former mill. Beneath and downgradient of the Large Tailings Pile, historical tailings seepage and groundwater corrective action water injection are the primary contributions to increased saturation. Since 2016, the water table has declined in the vicinity of the Large Tailings Pile by approximately 1-2 feet/year. The water table ranges between 40 and 85 feet below the ground surface, with elevations ranging from approximately 6,479 to 6,552 feet above msl during the fall 2024 monitoring events.

Rio Lobo Alluvial System

The Rio Lobo alluvium is typically a sandy material with minor clay and silt layers of limited continuity. Since these materials are similar to the San Mateo alluvium, the physical characteristics of the alluvium are expected to be similar.

Based on a 1995 investigation, it was determined that saturated portions of the Rio Lobo system were likely confined to narrow sections where the alluvium was deposited within incised channels, or that a subcrop of pervious bedrock drained the alluvial aquifer upgradient of the confluence with the San Mateo system. Water quality differences in wells northeast of the Large Tailings Pile and other background wells indicated that the confluence of the Rio Lobo and San Mateo alluvial systems may occur approximately 2,000 feet northeast of the Large Tailings Pile (Arcadis, 2019). Based on the lack of alluvial saturation encountered in the Lobo drainage basin, the quantity of Lobo alluvial water entering GRP, if any, is thought to be only a small fraction of the quantity from the San Mateo alluvial system.

Rio San Jose Alluvial System

Rio San Jose alluvium is generally composed of sand and gravel with a wide range of transmissivity. Groundwater in the Rio San Jose system flows southeast from the Bluewater Mill site and merges with San

Mateo Creek alluvial system. The combined flow continues southeast toward Milan (DOE, 2014). Groundwater flow direction is provided in Figure 1.2-30.

1.2.2.6.2.2 Upper Chinle

The upper unit of the Chinle Formation, Upper Chinle, has been described as consisting of reddish-brown mudstone and siltstone with interbedded sandstone, sometimes containing fine-grained limestone lenses. The Upper Chinle is a northeast-dipping, confined unit composed of a laterally continuous sandstone unit. Structural elevation contours of the top of the Upper Chinle indicate minor variations in the steepness of the northeasterly dip, particularly in the area immediately south of the Large Tailings Pile. The Upper Chinle unit is hydraulically bounded from other Chinle Formation aquifer units by competent overlying and underlying shale that has been structurally offset by the West and East Faults at the GRP. The average thickness of the sandstone is approximately 35 feet (HMC, 2012).

The Upper Chinle subcrops at the base of the alluvium on both sides of the East Fault, most notably at the base of the western side of the Large Tailings Pile. However, the sandstone subcrop does not occur west of the West Fault, rather, the subcrop was offset farther north as a result of the most recent high-angle normal faulting and northeast-dipping bed surface.

The groundwater quality of the Upper Chinle is influenced by the groundwater quality of the alluvial aquifer as a result of the alluvial aquifer discharging to the Upper Chinle east of the East Fault and in the vicinity near and north of the Large Tailings Pile (HMC, 2012). The saturated thickness of the Upper Chinle ranges from 15 to 65 feet thick with an average thickness of approximately 35 feet near the GRP.

Groundwater flow direction in the Upper Chinle is greatly influenced by remedial action involving the injection of fresh water into the Upper Chinle and collection from a series of extraction wells (Figure 1.2-31). Groundwater at the GRP generally flows from areas mounding near the injection wells toward extraction wells.

1.2.2.6.2.3 Middle Chinle

The Middle Chinle is composed of light orange to light gray poorly-sorted cross-bedded and conglomeritic sandstone (up to 30 feet thick) containing mudstone and siltstone lenses. The Middle Chinle is an east to northeast-dipping, confined unit composed of laterally continuous sandstone. The unit is similar to the Upper Chinle and is hydraulically bounded from other Chinle Formation units by competent overlying and underlying shale. The Middle Chinle is generally the thickest of the sandstone units in the formation with a saturated thickness ranging from 10 to 80 feet and an average thickness of approximately 44 feet near the GRP (HMC, 2012).

The Middle Chinle exists as three fault-bound groundwater systems separated by the West and East Faults (HMC and Hydro-Engineering, 2010b). All three systems for the Middle Chinle subcrop at the base of the alluvium. Subcrop areas on either side of the West Fault have been laterally offset by approximately 5,400 feet due to fault slip along the West Fault. The Middle Chinle is hydraulically connected to the overlying alluvial aquifer on the west side of the West Fault and between the West and East Faults at an isolated location in a confined alluvial channel south of the Felice Acres subdivision (HMC, 2012).

Hydraulic head in the Middle Chinle in areas outside of the two faults is significantly different from the head between the two faults, which demonstrates that the groundwater is not readily connected across fault boundaries (Figure 1.2-32). The West Fault represents a significant barrier to groundwater flow within the

Middle Chinle, with tens of feet of hydraulic head difference across the fault in the area west of the Large Tailings Pile.

Pumping of Middle Chinle South Collection wells near the south end of South Felice Acres developed a depression in the Middle Chinle potentiometric surface that extends nearly 500 feet to the northeast and southwest of well Y7 and intercepts much of the flow in the area of the Broadview Acres and South Felice Acres developments. A steep gradient developed to the southeast of this well indicating potential recharge to the Middle Chinle from the alluvial aquifer.

Groundwater flow west of the West Fault is historically to the southwest, and discharges into the alluvial aquifer. This prevented the alluvial aquifer from affecting the water quality of the Middle Chinle on the west side of the West Fault. The area west of the Large Tailings Pile receives flow from upgradient offsite areas, where based on water quality monitoring, the Middle Chinle is in hydraulic connection with the alluvial aquifer. Alluvial aquifer injection activities temporarily reversed the vertical hydraulic gradient in the northern portion of Township 12 North, Range l0 West Section 27 during 2006 through 2014. This situation was corrected in 2016 by targeting groundwater withdrawal from the Middle Chinle to the north and from the alluvial aquifer through the subcrop to the south.

The remainder of the Middle Chinle is recharged by the alluvial aquifer south of Felice Acres. The injection of fresh water into wells CW14 (north of Broadview Acres) and CW30 (west of Felice Acres) has created groundwater mounds in their respective areas. These mounds cause the groundwater to flow both north and south from these two wells.

1.2.2.6.2.4 Lower Chinle

The Lower Chinle consists of reddish-brown to purple and light gray to white silty sandstone with interbedded mudstone and siltstone. The confined Lower Chinle is the deepest permeable zone within the Chinle Formation and is generally located approximately 200 feet above the geologic contact with the San Andres limestone. The Lower Chinle is hydraulically isolated from the overlying Middle Chinle and underlying San Andres-Glorieta regional aquifer. In contrast with the overlying Chinle sandstone units, the Lower Chinle is composed of shale with enough developed secondary permeability to behave as a limited aquifer (HMC and Hydro-Engineering, 2010b). The permeability of the Lower Chinle is not consistently high enough to serve as a viable aquifer, and areas exist where the aquifer is effectively absent.

The Lower Chinle subcrops at the base of the alluvium on either side of the West Fault, which has been laterally offset by approximately 3,000 feet due to slip displacement along the West Fault. Direct hydraulic connectivity with the overlying alluvial aquifer exists in the area between the West and East Faults southwest of the Felice Acres subdivision and immediately west of the Valley Verde and Pleasant Valley subdivisions on the west side of the West Fault. The Lower Chinle is presumed to be laterally continuous immediately south of the terminus of the East Fault, where the aquifer functions as a single hydrologic unit (HMC, 2012).

The inferred direction of groundwater flow in the Lower Chinle is shown on Figure 1.2-33. Groundwater elevations for the Lower Chinle ranged from approximately 6,468 to 6,487 feet above msl during the fall 2024 annual monitoring events (HMC and Hydro-Engineering, 2025). Flow west of the West Fault in the Lower Chinle is mainly to the northeast. Flow between the two faults is to the northeast in the area of the tailings. The flow is to the northwest in the southern portion of the Lower Chinle between the faults.

Hydraulic head is higher in the alluvial aquifer than in the Lower Chinle with the exception of the subcrop locations, where the hydraulic communication occurs.

In general, the Lower Chinle is only viable as a water resource near the subcrop locations in connection with the alluvial aquifer, where adequate secondary permeability has likely resulted from weathering and faulting (HMC, 2012).

1.2.2.6.2.5 San Andres-Glorieta Aquifer

The San Andres-Glorieta aquifer is the regional aquifer in the GRP area, consisting of the San Andres Limestone and Glorieta Sandstone with a total thickness that exceeds 200 feet (HMC and Hydro-Engineering, 2010b). Similar to the Chinle Formation aquifers, the regional aquifer is mildly folded and dips to the east and northeast as a result of regional tectonic deformation. Refer to Figure 1.2-34 for a plan view of the GRP area showing well locations, measured groundwater elevations and inferred contours from 2019 measurements. The aquifer has been used historically by HMC as the source of unimpacted clean water used for hydraulic containment of the alluvial aquifer and Chinle Formation groundwater. The contours shown are based in part on wells that are not shown on Figure 1.2-34, including well 951 and DOE wells further upgradient.

Groundwater elevations near the GRP ranged from 6,417.72 to 6,429.66 feet amsl in 2024 (HMC and Hydro-Engineering, 2025). Flow direction is to the east-southeast. The water-level elevations measured during 2024 show a very flat piezometric surface. The continuity of the gradient across the GRP indicates that the East and West Faults do not significantly affect the groundwater flow in the San Andres-Glorieta aquifer. It is believed that the displacement at the faults is not large enough to completely displace the entire thickness of this aquifer system.

The San Andres-Glorieta regional aquifer and the alluvial aquifer are separated by the Chinle formation that acts as an aquitard (approximately 800 feet thick) at the GRP (Figure 1.2-24 to Figure 1.2-27). Difference in the head between the Chinle and San Andres-Glorieta aquifers confirms that the Chinle formation is acting as an aquitard (Figure 1.2-34). As shown on Figure 1.2-35, the San Andres-Glorieta aquifer subcrops the alluvial aquifer in Sections 5 and 32 west of the GRP.

1.2.2.7 Hydrology

1.2.2.7.1 Regional Groundwater Hydrology

The Morrison Formation, Entrada Complex, and San Andres-Glorieta aquifer are considered the major aquifers in the San Mateo Creek Basin (Figure 1.2-18). The San Mateo Creek Basin is primarily a region of recharge to groundwater, both to shallow and deeper hydrostratigraphic units. Figure 1.2-36 shows the general regional groundwater flow patterns for aquifer units that receive recharge within the San Mateo Creek Basin. Groundwater recharge, discharge, and flow characteristics as well as aquifer physical properties for each of the principal aquifers in the San Mateo Creek Basin are provided as part of the regional hydrostratigraphic conceptual model (Brown and Caldwell, 2018). The effects of groundwater extraction in the alluvium, Morrison Formation, and San Andres-Glorieta aquifer on regional flow conditions are also presented in the regional hydrostratigraphic conceptual model. The main structural features in the San Mateo Creek Basin consist of north- to northeast-trending sub-vertical normal faults, which may locally either impede or facilitate groundwater flow, depending on orientation and offset.

1.2.2.7.2 Local Groundwater Hydrology

1.2.2.7.2.1 San Mateo Alluvial System

The San Mateo Creek aquifer occurs as an east-west trending buried valley aquifer extending through the Site. The San Mateo Creek aquifer is an unconfined aquifer with specific yields estimated to range from 0.038 to 0.28. Water levels show groundwater flows from the LTP to the west in the San Mateo Creek aquifer where it combines with the Rio San Jose aquifer. The water table ranges from 40 to 60 ft below ground surface (bgs) with water level elevations ranging from 6,479 to 6,552 ft above mean sea level (amsl) during the (Fall 2024) monitoring event (Figure 1.2-29). On the southern and western sides of the LTP, the natural gradient is artificially interrupted by a combination of groundwater extraction and downgradient injection operations to create a hydraulic barrier as part of the current remediation system. The San Mateo Creek aquifer saturated thickness ranges from 10 to 68 ft. From the LTP to Pleasant Valley Estates/Murray Acres, the saturated thickness ranges from 10 to 68 ft; however, the saturated thickness ranges from 10 to 30 ft southwest of Pleasant Valley Estates/Murray Acres. The hydraulic conductivity of the high K units is estimated to range from 5 to 100 ft per day (ft/day) (Figure 1.2-37).

1.2.2.7.2.2 Quaternary Volcanics

Quaternary basalt flows are interbedded with the alluvial deposits in the area partially beneath and west of the Pleasant Valley Estates neighborhood in both San Mateo Creek and Rio San Jose alluvium. The saturated thickness of the basalt ranges from 5 ft at the 100-acre center pivot to 23 ft north of the Pleasant Valley Estates/Murray Acres. The hydraulic conductivity of the fractured basalt has been estimated to range from 10 to 3,400 ft/day. These volcanic flows could affect the vertical movement of groundwater and COCs in the San Mateo Creek and Rio San Jose aquifers. The Quaternary basalt is underlain by 2 to 30 ft of water-saturated alluvial deposits

1.2.2.7.2.3 Rio Lobo Aquifer

The Rio Lobo aquifer occurs as an unconfined northeast-southwest trending buried valley aquifer. Groundwater flow in the Rio Lobo aquifer is generally to the southwest, extending from south of the LTP to the Rio San Jose aquifer. The hydraulic conductivity has been estimated to range from approximately 5 to 37 ft/day. The saturated thickness of the Rio Lobo ranges from 10 to 40 ft thick with water level elevations ranging from 6,525 to 6,465 ft amsl during the Fall 2024 monitoring event.

1.2.2.7.2.4 Rio San Jose Aquifer

The Rio San Jose aquifer occurs as an unconfined north to south trending buried valley aquifer. Groundwater flow is generally north to south. The hydraulic conductivity of the Rio San Jose aquifer has been estimated to range from 10 to 50 ft/day. The saturated thickness ranges from 10 to 80 ft thick with water level elevations ranging from 6,480 to 6,430 ft amsl during the Fall 2024 monitoring event. Groundwater in the Rio San Jose aquifer flows south and merges with San Mateo Creek and Rio Lobo aquifers.

1.2.2.7.2.5 Upper Chinle

Aquifer properties vary significantly within the bedrock units due to the effects of secondary permeability; specifically, fracturing of the sandstone related to faulting. As a result, a narrow band (several hundred feet wide) of elevated transmissivity exists on both sides of the East Fault. Estimated transmissivity values along the western side of the East Fault exceed 10,000 gallons per day per foot (gpd/ft). Estimated transmissivity values on the eastern side of the East Fault exceed 2,000 gpd/ft, but generally range between approximately 100 to 2,000 gpd/ft (HMC and Hydro-Engineering, 2010b). In contrast, estimated

transmissivity values are much lower in the region between the West and East Faults (Figure 1.2-38), where the aquifer unit is not fractured and finer grain size was noted.

The hydraulic conductivity of the Upper Chinle ranges from less than 0.1 feet/day to more than 100 feet/day (HMC and Hydro-Engineering, 2010b). The saturated thickness of the aquifer ranges from 15 to 65 feet thick with an average thickness of approximately 35 feet near the GRP.

Groundwater flow direction in the Upper Chinle is greatly influenced by remedial action involving the injection of compliant water into the Upper Chinle and collection from a series of extraction wells (Figure 1.2-31). Groundwater at the GRP generally flows from areas mounding near the injection wells toward extraction wells.

1.2.2.7.2.6 Middle Chinle

Transmissivity of the Middle Chinle varies significantly due to the effects of reduced permeability associated with faulting, groundwater pumping, and containment measures (HMC and Hydro-Engineering, 2010b). East of the East Fault, transmissivity values range from 500 gpd/ft to less than 100 gpd/ft. Transmissivity values greater than 5,000 gpd/ft have been observed in the western portion of the Large Tailings Pile, eastern Murray Acres and western Broadview and Felice Acres (Figure 1.2-39).

1.2.2.7.2.7 Lower Chinle

The confined Lower Chinle is the deepest permeable zone within the Chinle Formation and is generally located approximately 200 feet above the geologic contact with the San Andres limestone (Figure 1.2-23). The Lower Chinle is hydraulically isolated from the overlying Middle Chinle and underlying San Andres-Glorieta regional aquifer. In contrast with the overlying Chinle water-yielding units, the Lower Chinle is composed of shale with enough developed secondary permeability to behave as a limited aquifer (HMC and Hydro-Engineering, 2010b). The permeability of the water-yielding unit is not consistently high enough to serve as a viable aquifer, and areas exist where the water-yielding unit is effectively absent.

The Lower Chinle subcrops at the base of the alluvium on either side of the West Fault, which has been laterally offset by approximately 3,000 feet due to slip displacement along the West Fault (Figure 1.2-26). Direct hydraulic connectivity with the overlying alluvial aquifer exists in the area between the West and East Faults southwest of the Felice Acres subdivision and immediately west of the Valley Verde and Pleasant Valley subdivisions on the west side of the West Fault (Figure 1.2-33). The Lower Chinle water-yielding unit is presumed to be laterally continuous immediately south of the terminus of the East Fault, where the water-yielding unit functions as a single hydrologic unit (HMC, 2012).

The hydraulic properties of the Lower Chinle are highly variable and largely depend on secondary permeability within the shale. The ability of the Lower Chinle to produce water is much lower and less consistent than overlying Chinle sandstone. Hydraulic conductivity ranges from 0.1 to more than 50 feet/day (HMC and Hydro-Engineering, 2010b). Estimated transmissivity values for the Lower Chinle are generally higher than 100 gpd/ft near subcrop locations (HMC and Hydro-Engineering, 2010b). However, selected areas near subcrop locations exceed 1,000 gpd/ft (Figure 1.2-40).

In general, the Lower Chinle is only viable as a water resource near the subcrop locations that are connected with the alluvial aquifer, where adequate secondary permeability has likely resulted from weathering and faulting (HMC, 2012).

1.2.2.7.2.8 San Andres-Glorieta Aquifer

The U.S. Geological Survey (USGS) suggested an average transmissivity of 374,000 gpd/foot (Baldwin and Anderholm, 1992; Frenzel, 1992). An average groundwater velocity of 4 feet/day is estimated based on a hydraulic conductivity of 615 feet/day, a gradient of 0.00086 foot per foot (ft/ft), and an assumed effective porosity of 0.1 (HMC and Hydro-Engineering, 2010b). The groundwater velocity is likely to vary greatly in this type of aquifer due to a very wide variation of hydraulic conductivity and effective porosity.

1.2.2.7.3 Regional Surface Water Hydrology

The GRP area has no perennial surface water because of the limited rainfall and high evaporation rates in the region. Surface water in the immediate vicinity of the GRP is ephemeral and may occur for very short periods of time seasonally in the San Mateo Creek, Lobo Creek, and Rio San Jose drainages. Surface flows in these creeks are virtually non-existent and may only occur for short periods of time in response to extreme snowmelt and/or summer thunderstorm events (Brown and Caldwell, 2018). Maps showing upgradient drainage areas and surface water drainages in the vicinity of the GRP are presented in Figure 1.2-41 and Figure 1.2-42, respectively.

The San Mateo Creek watershed drainage covers an area of approximately 76 square miles and is part of the Rio Grande drainage basin (Byrd and Montano, 2004). The headwaters of San Mateo Creek are on the north flank of Mt. Taylor located approximately 15 miles east of the GRP. San Mateo Creek is intermittent (flows only during certain seasons each year) over its middle reach, which is normally dry in the summer except for high rainfall events when runoff occurs. San Mateo Creek is ephemeral (flows only briefly from precipitation events) in its lower reach and there is no distinct channel near the GRP (NRC, 2008).

In the upper parts of San Mateo Creek and Lobo Canyon, on the western side of Mount Taylor, perennial flow occurs at San Mateo Springs, an unnamed tributary of San Mateo Creek, and an unnamed tributary of Lobo Creek.

Current and likely future regional surface water uses are limited due to the ephemeral nature of most drainages in the region. The primary regional surface water use is stock watering in small surface impoundments in local drainages. Due to the absence of perennial surface water in the area, few data on surface water quality are available but surface water quality likely varies seasonally in direct response to precipitation runoff events, local surface soil characteristics and evapoconcentration.

1.2.2.7.4 Local Surface Water Hydrology

There is no perennial surface water flow in the GRP area drainages. These drainages only flow in response to intense rainfall events that periodically cause flood conditions. Consequently, there are no surface water uses in the GRP area. San Mateo Creek and Lobo Creek both drain onto the GRP (Figure 1.2-41). Surface water discharges from the Lobo Canyon portion of the San Mateo watershed follow a drainage that cuts across the northeast corner of the former Homestake Mill site. Two Lobo Creek drainages enter the east side of the GRP (Figure 1.2-42).

HMC constructed a diversion levee north of the former mill area to divert surface water flows from the northern branch of Lobo Creek (Figure 1.2-43; AK Geoconsult and Jenkins, 1993), which only flows in response to intense rainfall events that cause flood conditions. During flood events, the levee diverts Lobo Creek to the North Diversion Channel along the north edge of the Large Tailings Pile, preventing water from flowing across the former mill area. The levee was constructed using uncontaminated soil generally

consisting of clayey sands and sandy clays. The slopes of the levee are protected against erosion using the same cover material specified for the Large Tailings Pile (HMC, 2013). San Mateo Creek drainage enters the GRP from the north (Figure 1.2-42) and is also diverted by the North Diversion Channel west around the Large Tailings Pile as shown on Figure 1.2-43.

1.2.2.8 Water Quality and Water Use

1.2.2.8.1 Surface Water Use

There are no known uses of surface water at the GRP. No perennial surface water flow exists in the GRP area drainages. Surface water only flows in response to intense rainfall events that periodically cause flood conditions. Because these episodic flows are highly infrequent, data from these flows have not been collected.

1.2.2.8.2 Groundwater Quality

The following subsections provide a discussion on the groundwater quality as it pertains to background and the different stratigraphic units that exist in the vicinity of the site.

Groundwater quality samples were collected according to the HMC groundwater sampling standard operating procedure. Quality assurance and quality control were performed per the quality assurance plan current at the time of sampling. The most current Quality Assurance Plan is Rev.4, February 2022. The Quality Assurance Plan addresses the QA/QC program management and organization including roles and responsibilities, data generation and acquisition including field and laboratory quality control, instrument calibration and data management, control of documents and records, program assessment and oversight, as well as data validation and usability.

1.2.2.8.2.1 Background Groundwater Quality

The NRC established initial groundwater protection standards in 1989 for the GRP based on background concentrations from a single San Mateo alluvium (alluvial aquifer) monitor well, well P (NRC, 1989). In 2001, HMC submitted a license amendment request for changes in the groundwater protection standards at the GRP (HMC, 2001) and provided additional submittals in support of that request (ERG, 2003a; ERG, 2003b; HMC and Hydro-Engineering, 2003; ERG, 2004; HMC and Hydro-Engineering, 2004; HMC, 2005a; HMC, 2005b; HMC, 2006). These submittals culminated in a request to amend the license to incorporate the current groundwater protection standards in light of new background analyses. Specifically, the amendment requested revised groundwater protection standards for selenium, uranium and molybdenum for the alluvial aquifer; addition of groundwater protection standards for nitrate, total dissolved solids, sulfate, and chloride for the alluvial aquifer to be consistent with the State of New Mexico Discharge Permit requirements; and establishment of groundwater protection standards for the Chinle mixing and non-mixing zones. These amendment requests were based on 23 years of data from 1976 through 1998. The differing background groundwater quality for the respective hydrostratigraphic units at the GRP relate primarily to the difference in composition and rock types of the units.

The new background analyses that prompted the request to revise the groundwater protection standards are consistent with and developed in accordance with NRC, EPA, and NMED requirements. All three agencies

define background in terms of substance in the environment that either exist naturally or come from human activities unrelated to the specific site in question. NRC regulation (10 CFR § 20.1003) defines background radiation as radiation from cosmic sources, naturally occurring radioactive material, global fallout from weapons testing or past nuclear accidents, and any other sources not under the control of the site licensee, which would be present in comparable levels in the environment both on and off a particular site. Similarly, EPA guidance for CERCLA sites (EPA, 2022a) defines background to include constituents in the environment that are not influenced by releases from a particular site, which could be naturally occurring or anthropogenic (i.e., substances in the environment as a result of human activities unrelated to the CERCLA site). NMED's water quality regulations (N.M. Admin. Code 20.6.2.7(B)(1)) defines background for purposes of groundwater abatement plans to include contaminants from naturally occurring, undisturbed geologic sources and other contaminants established to be occurring from a source other than the particular site at issue.

NRC issued an Environmental Assessment documenting the agency's environmental analysis of the amendment request (NRC, 2006b), which resulted in a finding of no significant impact. The new standards were incorporated into the License on July 10, 2006 via Amendment 39. EPA approved these background values as the criteria for aquifer restoration (EPA, 2005b). NMED approved these background values in a letter dated August 18, 2005 (NMED, 2005). These background values are summarized in Table 1.1-1.

The EPA has identified the possibility that groundwater concentrations in the San Mateo alluvial aquifer directly upgradient of the GRP may be elevated for reasons not directly related to the NRC-licensed operations (EPA, 2021). Regardless of the cause of upgradient concentrations, if they are not related to NRC-licensed activities at the GRP, those conditions represent background conditions for the GRP, consistent with the regulations and guidance summarized above.

Alluvial Groundwater Quality

The major (i.e., most prevalent) cation found in background alluvial groundwater is calcium and the major anion is sulfate (Figure 1.2-44). The composition of groundwater is very similar in each of these wells, indicating a general consistency of water composition in the background alluvial system.

An exception is well ND, which has the highest sodium, bicarbonate and chloride levels of the alluvial wells. Sodium is the prevalent cation in well ND water. Concentrations of the remaining most prevalent ionic constituents in well ND groundwater are significantly lower than those of the typical background alluvial groundwater. Groundwater in well ND has very low calcium concentrations and other water-quality characteristics (such as a greater natural sodium concentration) that are similar to the characteristics observed in Chinle groundwater. The differences in well ND water composition demonstrate some naturally occurring variation in water type within the alluvium on the eastern portion of the project. Given the similarities in alluvial well ND groundwater composition and the Chinle groundwater, there may be a localized subsurface discharge of Chinle groundwater to the alluvial aquifer on the east side of the upgradient area that affects water quality in the alluvial aquifer (Figure 1.2-45).

Major ionic constituent concentrations have been posted on Figure 1.2-45 to show the spatial variation in calcium, sodium, bicarbonate and chloride concentration in the alluvial aquifer. The wells north of the Large

Tailings Pile are all upgradient of the GRP and not influenced by seepage from the tailings. A review of chemistry data from the upgradient wells reveals that the background calcium concentration in alluvial water varies from 202 to 349 mg/L. As previously noted, the exception is the calcium concentration of 31 mg/L in well ND. Calcium concentrations vary over a larger range in the groundwater downgradient of the tailings. Background concentrations of sodium vary from 234 to 381 mg/L in alluvial groundwater. Groundwater concentrations of bicarbonate in the upgradient alluvial wells vary over a wide range, from 149 to 376 mg/L. The range of measured background groundwater chloride concentrations is much smaller at 47 to 67 mg/L.

The prevalent ionic constituent concentrations for wells downgradient of the Large Tailings area are also presented on Figure 1.2-45. The locations and constituent concentrations are presented for the three POC wells (S4, D1 and X) and three wells in the adjacent subdivisions. Typical concentrations of major ionic constituents in the San Andres deep aquifer groundwater, that is used in the groundwater restoration program for injection into the alluvial aquifer, are noted in the legend. Calcium concentrations in alluvial groundwater are typically greater than 200 mg/L downgradient of the tailings, with the lowest concentrations observed at the POC well X. However, the groundwater quality near well X has been influenced by injection of reverse osmosis (RO) product water.

Upper Chinle Groundwater Quality

Regional Chinle groundwater-quality data are presented in Gordon (1961) for eight Chinle wells and numerous other Chinle wells in Baldwin and Rankin (1995). These reports indicate only that the wells are completed in the Chinle Formation and not any specific sandstone. The groundwater quality results in Gordon (1961) are for Chinle wells generally within 10 miles of the GRP (Figure 1.2-46). The wells identified by Baldwin and Rankin (1995) are mainly in the southeast or southwest portions of Cibola County in New Mexico more than thirty miles from the GRP. Both the results in Gordon (1961) and Baldwin and Rankin (1995) show a large range in concentrations for the Chinle groundwater quality. The groundwater calcium concentration in some of the Chinle wells is very low but is high in other Chinle wells. None of these groundwater-quality data are useful in defining background concentrations of the Chinle groundwater at the GRP but is useful in confirming that the natural range of concentrations in this hydrogeologic system can be very large.

A Stiff diagram comparison for the northern Upper Chinle wells CW3, CW9, CW10, CW50 and CW52 is presented in Figure 1.2-47. Sodium is the prevalent cation in groundwater collected from these wells, and sulfate is the most prevalent anion with one exception. Bicarbonate and sulfate are the prevalent anions in well CW52 groundwater. As would be expected, the shapes of the diagrams for groundwater from the Upper Chinle from wells CW3 and CW9 are significantly different than those for the upgradient alluvial wells. For example, a comparison of Stiff diagrams of groundwater from Upper Chinle well CW3 and alluvial aquifer groundwater reveals that well CW3 groundwater has lower calcium concentrations and higher natural sodium concentrations than alluvial groundwater.

The Stiff diagrams for Upper Chinle wells CW10 and CW50 are similar to the alluvial Stiff diagrams because in the area that these wells represent the inflow of alluvial groundwater has affected the Upper Chinle groundwater quality. These wells are located in the area defined as the Upper Chinle mixing zone. The similarities with alluvial groundwater indicate that the long-term exposure of the Upper Chinle sandstone to alluvial groundwater in the mixing zone results in minimal alteration of groundwater

composition in this localized area. In this area, the sandstone unit itself is no longer influencing groundwater composition due to the duration of contact with alluvial groundwater.

Well CW52 is the farthest north of the Upper Chinle wells. Even though the prevalent anion in this well is bicarbonate, the groundwater composition from well CW52 is considered characteristic of mixing zone groundwater due to its other characteristics. This well is located in the area of transition from mixing zone to Upper Chinle non-mixing zone groundwater composition.

A Stiff diagram comparison is presented on Figure 1.2-48 for groundwater from Upper Chinle wells 0931, 0934, CW13, and CW18, which are located east of the East Fault. The injection of San Andres groundwater into well CW13 has resulted in an anomalously higher bicarbonate concentration observed in groundwater from well CW18 because San Andres groundwater has higher bicarbonate and calcium concentrations than Upper Chinle groundwater. The concentration of calcium and the other major ionic constituents in well CW18 water are comparable to natural levels found in the Upper Chinle outside the mixing zone. The concentration of calcium in the San Andres groundwater injected into well CW13 is typically 230 mg/L. The most recent calcium value for groundwater collected from well CW18 was 49 mg/L. The elevated bicarbonate concentration in groundwater from well CW18 indicates that San Andres groundwater is located in this area.

However, the absence of elevated calcium concentrations demonstrates that the Upper Chinle sandstone has some capacity to alter the composition of groundwater, but the changes are specific to the constituent. The Upper Chinle sandstone at well CW18 has been exposed to San Andres groundwater for several years, but the selective changes in Upper Chinle groundwater quality indicate ongoing ion exchange processes and water composition alteration. This contrasts with the discussion in a previous paragraph where it was noted that little or no alteration of groundwater composition occurs after prolonged exposure of the Upper Chinle sandstone to alluvial groundwater in the mixing zone. Other examples of mixing zone areas where no significant alteration of invasive groundwater composition occurs are areas near wells CW50 and CW10.

Calcium concentrations are naturally low in the Upper Chinle groundwater, but concentrations in the mixing zone are similar to those found in alluvial groundwater. Concentrations of sodium are typically higher in the Upper Chinle groundwater than in the San Mateo alluvial aquifer. Bicarbonate concentrations are also naturally higher in the Upper Chinle groundwater than in the alluvial groundwater. Naturally occurring chloride concentrations measured in Upper Chinle groundwater are similar to measured chloride concentrations in the alluvial aquifer except for the area east of the East Fault, where chloride concentrations naturally increase in the lower permeability areas of the Upper Chinle.

A pattern has been added to Figure 1.2-49 to distinguish the mixing zone area in which the Upper Chinle groundwater quality has been influenced by inflow of alluvial groundwater. A calcium concentration of less than 30 mg/L has been used to indicate the non-mixing zone. A calcium concentration of 30 mg/L reasonably separates the higher values near the subcrop and the lower concentrations away from the subcrop. The 2003 calcium concentration in well CW9 was below 30 mg/L at 24 mg/L but was still placed in the mixing zone because historical values have been above 30 mg/L. The 2003 calcium concentration from well CWI8 was above 30 mg/L but was placed in the non-mixing zone because historical values have been below 30 mg/L prior to the injection influence of CW13 discussed earlier.

Communication between the alluvial aquifer and the Upper Chinle has permitted alluvial groundwater to enter the Upper Chinle resulting in a change in groundwater composition in this area. The groundwater quality in the Upper Chinle mixing zone shown on Figure 1.2-49 is similar to the groundwater quality of the alluvial aquifer. The mixing zone for the Upper Chinle includes all the subcrop area, where direct communication between the alluvial aquifer and Upper Chinle exists, but also includes the area south of the Large Tailings Pile extending to the East Fault. Background alluvial groundwater has moved into the Upper Chinle in the subcrop area north of the tailings. This groundwater then moves in the Upper Chinle and eventually discharges back to the alluvial aquifer on the south side of Felice Acres. Seepage from the tailings below the Large Tailings Pile enters portions of the alluvial aquifer which migrates to the Upper Chinle subcrop in this area. This water commingles with Upper Chinle groundwater as it moves downgradient south of the tailings areas. Portions of the mixing zone that are a greater distant from the tailings area have not been affected by tailings seepage. Section 1.3 presents figures illustrating the extent of contamination in all affected aquifers.

The areal extent of the Upper Chinle mixing zone prior to the tailings deposition is believed to be similar to its current extent and location. Upper Chinle wells that have had elevated selenium and uranium concentrations from tailings seepage such as CE2, CW4R, CW5 and CW25 are within the present mixing zone. Calcium concentrations in the Upper Chinle groundwater near these four wells were believed to be elevated prior to the tailings deposition due to historical flow of alluvial groundwater through this mixing zone portion of the Upper Chinle.

Middle Chinle Groundwater Quality

Stiff diagram comparisons of the groundwater quality composition for the Middle Chinle wells are presented on Figure 1.2-50. The Stiff diagrams for the five Middle Chinle wells are consistent with each other in shape and are similar to typical Upper Chinle Stiff diagrams. A plan view that includes well locations and posting of calcium, sodium, bicarbonate and chloride concentrations for Middle Chinle wells is presented on Figure 1.2-51. Calcium concentrations are low in the Middle Chinle west and east of the East Fault except in the area that has been affected by the subcrop connection with the alluvial aquifer south of Felice Acres. Higher calcium concentrations are typically found in samples from Middle Chinle groundwater west of the West Fault. A mixing zone pattern has been added to this figure to show an area of calcium concentrations equal to or greater than 30 mg/L. Middle Chinle groundwater quality in this area is similar to that of the alluvial aquifer, and therefore this area is considered to be within the Chinle/alluvial mixing zone.

A Stiff diagram comparison of the four Middle Chinle wells west of the West Fault and wells CWl and CW2 that are located between the two faults immediately upgradient of the Large Tailings Pile is presented on Figure 1.2-52. The Stiff diagrams for the wells west of the West Fault are substantially different from those for wells CWI and CW2. The major ion concentrations in the Middle Chinle west of the West Fault are generally higher than the alluvial aquifer background concentrations and they generally increase to the south. Communication with the alluvial aquifer north of the GRP and west of the West Fault allows alluvial groundwater to flow through the Middle Chinle to the southwest and discharge in its subcrop area. This has altered the water quality of the Middle Chinle west of the West Fault to a water quality similar to the alluvial aquifer groundwater. However, the north to south natural gradient from upgradient of the tailings pile to downgradient of the tailings pile west of the West Fault precludes the entry of seepage-altered alluvial water in this area. The mixing zone pattern on Figure 1.2-51 covers the entire portion of the Middle

Chinle west of the West Fault. This figure also shows the calcium, sodium, bicarbonate and chloride data for the Middle Chinle wells in this area. All of these Middle Chinle wells contain groundwater of a quality similar to that of the alluvial aquifer.

Unlike the mixing zone in the Middle Chinle west of the West Fault, the mixing zone in the Middle Chinle between the two faults and southeast of Felice Acres have been affected by tailings seepage through hydraulic contact with seepage-altered alluvial groundwater at its subcrop. The uranium concentration in alluvial well 496, for example, is elevated at 0.44 mg/L, which illustrates the effects of tailings seepage in southern Felice Acres. However, the major constituent concentrations of the alluvial groundwater at the subcrop of the Middle Chinle with the alluvium are well within background concentrations. Therefore, tailings seepage has affected some minor constituents even though the major constituents have not been significantly changed in the mixing zone in the Middle Chinle in this area.

Lower Chinle Groundwater Quality

The natural groundwater composition in the Lower Chinle varies considerably, reflecting the limited permeability and dependence on fracture permeability within Chinle shale for groundwater. The chemical composition of groundwater for the Lower Chinle also differs from that of the other Chinle units. Stiff diagram comparisons are provided for the six southern Lower Chinle wells and the five northern Lower Chinle wells on Figures 1.2-53 and 1.2-54, respectively. Based on the calcium concentration, the composition of groundwater in Lower Chinle well CW41 is similar to the typical groundwater composition for the Upper and Middle Chinle non-mixing zones while groundwater composition in samples from other wells varies widely. The calcium, sodium, bicarbonate and chloride concentrations in the Lower Chinle wells are presented on Figure 1.2-55. Review of these data confirms that the range of concentrations of major ion constituents in the Lower Chinle groundwater is relatively broad. Inflow of alluvial groundwater appears to have affected some of the Lower Chinle groundwater near its subcrop area. Major constituent concentrations may tend to naturally increase as groundwater flows downgradient in a shale. This natural increase is due to the long residence time of groundwater in the low permeability rock. The poor quality of groundwater in the Lower Chinle may reflect both of these influences.

The natural deterioration of groundwater quality as the groundwater moves downgradient from the subcrop makes it more difficult to define the mixing zone in the Lower Chinle. The mixing zones for the Lower Chinle are adjacent to the subcrop areas. A comparison of differences in calcium concentration is not useful in distinguishing between the mixing zone and the non-mixing zone for the Lower Chinle because calcium concentrations generally increase in the downgradient direction in shale. Only well CW41 contains groundwater with calcium concentrations less than 30 mg/L. The data from well CW41 indicate that the groundwater quality found in the mixing zone has not influenced the groundwater in this well, but calcium cannot necessarily be used in the remainder of the Lower Chinle wells to identify the area of the mixing zone.

The concentrations of major constituents in the alluvial groundwater at the Lower Chinle subcrop area have not been affected by seepage from the tailings. Therefore, the current mixing zone in the Lower Chinle is also unaffected, and thus, very likely the same as it was prior to the deposition of tailings.

1.2.2.8.3 Groundwater Use

Groundwater from residential private wells was used in the past for garden irrigation and possibly domestic uses such as drinking, cooking, showering, and washing. Mitigation of potential exposure to groundwater

impacted by 11e.(2) Byproduct Material by nearby residents was initiated in 1975 and continues today. In 1975, HMC began providing bottled water to residents of the nearby subdivisions upon request. On August 18, 1976, HMC entered into an agreement with New Mexico Environmental Improvement Division (NMEID) to provide bottled water to residents located hydraulically downgradient of the source areas.

In 1983, HMC signed an agreement with EPA that required HMC to provide an extension of the Village of Milan municipal water system to four residential subdivisions south and southwest of the Mill which were in the impacted groundwater area. As outlined in the agreement, HMC paid for the resident's water use for a period of 10 years. The connection of the subdivision residences to the Village of Milan's water supply was completed in 1985. HMC resumed paying for residential water usage again in late 2018.

In 2009, NMED issued a health advisory intended to minimize the possibility of new wells being installed within the area of contamination. The health advisory was published in two newspapers of general circulation in Cibola and McKinley Counties. Also, NMED required the New Mexico Office of State Engineer to provide a copy of the health advisory to every person who applied for a well permit within the area referenced in the drinking water advisory.

On May 2, 2018, the Office of the State Engineer issued an order to protect human health and prevent interference with groundwater flow associated with ongoing remediation (NMOSE, 2018). The order restricts the permitting and drilling of wells for new appropriations, or replacement or supplemental wells, and restricts the permitting of any change to the point of diversion of any existing wells within the boundaries defined (Figure 1.2-56). This prohibition excludes permit applications that are submitted on behalf of NMED or that may be required for remedial action and monitoring and excludes areas within the NRC License boundary for the GRP and the Bluewater Mill site. The order is stated to be in effect in perpetuity or until groundwater concentrations decrease to levels less than Water Quality Control Commission standards.

The GRP uses bottled water for drinking. The GRP also uses water from a production well completed in the San Andres-Glorieta aquifer for other domestic and sanitary uses. Declarations of restrictive covenants will be recorded for GRP's former land application areas and all HMC property within the proposed control boundary prohibiting use of groundwater and prohibiting residential and agricultural use of the land application areas.

A query of the Office of the State Engineer well records for the area within the proposed control boundary, discussed in more detail in Section 4.4.1.1 of this ACL Application, identified private well permit files for wells not controlled by HMC. The records include active and inactive permit files. Inactive files are those files with canceled or expired permits that have been otherwise closed, active files are all other open files. The query was further refined by removing wells with a diversion allotment of zero acre-feet of groundwater, knowledge of wells plugged and abandoned by HMC, and a visual inspection of recent aerial imagery of the remaining well permits indicated no current infrastructure supporting beneficial use of the well or water diversion (e.g., no piping, associated structures of power supply, evidence of water irrigation, or other evidence of well use).

The final data set includes 20 well permits with permitted access to groundwater within the proposed control boundary, including 16 domestic use well permits, one multiple household domestic use well permit, one irrigation use well permits, and two subdivision well use permit (sanitary water for commercial use; e.g.,

sinks and toilets). State records do not document water use rates or volumes for these permitted wells. All properties on which these wells are located are currently connected to the existing municipal water supply lines from the Village of Milan (Figure 1.2-57). There is no documented groundwater use from any of the domestic or commercial well permits for properties connected to the municipal water supply. The permitted irrigation well completed in the San Andres-Glorieta aquifer, is believed to have previously been used for land irrigation for livestock forage crops (e.g., alfalfa). Visual inspection of this area from aerial photographs suggests the current area that could be irrigated from this well is less than 100 acres (0.15 square miles).

As an annual reporting requirement in the 2009 Memorandum of Understanding with NMED (HMC and NMED, 2009), HMC determines if any new wells have been installed within the area of contamination, reports the findings in the annual report, and allows any resident in a designated area of concern who is not on the Village of Milan water supply the opportunity to be hooked up to the municipal water system at HMC's expense. Based on the results of the 2024 annual survey, all water users in the area of concern are supplied by the Village of Milan water supply.

All wells not required for the approved groundwater monitoring plan within the proposed control boundary on surface/subsurface estates owned by HMC will be plugged and abandoned. No groundwater use will be allowed by HMC on any surface and subsurface estates owned by HMC within the proposed control boundary. HMC is continuing its good faith and serious efforts to acquire all surface and subsurface estates within the control boundary. In addition, in many cases where HMC has not acquired an estate that contains a well, HMC has provided a cash payment per private well and covered the costs for plugging and abandonment of the private well. HMC intends to document the surface and subsurface estates ownership status, and the well plugging and abandonment status on unacquired estates. This documentation is available for NRC staff review onsite. For any estate not acquired by HMC, and for any existing private well on such estate that is not plugged and abandoned, reasonable assurance exists that the public health and safety and the environment will be protected because of (1) the aforementioned State of New Mexico advisory; (2) the State of New Mexico legally enforceable prohibition against the drilling of new, replacement, or supplemental wells within the proposed control boundary; and the notification requirements provided in 10 CFR Part Appendix A Criterion 11C, which HMC will follow.

1.2.3 Facility Layout

Figures 1.2-58 and 1.2-59 show the mill facilities prior to decommissioning. During mill operations, ore was stockpiled at the ore pad north of the mill after being weighed on the receiving scale, which made up the ore receiving section. Ore was passed through the Crushing and Sampling Section, consisting of a grizzly impact breaker, rotary dryer and reciprocating samplers. Crushed ore was temporarily stored in the fine ore bins. Ore was passed through the Grinding Section, consisting of two ball mills and thickener tanks into the Uranium Leaching Section and then through the Precipitation Section. Uranium and vanadium were removed before packaging, storage and shipping. The mill also contained a variety of miscellaneous structures needed to support and manage the milling operations. The solid 11e.(2) Byproduct Material, mill tailings, was transported by slurry pipeline initially to the Small Tailings Pile located southwest of the main mill and, subsequently, to the Large Tailings Pile located directly west of the main mill.

1.2.4 Description of Operations

The primary source of ore for the Homestake mill was underground mines located within 30 miles of the mill in the Ambrosia Lake district (Skiff and Turner, 1981). Two basic types of uranium ore are known to have been processed by the mill: (1) sandstone ore, 80 to 85 percent of the mill feed, and (2) limestone ore, 15 to 20 percent of the mill feed (Skiff and Turner, 1981). Uranium mineralization occurred as coffinite, uraninite, tyuyamunite, and carnotite as impregnations, pore fillings, and cementation between sand grains or along fractures. The ore grade ranged from 0.04 to 0.3 percent as yellowcake (U_3O_8). Uranium mineralization was associated with carbonaceous material and contained lesser amounts of molybdenum and selenium (McLemore, 2007).

Milling of the ore was conducted in five general stages: (1) ore handling and preparation, (2) extraction, (3) liquid-solid separation, (4) precipitation and purification, and (5) product preparation (Skiff and Turner, 1981). The mill used two parallel circuits for grinding, thickening, and leaching of the ore. The North Circuit was used to process the majority of sandstone ore, while the South Circuit used a secondary grind and longer leach time to process the refractory limestone ore. Product from each grinding circuit was then advanced to their respective thickening circuits and removed at approximately 40 percent solids prior to leaching. The mill employed an alkaline leach process to recover uranium from the thickened slurry.

1.2.4.1 Mill Operations

Chemicals used during the milling process included sodium carbonate, sodium bicarbonate, polyacrylamide flocculant, sodium hydroxide, sulfuric acid, and ammonia (Skiff and Turner, 1981). Alkaline leaching is based on the enhanced dissolution of uranium minerals by the addition of carbonate, resulting in the formation of the stable uranium (VI) tricarbonate solution species (Butler, 1972; Skiff and Turner, 1981). Records regarding quantities of these chemicals have not been identified.

The thickened slurry was leached in a two-stage circuit, where the first stage consisted of a high pressure and temperature leach of 414 kiloPascals (kPa) at 93 degrees Celsius (°C) for 4.5 hours. The second stage utilized a 12-hour atmospheric pressure leach at 77°C for the sandstone ore and 24 hours for the limestone ore. Leached slurries were then processed through three levels of filtration: (1) first stage filtrate contained the pregnant uranium solution which was sent to the clarifier before the precipitation circuit, (2) second stage filtrate was sent to the mill solution circuit, and (3) third stage filtrate was used as a wash and re-pulper solution on the first stage of filters. Filter cake from the third stage was repulped with recycled tailings pond solution and slurried for tailings disposal (Skiff and Turner, 1981). Definitive records regarding the proportions or volumes of chemicals used and their proportions in the waste were not located from the historical documentation.

Pregnant solution from the clarifier was then pumped to the precipitation circuit after heating to 82°C and precipitation of sodium diuranate was conducted in two stages (Butler, 1972; Skiff and Turner, 1981). The precipitate was further purified to increase the uranium concentration and remove impurities and reprecipitated as yellowcake. The yellow cake was packaged into 55-gallon drums for shipment.

Description of the ores processed at the mill are presented in a report by Worthington Miller Environmental (2020b).

1.2.4.2 Tailings Operations

Two unlined tailing impoundments, the Large Tailings Pile and the Small Tailings Pile, were developed on HMC's property. In December 1956, the U.S. Atomic Energy Commission (AEC) and Homestake-New Mexico Partners signed a contract for the delivery of yellowcake to the federal government. The second contract was signed with the AEC in 1961 for the delivery of additional yellowcake. Subsequently, HMC produced yellowcake for the AEC under four additional contracts. The first and smaller of the two impoundments, the Small Tailings Pile, covers about 40 acres (Kuhn and Jenkins, 1986) and resulted entirely from these contracts with the federal government. Tailings deposition occurred between 1958 and 1990. Groundwater corrective action began in 1977. The total quantity of tailings placed in the Small Tailings Pile was 1.22 million tons. The Small Tailings Pile is located in the southwest quarter of Section 26, Township 12 North, Range 10 West. The unlined Small Tailings Pile was constructed with a perimeter embankment, and tailings disposal occurred within the embankment (Kuhn and Jenkins, 1986) composed of compacted natural soil. The embankment was compacted by heavy equipment and brought to a height of 20 to 25 feet. The crest was a minimum of 10 feet wide, with the base being approximately 40 feet wide. In 1990, an evaporation pond was constructed in this impoundment to assist in the dewatering of the Large Tailings Pile and to hold water pumped from the collection wells of the groundwater restoration plan.

The larger of the two impoundments, the Large Tailings Pile, located in the north half of Section 26, Township 12 North, Range 10 West, resulted from production under both federal government and commercial contracts and was operated from 1958 to 1990. Homestake-Sapin Partners and the AEC entered into a contract to deliver yellowcake to the federal government in April 1957. Two other contracts were signed with the AEC in 1960 and 1961. In addition, numerous contracts were placed with electric utilities for nuclear reactor fuel production. The total quantity of tailings generated under AEC contracts was 13.45 million tons. In addition, another 7.6 million tons of commercial tailings were generated and comingled with the AEC tailings.

Until 1966, HMC deposited tailing material into only one cell of the Large Tailings Pile. Subsequently, HMC added an additional cell adjacent to and west of the existing cell. Since that time, tailings disposal alternated between the two cells (east and west) whenever necessary to maintain optimal operating conditions.

The starter dike for the Large Tailings Pile was constructed in compacted six-inch lifts of natural soil excavated within the tailing cell area (Kuhn and Jenkins, 1986). The dike was constructed to a height of about 10 feet and a width of about 10 to 15 feet at the top and 25 to 30 feet at the bottom. The tailings embankment was then built out from this starter dike by centerline method until 1981, when an inboard offset of the crest was made to improve stability conditions of the embankment. Successive embankment lifts were added by centerline method to the offset crest dike around the entire circumference of the impoundment. The embankments were then raised using a cyclone separator to discharge the coarser tailings fraction along the perimeter and center dikes (AK Geoconsult et al, 1991). This resulted in segregation of the tailings into the sandier perimeter and centerline dikes and the fine-grained slime material in the central cell areas. Tailings were placed into two cells, referred to as the east and west cells. The east and west cells were typically used in an alternating sequence with decant towers in each cell returning clarified fluids for reuse as mill process water (AK Geoconsult et al, 1991).

In 1990, a lined evaporation pond, EP1 was constructed within the Small Tailings Pile and occupies most of the interior surface area of the original Small Tailings Pile (Figure 1.2-1). Evaporation Pond 1 was used to hold water discharged from the groundwater restoration collection wells (AK Geoconsult et al, 1991). Due to the age and condition of the liner, Evaporation Pond 1 was taken out of service in 2024. Prior to the construction of EP1, two small, lined collection ponds constructed west of the Small Tailings Pile in 1986 were used to store and evaporate collected groundwater. Prior to the end of milling and the construction of evaporation or holding ponds, collected groundwater was introduced to the mill process water with some recovery of uranium in the mill. A second evaporation pond (EP2) located on the western side and directly adjacent to the Small Tailings Pile and extending to the small collection ponds was put into service in 1996. A third lined evaporation pond (EP3) was constructed with a double liner and leak detection system north of the Large Tailings Pile in 2010 (Figure 1.2-1).

1.2.4.3 Other Wastes

Wastes generated during milling operations included tailings and tailings slurry fluids, which were managed within the Large Tailings Pile and Small Tailings Pile. Contaminated groundwater recovered during corrective actions is treated using lime addition pre-treatment (pH adjustment), reverse osmosis, filtration, prior to re-injection into the aquifer. Non-compliant treated groundwater has been managed in two lined evaporation ponds (EP2, and EP3). Non-compliant treated groundwater is approximately 20 percent of the influent streams to the RO treatment system. This non-compliant effluent is managed by evaporation and is permanently removed from the groundwater system, while the remaining 80 percent of the influent streams is re-injected into the aquifers. At these pumping and treatment rates (435 gpm is 2024 average), approximately 50 million gallons per year of groundwater is evaporated. Evaporation from these ponds is enhanced through the seasonal use of floating, mechanized, spray evaporators with automated wind speed, humidity and temperature shut-off controls (APEX brand). Solid wastes generated from water treatment consist primarily of excess lime and contaminated decommissioned RO equipment. The current solid waste production from water treatment is approximately 23,250 tons/year. These wastes are temporarily stored in the lined East Collection Pond (ECP) and West Collection Pond (WCP) and then periodically transferred to Evaporation Pond 1 on the Small Tailings Pile and disposed.

Other wastes include contaminated equipment, supplies, and personal protective equipment (PPE) that cannot be cleaned and released for unrestricted use (e.g., pumps, piping, rubber gloves, etc.). These wastes are disposed into specific trenches in the surface of the Small Tailings Pile.

1.2.5 Mill Decommissioning

Milling operations ceased on February 2, 1990. In January 1991, HMC submitted a proposed tailings reclamation and mill decommissioning plan to NRC (AK Geoconsult et al, 1991). On October 29, 1993, HMC submitted an Updated Reclamation Plan that superseded the 1991 submittal (AK Geoconsult and Jenkins, 1993). Mill decommissioning and reclamation activities for soil cleanup began in 1993. An update to the Decommissioning and Reclamation Plan was submitted in 2013 (HMC, 2013), NRC issued requests for additional information in 2016 to which HMC responded in 2016. However, NRC's review of the plan ceased with issuance of the Confirmatory Order in 2017 and this plan has not been approved by NRC.

1.2.5.1 Mill Decommissioning and Burial

Demolition activities began on May 5, 1992, with removal of asbestos-containing materials from various mill facilities prior to demolition. The New Mexico Environment Department (NMED) approved burial of the asbestos in the tailings pile (AK Geoconsult, 1996). The asbestos-containing materials were disposed of in a disposal pit at the toe of the original slope of the Large Tailings Pile (Figure 1.2-60).

Residual byproduct and scale materials were removed from milling process components before these components were demolished and buried. The 11e.(2) Byproduct Material, consisting primarily of scale, sludge, and tailings in tank precipitators, was removed by mechanized equipment and by hand tools and hauled to the Large Tailings Pile for isolation and burial per the approved Reclamation and Decommissioning Plan. Demolition of milling facilities was accomplished using heavy equipment and was completed in March 1995 as documented in the Completion Report (AK Geoconsult, 1996) and approved by NRC in 1999 (NRC, 1999).

Mill debris was buried in pits located within the mill area or south of the Large Tailings Pile (Figure 1.2-60). Burial pits were excavated using heavy equipment and debris was placed into pits in lifts up to five feet thick. Slurry grout was poured into the pit until it had filled the voids and reached a level approximately equal to the top of the debris lift. This process was repeated until each pit was filled with debris and slurry. Debris pits were capped with up to four feet of soil (AK Geoconsult, 1996).

1.2.5.2 Removal of Windblown Tailings Contamination Areas

In 1987, HMC committed to a contaminated soil cleanup effort in which soil exceeding 5 picocuries per gram (pCi/g) radium-226 above background in the top 15 centimeters (cm) of soil (HMC, 1987) would be remediated in accordance with 10 CFR 40 Appendix A Criterion 6 (6). Background for radium-226 was calculated to be 5.5 pCi/g. Thus, the cleanup level was set at 10.5 pCi/g (5.5 pCi/g background + 5 pCi/g). The cleanup of windblown contaminated soil began early in 1988 (ERG, 1995). On February 16, 1989, a plan approved by NRC as License Condition 19 committed HMC to remediating certain areas near the tailings piles that exceeded the 10.5 pCi/g cleanup criterion for radium-226 (ERG, 1995) in the top 15 cm of soil. At depths greater than 15 cm below the surface, the radium-226 cleanup criterion was 20.5 pCi/g (5.5 pCi/g background + 15 pCi/g) in accordance with 10 CFR 40 Appendix A Criterion 6 (6). Soil cleanup activities were temporarily paused during Homestake mill decommissioning to allow decommissioning activities to proceed. After the Homestake mill decommissioning was complete, cleanup of the windblown contamination and other off-pile contaminated materials resumed in 1993 in accordance with License Condition 29C and 10 CFR 40 Appendix A Criterion 6 (6).

Surface soils from approximately 1,200 acres of land were removed (Figure 1.2-61). Most of the excavated soil was placed on the eastern side slope of the Large Tailings Pile, but significant quantities were placed on the southern end of the Small Tailings Pile and the aprons of the Large Tailings Pile. Subsequent to placement, deposited soil was covered with soil and rock as described in the section below.

1.2.5.3 Placement of Cover Materials

Regrading and placement of final and interim cover materials on the former Homestake mill area, the Large Tailings Pile, and the Small Tailings Pile were completed as part of the mill decommissioning efforts completed in the mid-1990s.

At the Large Tailings Pile, extensive regrading was completed to fill in the tailings ponds and flatten the side slopes to improve stability. Final cover material was placed on the side slopes at a thickness varying from 2 to 3.8 feet, as needed to effectively buffer radon emissions. In addition, 6 to 9 inches of rock cover was placed on the side slopes for erosion protection.

One foot of interim cover material was placed on the top of the Large Tailings Pile and the Small Tailings Pile. Since this initial placement, additional cover has been placed on both Large Tailings Pile and Small Tailings Pile to fill depressions caused by settlement, to improve drainage, and to address specific areas to assure sufficient protective cover to maintain radon flux measurements within regulatory parameters. Final reclamation of the Large Tailings Pile will be completed in 2026 in accordance with the approved ET Cover design report (Stantec, 2025). Final reclamation of the Small Tailings Pile will be completed as part of the final closure of the Small Tailings Pile after cessation of groundwater corrective actions.

At the former mill area, located southeast of the Large Tailings Pile (Figure 1.2-61), an average of two feet of contaminated soil (containing radium levels above the cleanup standard) was removed following completion of mill demolition. Excavated soil was transported to the east end of the Large Tailings Pile or the south end of the Small Tailings Pile for burial. Areas that had been excavated were backfilled with clean alluvial soils. After backfilling, at least two feet of clean soil was placed over the entire mill area. The average thickness of material placed was 4.7 feet. The rock was the same crushed basalt used for erosion protection on the impoundment surfaces. During the period of November 16 to December 10, 1995, this rock was applied in a single lift of 2 to 6 inches, and then mixed with the underlying soil to a depth of up to twice the rock lift thickness. After the mill cover material was placed, gamma surveys were conducted to verify gamma emission rates were in compliance with governing standards at the cover surface.

Cover materials were obtained from borrow areas near the Large Tailings Pile, Small Tailings Pile, mill area, and evaporation and collection ponds (Figure 1.2-62).

Drainage was reestablished following soil cleanup activities conducted in 1994 and 1995. Drainage areas within the GRP (including areas adjacent to the Large Tailings Pile, Homestake mill and ore storage areas, windblown soil cleanup areas, and borrow areas) were regraded and surface channels were established for drainage. Constructed surface channels are shown on Figure 1.2-43.

1.2.5.4 Seepage Impacted Area

After EPA's investigation of groundwater contamination from mill operations (EPA, 1975), additional well installation, groundwater sampling and further studies were undertaken to identify and delineate seepage impacts from uranium milling operations. The result of the studies was the identification of seepage impacts in areas of the alluvial aquifer and the development of a Ground Water Protection Plan Agreement in 1976 between HMC and the State of New Mexico Environmental Improvement Division (Hydro-Engineering,

1983). For the initial corrective action activities, HMC installed a series of collection wells that began operating in 1978, and a line of injection wells that started operating in 1977. Since the Ground Water Protection Plan was established in 1976, numerous wells have been installed and groundwater restoration activities have been expanded to include the Upper, Middle and Lower Chinle as well as the alluvium. Section 4.1.2 of this ACL Application provides additional detail on seepage impacted aquifers.

In 1980 it was noted that unsaturated seepage of tailings fluid below the Large Tailings Pile had produced a groundwater mound in a perched zone of the alluvium, where the elevation of the mound beneath the embankment crest was generally about 20 ft higher than the phreatic surface at the toe of the Large Tailings Pile (D'Appolonia, 1980).

1.2.5.5 Water Treatment Systems

A Reverse Osmosis Treatment Plant was constructed and commissioned in 1999. The Reverse Osmosis Treatment Plant (RO Plant) was significantly modified and expanded in 2014 and 2015 to improve treatment and increase capacity. The RO Plant receives collected groundwater from the On-Site area (Figure 1.2-1). Two field-scale pilot zeolite water treatment systems were also implemented on the surface of the Large Tailings Pile. Section 4.1.3 of this ACL Application provides additional detail on the water treatment systems. The RO Plant and related facilities are currently active and will be decommissioned after groundwater corrective actions cease. The Zeolite Treatment facilities ceased operations in 2023 and have been decommissioned in preparation for the final Large Tailings Pile cover.

1.2.5.6 Land Application

The groundwater restoration program included land application of mildly impacted groundwater. The purpose of the land application program included collection and capture of mildly impacted groundwater for irrigation to reduce impacts of past seepage from the tailings, promote vegetative growth in irrigated areas, to reduce wind erosion and windblown dust, and to produce a crop. The water used met site-specific background standards for all constituents other than uranium, and the concentrations of uranium ranged from 0.12 to 0.39 mg/L.

The groundwater land application program included one center pivot sprinkler irrigation system on 150 acres in Township 12 North, Range l0 West Section 33, and one in Township 12 North, Range l0 West Section 28 for 100 acres (Figure 1.2-37). In addition, this program included flood irrigation systems on 120 acres in Township 12 North, Range l0 West Section 34 and 24 acres in Township 12 North, Range l0 West Section 33 (Figure 1.2-37). Land application ceased in 2012. The irrigation systems have been decommissioned, post-application soil sampling and surveys performed, and NRC has concurred that the areas meet the NRC-approved remedial action levels and HMC is not required to take further corrective actions (NRC, 2021a). Section 4.1.3 of this ACL Application provides additional detail on the land application systems.

1.2.5.7 HMC Supply of Drinking Water to Residential Subdivision

In 1975, shortly after HMC identified elevated groundwater concentrations in and around residential wells, HMC provided bottled water to affected residents. In 1976, HMC entered into agreement with NMEID to provide bottled water to residents located hydraulically downgradient of the source areas. Pursuant to a

1983 Agreement between HMC and EPA, HMC financed the extension of the Village of Milan's municipal water supply to the residences of the subdivisions and made payments to the Village of Milan for the residents' water usage over a period of 10 years. The extension of the water supply was completed in 1985 (EPA, 2006). In late 2018, HMC restarted the water supply payment program for the subdivisions downgradient of the GRP.

The New Mexico Environment Department and HMC entered into a Memorandum of Agreement pursuant to which HMC voluntarily agreed to connect residents within a designated area near the GRP to the Village of Milan's water system on January 21, 2009 (HMC and NMED, 2009). This work has been completed.

1.3 Extent of Groundwater Contamination

1.3.1 Summary

As discussed in Section 1.2, the geology of the alluvial aquifers at the GRP is heterogeneous in nature as is the associated groundwater flow. Groundwater in the coarse sands and gravels have the highest advective groundwater velocity. Groundwater in the medium to fine sands have the next highest groundwater velocity. Groundwater in the very fine sand or fine to medium sand, which may also have interbedded silt and clay, have a slower advective groundwater velocity. Groundwater in the silts and clays has the slowest groundwater advection.

In highly heterogeneous systems such as the alluvial aquifer, groundwater flow and constituent transport can be described by a dual domain system, which are segregated between the coarse aquifer fractions (very fine sand to gravel, sometimes called the mobile domain) and fine-grained aquifer fractions where there is little groundwater movement (e.g., silts clays, and shales, sometimes called the immobile domain). Groundwater advective flow, and more importantly the majority of constituent transport, is described by advection (Darcy's law). In immobile aquifer fractions, where there is little groundwater movement, constituents in groundwater diffuse into the pore water in the immobile aquifer fractions driven by concentration gradients as described by Fick's law of diffusive flux (Freeze and Cherry, 1979).

When the concentration of a particular constituent in the mobile aquifer fractions (i.e., groundwater) is higher than the concentration of that constituent in the immobile aquifer fractions (i.e., pore water in the silt and clay) into which the mobile aquifer fraction is moving, that concentration gradient will drive the constituent to diffuse from the groundwater into the pore water. Over time, the concentration of the target constituents in the incoming mobile aquifer fractions (groundwater) diminishes, as more of the constituents move from the source to areas downgradient. Eventually, the concentration of constituents in the mobile aquifer fractions (groundwater) will decrease sufficiently that the gradient will reverse. In other words, concentrations of constituents in the immobile silt and clay porewater will be higher than concentrations in the groundwater and will therefore diffuse out of the silts and clays into the incoming groundwater. This will create a long-term secondary source of constituents entering the mobile aquifer fractions. This phenomenon is sometimes described as dual porosity domains for flow and transport. Both advective flow and transport and diffusive transport are understood to play significant roles in GRP groundwater conditions.

The current extent of groundwater contamination in the alluvial aquifer includes the highest concentrations directly under and immediately surrounding the Large and Small Tailings Piles. Concentrations decrease with distance from the tailings piles along two principal flow paths, one flows west from the tailings pile

to areas outside the NRC License Boundary (sometimes referred to as the North Off-Site plume) via the San Mateo Creek alluvial channel and one to the south and southwest (sometimes referred to as the South Off-Site plume) (Figure 1.2-1). Currently, neither of these Off-Site area plumes extend to the Rio San Jose alluvial channel at concentrations above the License groundwater protection standards. Transport of constituents from the Large Tailings Pile in the alluvial aquifer appears to be influenced by mass transfer between the mobile and immobile aquifer domains in the alluvium.

The Chinle sandstone units that underlie and subcrop in the alluvial aquifer receive recharge from the alluvium with site derived contaminants. Contaminant distributions in the Chinle sandstone units reflect the transport of contaminants via the alluvium through the subcrop areas where water from the two zones mix (sometimes referred to as Chinle mixing zones), with contaminants extending down dip (northeast) from the subcrop areas approximately 1,000 to 2,600 feet. No contamination is present in the San Andres-Glorieta Aquifer.

The monitoring program used to define the extent of groundwater contamination is presented in the 2024 Annual Monitoring Report/Performance Review for Homestake's Grants Project (HMC and Hydro-Engineering, 2025).

1.3.2 Groundwater Impacts

Seepage from the tailings piles has resulted in the contamination of groundwater in the alluvial, Upper, Middle, and Lower Chinle groundwater at the GRP. HMC has operated remediation systems to mitigate the impact of seepage from tailings to groundwater since 1977.

1.3.2.1 Alluvial Aquifer

Figure 1.3-1 presents uranium data and contours collected in 2024. The colored hatch patterns on Figure 1.3-1 represent areas where groundwater uranium concentrations are elevated above the License groundwater protection standard. These areas include the Large Tailings Pile, the Small Tailings Pile, and the area west of the tailings piles extending into Township 12 North, Range l0 West, Section 28. Additional areas where uranium concentrations in the alluvium were greater than the License groundwater protection standard exist south of the Small Tailings Pile along Highway 605 and in Felice Acres. The area of elevated groundwater uranium concentrations in Felice Acres extends southwest approximately a few hundred feet west of Thunderbird Lane.

A closer look at the groundwater uranium concentrations in the Rio San Jose is provided in Figure 1.3-2, which presents the 2017 measured uranium concentrations for the area extending from the confluence of the Rio San Jose alluvial aquifer and the San Mateo alluvial aquifer to the south. The Rio San Jose alluvial groundwater to the northwest of the San Mateo confluence has elevated uranium concentrations. Groundwater uranium contamination has not been observed in the Rio Lobo alluvial system.

The 2024 groundwater selenium concentrations are presented in Figure 1.3-3. Selenium concentrations in groundwater do not exceed the License groundwater protection standard outside of the License boundary. Groundwater selenium concentrations in the nearby subdivisions are below the License groundwater protection standards.

Figure 1.3-4 presents data for, and contours of molybdenum groundwater concentrations in the alluvial aquifer during 2024. The License groundwater protection standard for molybdenum is 0.10 mg/L. Groundwater molybdenum concentrations above the License groundwater protection standard extend approximately one-quarter mile west of the Large Tailings Pile and to the southeast of the Small Tailings Pile along Highway 605. A 10 mg/L contour extends around the Large Tailings Pile and to the west side of the Small Tailings Pile.

Figure 1.3-5 presents combined radium-226 and radium-228 concentrations for alluvial groundwater near the former Homestake mill. Combined radium-226 and radium-228 concentrations in the alluvial aquifer that are above the License groundwater protection standards are limited to areas directly underneath the Large Tailings Pile. Groundwater vanadium and thorium-230 concentrations are presented on Figures 1.3-6 and 1.3-7, respectively. Groundwater vanadium concentrations were above or equal to the License groundwater protection standard of 0.02 mg/L in two of the five alluvial wells located within the footprint of the Large Tailings Pile and one well located beneath the Small Tailings Pile. In two of the five sampled alluvial wells within the footprint of the Large Tailings Pile, thorium-230 was present in groundwater above the License groundwater protection standard of 0.3 pCi/L (Figure 1.3-7) In addition, groundwater sampled from two wells near the perimeter of the Large Tailings Pile also exhibited thorium-230 concentrations above the 0.3 pCi/L License groundwater protection standard.

The 2024 groundwater sulfate concentration contours for the alluvial aquifer are presented in Figure 1.3-8. Areas where sulfate exceeds the License groundwater protection standard include the area below the Large Tailings Pile and one well west of the former 120-acre flood irrigation field.

Nitrate concentrations measured in the alluvial groundwater in 2024 near the GRP are presented in Figure 1.3-9. Areas where the groundwater nitrate concentrations exceeded the License groundwater protection standard of 12 mg/L include one well within the footprint of the Large Tailings Pile, two wells between the Large Tailings Pile and Small Tailings Pile, and one well west of the 120-acre flood irrigation field. Groundwater nitrate concentrations in all of the alluvial subdivision wells were below 12 mg/L.

Additional constituents identified through the screening of GRP data (discussed further in Section 2.2) are limited to a small area in this aquifer. Figures 1.3-10 through 1.3-13 present the current extent of arsenic, boron, cadmium, and fluoride, in alluvial groundwater. Arsenic, cadmium, and fluoride concentrations in groundwater are present above the lowest promulgated standards only in the area directly under the Large Tailings Pile and Small Tailings Pond. Boron is present above the lowest promulgated standard in isolated areas (i.e., not contiguous with the area under the Large Tailings Pile and Small Tailings Pile) that are contiguous to each other and are located to the south southwest of the GRP in the vicinity of the Pleasant Valley Estates and Murray Acres subdivisions. However, it should be noted that, although there are no background groundwater quality descriptive statistics for these constituents, contemporaneous upgradient groundwater quality data from the alluvial aquifer indicate that some constituents may be present upgradient of the GRP at concentrations above the lowest promulgated standard as well. This complicates interpretation of data but also suggests that migration of some constituents from the Large Tailings Pile may be limited in area and that elevated groundwater concentrations at, and downgradient of the GRP, may not be fully attributable to the former Homestake Mill.

1.3.2.2 Upper Chinle

Impact to Upper Chinle groundwater is limited to a mixing zone, adjacent to the subcrop area, where the alluvial aquifer has had a direct impact on water quality in the Chinle (Figure 1.3-14). Groundwater uranium concentrations in 2024 exceeded the Upper Chinle mixing zone License groundwater protection standard of 0.18 mg/L in the area of the Large Tailings Pile, the area extending down from the Large Tailings Pond to the south of the Collection Ponds, and one isolated location further south. The non-mixing zone License groundwater protection standard for uranium was exceeded in one well.

Selenium concentrations in Upper Chinle groundwater are presented on Figure 1.3-16. In 2024, the selenium concentrations were less than the mixing-zone License groundwater protection standard of 0.14 mg/L, with the exception of wells in and near the subcrop area near the Large Tailings Pile and extending down to the collection ponds. The non-mixing zone License groundwater protection standard of 0.06 mg/L was not exceeded in 2024.

Figure 1.3-17 presents the molybdenum concentrations in the Upper Chinle groundwater during 2024. Molybdenum concentrations near and underlying the Large Tailings Pile exceeded both the mixing and non-mixing zone GRP groundwater protection standard of 0.1 mg/L. Groundwater molybdenum concentrations greater than 1.0 mg/L were observed in a region extending from the Upper Chinle-alluvium subcrop area, below the Large Tailings Pile, toward the east side of the Large Tailings Pile and to the south of Evaporation Pond 2 and the collection ponds. The License groundwater protection standard also was exceeded in one well north of Broadview Acres. Groundwater molybdenum concentrations from Broadview Acres to the south and east of the East Fault were equal to or below the License groundwater protection standard in 2024.

Upper Chinle groundwater vanadium concentrations measured in 2024 are presented in Figure 1.3-18. No vanadium concentrations over 0.02 mg/L were measured.

Figure 1.3-19 present the combined groundwater radium-226 and radium-228 values measured in 2024. None of the values exceed the Criterion 5C standard of 5 pCi/L. The highest radium-226 concentration measured in the Upper Chinle wells in 2024 was 0.4 pCi/l in well CW3. The largest radium-228 value was 2.0 pCi/L in well CE7.

Sulfate concentrations in the Upper Chinle groundwater during 2024 are presented in Figure 1.3-20. Only groundwater sampled from wells below and near the Large Tailings Pile area exceeded the 1750 mg/L License groundwater protection standard for the mixing zone. In 2024, the non-mixing zone License groundwater protection standard of 914 mg/L was not exceeded.

The 2024 groundwater nitrate concentrations in the Upper Chinle are presented in Figure 1.3-21. All 2024 measured groundwater nitrate concentrations in the Upper Chinle are less than the License groundwater protection standard.

Additional constituents identified through the screening of GRP data (discussed further in Section 2.2) show little spatial extent in Upper Chinle groundwater. Figures 1.3-22 and 1.3-23 present the current extent of boron and fluoride in Upper Chinle groundwater. These concentrations are above their lowest promulgated

standard in the area south of the Large Tailings Pile and Small Tailings Pile and downgradient (east) of the mixing zone with the alluvial aquifer. However, there are no descriptive statistics to identify background for these constituents, complicating interpretation of the data and determining the true extent of any migration of these constituents from the GRP.

1.3.2.3 Middle Chinle

Separate License groundwater protection standards apply to the mixing zone and non-mixing zone groundwater in the Middle Chinle. The extent of the Middle Chinle Mixing Zone is shown on Figure 1.3-24. In the area west of the West Fault, geochemical conditions, primarily calcium concentrations, indicate that the Middle Chinle groundwater is impacted by a connection to an alluvial aquifer further north of the GRP. The License groundwater protection standards for the Middle Chinle mixing zone reflect this northern connection to the alluvial aquifer.

The extent of the area in which uranium exceeds the License groundwater protection standard in Middle Chinle groundwater, based on 2024 data, is shown on Figure 1.3-25. Areas in the southern portion of Felice Acres, extending into Section 3, west and northwest of the Large Tailings Pile, exhibited groundwater uranium concentrations greater than the mixing-zone License groundwater protection standard as a result of direct migration through the subcrop. Groundwater uranium concentrations in Broadview Acres and Felice Acres that exceeded the non-mixing zone License groundwater protection standard show that limited migration from the mixing zone is occurring.

Middle Chinle groundwater selenium concentrations, measured in 2024, are presented on Figure 1.3-26. Concentrations in an area northwest of the Large Tailings Pile exceeded the mixing zone License groundwater protection standard. The higher selenium concentrations in these wells followed the same path of downward movement of alluvial groundwater into the Middle Chinle groundwater shown for uranium. Two wells in Felice Acres exceeded the non-mixing zone License groundwater protection standard, which is consistent with this path.

The 2024 molybdenum concentrations in Middle Chinle groundwater are presented on Figure 1.3-27. Groundwater molybdenum concentrations greater than the License groundwater protection standard of 0.10 mg/L were detected west of the West Fault and northwest of the Large Tailings Pile, in the same area as elevated uranium and selenium concentrations.

Middle Chinle groundwater sulfate concentration contours for 2024 are presented in Figure 1.3-28. No exceedances of the License groundwater protection standards were observed in 2024.

Figure 1.3-29 presents the nitrate concentrations in the Middle Chinle wells from samples collected in 2024. No wells exceeded the mixing zone standard of 15 mg/L.

A groundwater sample from well 434, located in the northern portion of the Broadview Acres subdivision, reported a single instance of boron above the lowest promulgated standard of 0.75 mg/L (Table 1.1-1). Boron is not present in groundwater above the lowest promulgated standard of 0.75 mg/L (Table 1.1-1) in any other monitored Middle Chinle well (Figure 1.3-30).

1.3.2.4 Lower Chinle

Separate License groundwater protection standards have been established for the mixing zone and the non-mixing zone within the Lower Chinle, as shown in Table 1.1-1. The location of the Lower Chinle mixing zone is shown on Figure 1.3-31. Uranium concentrations in Lower Chinle groundwater collected in 2024 are shown on Figure 1.3-32. Groundwater uranium concentrations observed in 2024 in the area southwest of Felice Acres in Section 3 exceeded the mixing-zone License groundwater protection standard. The groundwater in the non-mixing zone adjacent and northeast of the mixing zone also exceeded the License groundwater protection standard.

Selenium concentrations in Lower Chinle groundwater for 2024 are presented on Figure 1.3-33. None of the selenium concentrations obtained in 2024 from the Lower Chinle wells exceeded the License groundwater protection standard.

The 2024 molybdenum concentrations in Lower Chinle groundwater were at levels near the reporting limit and did not exceed License groundwater protection standards. These measurements were consistent with historic measurements of molybdenum in Lower Chinle groundwater.

Sulfate concentrations in Lower Chinle groundwater during 2024 are presented in Figure 1.3-34. None of the Lower Chinle groundwater sulfate concentrations exceed the License groundwater protection standard in the mixing zone. Areas west of the West Fault and north of the Large Tailings Pile have reported groundwater sulfate concentrations greater than License groundwater protection standards in the non-mixing zone. Based on the hydraulic behavior of the Lower Chinle, it appears that the sulfate concentrations are natural.

Groundwater nitrate concentrations measured in 2024 are all significantly below License groundwater protection standards. With the exception of a single, isolated instance of boron, additional constituents identified through the screening of GRP data (discussed further in Section 2.2) do not exceed the lowest promulgated standards. Boron has been measured in one location west of the Large Tailings Pile above the lowest promulgated standard of 0.75 mg/L (Figure 1.3-35).

1.3.2.5 San Andres-Glorieta Aquifer

The San Mateo alluvial and San Andres-Glorieta aquifer are separated by the Chinle Formation, preventing direct communication between the aquifers. A subcrop of the San Andres-Glorieta adjacent to the San Jose alluvial aquifer occurs about two and a half miles southwest of the Large Tailings Pile, at a location that has not been affected by constituents from the GRP.

Figure 1.3-36 plots groundwater uranium concentrations over time from San Andres-Glorieta wells that are routinely monitored by HMC. The location of these wells is shown on Figure 1.2-34. During 2024, No uranium concentrations were observed above 0.03 mg/L in the wells sampled, with the highest being 0.0285 at well 951.

Uranium milling operations at the Bluewater Mill Site, which is located approximately four miles west north-west and directly upgradient of the Large Tailings Pile released uranium to the San Andres-Glorieta aquifer. Refer to Figure 1.3-37 for an isoconcentration contour map for uranium in the San Andres-Glorieta

groundwater from 2017. Based on this information, the uranium concentration in wells 951 and 951R is interpreted to be the result of uranium releases from the upgradient of the Homestake mill.

Groundwater selenium concentrations in the San Andres-Glorieta aquifer vary from less than 0.005 to 0.09 mg/L in 2024. All measured groundwater molybdenum concentrations are less than 0.01 mg/L.

1.3.2.6 Geochemistry

1.3.2.6.1 Alluvial Geochemistry

Alluvial aquifer groundwater in the vicinity of the Large Tailings Pile is sodium-sulfate dominated due to the influence of tailings seepage. The alluvial groundwater becomes increasingly calcium-sulfate dominated, consistent with background conditions, with increasing distance from the Large Tailings Pile. The alluvial aquifer has measurable dissolved oxygen up to 6 mg/L, and very low to non-detectable concentrations of ferrous iron (Fe^{2+}), ammonia-nitrogen (NH_3-N), and hydrogen sulfide (H_2S). Redox conditions are generally classified as oxic based on dissolved oxygen concentrations; dissolved uranium, molybdenum, and selenium are predicted to occur primarily in their oxidized forms [uranium (VI), molybdenum (VI), selenium (VI)]. The geochemical modeling code PHREEQC (Parkhurst and Appelo, 2013) was used to predict speciation in the alluvial aquifer groundwater. Speciation results indicate that molybdenum in the alluvial groundwater exists primarily as the molybdate ion (MoO_4^{2-}), uranium speciation is dominated by the uranium (VI)-calcium complexes ($CaUO_2(CO_3)_3^{2-}$, $Ca_2UO_2(CO_3)_3$), and selenium is mainly present as selenate (SeO_4^{2-}). The saturation index values for the reduced uranium (IV) minerals (amorphous and crystalline UO_2) indicate a high degree of undersaturation due to the low calculated proportion of reduced uranium (IV) in solution. Undersaturation was also calculated for the common oxidized uranium (VI) minerals (e.g., carnotite or tyuyamunite), elemental selenium, ferroselite ($FeSe_2$), and calcium molybdate. The alluvial aquifer groundwater is predicted to be in equilibrium with calcite, oversaturated with respect to ferrihydrite, and undersaturated with respect to pyrite.

Nine alluvium samples were collected in 2018, midway through the saturated zone, from locations upgradient and downgradient of the Large Tailings Pile and analyzed for bulk mineralogical composition and selected chemical properties (WME, 2020a; Figure 1.3-38). The alluvial aquifer mineralogy is dominated by quartz, feldspar and calcite. Only minor clay was identified (2 percent to 15 percent kaolinite, smectite, illite) and the resulting cation exchange capacity (CEC) values were low (2.9 to 7.7 meq/100 g). Pyrite was below detection in all samples (less than one percent) using X-ray diffraction (XRD) analysis, and the sulfur-sulfide content was less than 0.01 percent from sulfur fractionation testing. Natural weathering of the alluvium in a predominantly oxidizing environment limits the preservation of iron sulfides, however these have been shown to be present in finer grained silts and clays associated with the alluvial system (HMC, 2018). Weathering of pyrite and other iron-bearing primary minerals generates iron oxides as stable weathering products under oxidizing conditions.

Iron oxides are considered the most important adsorbents for trace elements in nature due to their high capacity for adsorption, coupled with their tendency to be finely dispersed and to occur as mineral coatings (Dzombak and Morel, 1990; Langmuir, 1997). Iron oxides were not apparent because the crystalline forms (e.g., hematite) were below the XRD analysis detection limit (1 percent to 3 percent) and/or a significant fraction of the iron oxide is non-crystalline (amorphous iron hydroxide, ferrihydrite). Chemical analysis showed the total iron content of the alluvium samples ranged from 0.54 to 3.57 percent with an average of

1.37 percent. This value is consistent with the average of five samples (1.09 percent) reported by HMC (2018b) containing a mixture of sands, silts, and clays; hematite was identified with XRD analysis in two of the samples (1 percent). Selective chemical extraction for the 2018 samples (WME, 2020a) indicated that a small proportion of the iron exists as amorphous iron hydroxide. Overall, oxidizing conditions and the presence of uranium, molybdenum, and selenium as anionic species contribute to relatively high contaminant mobility when adsorption to iron oxides is the primary attenuation mechanism controlling groundwater transport.

Chinle Formation Geochemistry

The general geological and mineralogical characteristics of the Chinle Formation have been previously summarized by Gordon (1961) and Baldwin and Anderholm (1992). No quantitative mineralogical data for the Chinle could be located in historic geological reports. Groundwater in the Chinle Formation is generally a sodium-bicarbonate or sodium-bicarbonate-sulfate type water containing lower proportions of calcium and chloride. The Chinle Formation does not contain an abundance of sodium-bearing minerals, but rather the predominance of sodium in Chinle groundwater has been attributed to ion exchange reactions (calcium replacing sodium from Chinle clays) which occur during interformational mixing with the underlying San Andres-Glorieta aquifer (Gordon, 1961).

In January 2021, two samples of the shale from the Lower Chinle were collected for chemical and mineralogical analyses as part of the investigation into the San Andres-Glorieta aquifer (HDR, 2021). The Lower Chinle shale samples were characterized for total metals, sulfur plus carbon forms, and cation exchange capacity (CEC). The samples were predominantly composed of iron, aluminum, potassium, and silicon, consistent with silts and clays containing iron oxides, as observed to occur in the form of reddish-colored, oxidized and weathered siltstone. The total iron content ranged from 0.22 percent to 3.74 percent. However, the cation exchange capacity of the samples was low (approximately 3 to 7 meq/100 g) and described as equivalent to a sandy soil containing clays with a low intrinsic cation exchange capacity, such as kaolinite. In addition, uranium, molybdenum, and selenium occur primarily as negatively-charged species, which would not undergo cation exchange with clay minerals. Therefore, it was concluded that ion exchange would not be expected to exert significant controls on groundwater chemistry, nor expected to play a major role in attenuation of dissolved constituents during transport through the aquifers. Total carbon was detected only as organic carbon at a content of 0.1 percent and total sulfur was below detection (less than 0.01 percent).

In 2019, a sample of the Lower Chinle shale was characterized for chemical and mineralogical properties and found to consist primarily of smectite clay (77 percent) with lesser amounts of quartz (17 percent) and calcite (4 percent; WME et al. 2020). The cation exchange capacity from this sample was 70.7 meq/100 g. It has been previously established that adsorption to functional groups on the surfaces of iron oxides, rather than ion exchange with clay minerals, is the primary attenuation mechanism for negatively-charged constituents in the alluvial aquifer (WME, 2020b). Based on the chemical and mineralogical results from this sample, it was concluded that the primary mechanism for constituent attenuation in the Lower Chinle shale would be adsorption to functional groups on edge sites of the smectite (Bachmaf and Merkel, 2011), analogous to surface complexation on the surface of iron oxides.

The total iron content of the Lower Chinle shale samples ranged from 0.22 percent to 3.47 percent, with an average of 1.85 percent (HDR, 2021). Although samples of the Chinle sandstones were not characterized,

a mean iron content for sandstones (1.27 percent) can be assumed (Parnell et al., 2021). Assuming 10 percent of the total iron is present as reactive hydrous ferric oxide (HFO) (Parkhurst and Appelo, 2013), the average hydrous ferric oxide contents would be 0.185 percent for the Chinle Shale and 0.127 percent for the Chinle Sandstone. Freundlich adsorption constants were previously developed for the alluvial aquifer using a conservatively low hydrous ferric oxide content of 0.05 percent as iron. Because the adsorption mechanisms are identical (surface complexation to edge or surface functional groups of clays and iron-oxide surface coatings on clays), the same Freundlich constants can be used for modeling in the Chinle Formation. In addition, because the actual hydrous ferric oxide contents (0.127 percent and 0.185 percent) in the Chinle are more than 2.5 to 3.7 times higher than the hydrous ferric oxide content used for modeling in the alluvial aquifer, use of the Freundlich parameters developed from 0.05 percent hydrous ferric oxide as iron would be appropriate, but also very conservative, since this would result in an underprediction of uranium adsorption.

1.3.2.6.2 San Andres and Glorieta Formation Geochemistry

In 1961, the United States Geological Survey (Gordon, 1961) characterized the San Andres and Glorieta Formation geochemistry in the Grants-Bluewater area. The test in the following subsections is excerpted largely verbatim from that report. The San Andres limestone is an impure, somewhat dolomitized limestone that contains some quartz sand. Lithologically, the Glorieta sandstone grades into the San Andres limestone, but, in general, the Glorieta contains a higher percentage of insoluble clastic material. These formations do not contain significant amounts of other soluble minerals, and much of the solute in the groundwater of these formations consists of calcium, magnesium, and bicarbonate ions. Some groundwater in these formations, however, also contains high concentrations of sodium and sulfate ions.

The following sections summarize findings from the detailed evaluation of the San Andres/Glorieta aquifer system (WME, 2021).

1.3.2.6.2.1 <u>San Andres-Glorieta Aquifer Transport Assessment Approach</u>

Constituent mobility is controlled by pH and redox conditions, which determine the dissolved forms of constituents in groundwater. The mineralogy of the aquifer solids is equally important in assessing reactions controlling constituent transport. Therefore, the transport assessment approach utilized complete water quality analyses and mineralogical characterization of San Andres-Glorieta aquifer samples to develop a conceptual model for constituent transport, particularly for uranium. It was hypothesized that conditions are more reducing in the deeper San Andres-Glorieta aquifer compared to the overlying, near-surface alluvial aquifer. Thus, the factors controlling uranium transport in the San Andres-Glorieta aquifer may be quite different from those in the alluvial aquifer. For example, if conditions are adequately reducing, iron oxides may not be stable and uranium could precipitate as insoluble uranium (IV) (uraninite, or UO_2), rather than being controlled by iron oxide adsorption in an oxidizing environment. Therefore, a main focus of this investigation was to characterize the redox conditions in the San Andres-Glorieta aquifer. The geochemical model PHREEQC (Parkhurst and Appelo, 2013) was utilized to predict the dominant forms of dissolved constituents and potential for precipitation and/or adsorption which may act to control the concentrations of those constituents upon migration into the San Andres-Glorieta aquifer

1.3.2.6.2.2 <u>Sample Collection and Analysis</u>

The data for this assessment were collected as part of a geochemical investigation conducted by HDR (HDR, 2021). Two borings (SAG-1 and SAG-2) were advanced through the San Andres Limestone into the Glorieta Sandstone with monitoring wells completed in the San Andres Limestone. Aquifer solids (two

sample each from the Glorieta Sandstone and San Andres Limestone) were collected for bulk mineral identification using XRD analysis, and for examination of both major and minor minerals using optical mineralogy. The samples were also analyzed for total/inorganic carbon and sulfur content, which provides an overall indication of inorganic carbonate, detrital organic matter, and sulfide minerals (e.g., pyrite) with which to assess the reduction capacity of the aquifer solids.

Groundwater samples were collected from wells SAG-1 and SAG-2, in February and April of 2021, using low-flow purging in conjunction with a flow cell to obtain representative samples. Five samples were collected from each well at various depths. Field parameters included temperature, pH, dissolved oxygen (DO), electrical conductivity (EC), oxidation-reduction potential (ORP; expressed as Eh), and ferrous iron (iron as Fe^{2+}). The samples were analyzed for major cations, major anions, nutrients, metals, and radionuclides. Additional samples were also collected from wells 0943M and 0951R in March 2021 to provide supplemental information to support the transport assessment.

1.3.2.6.2.3 San Andres-Glorieta Aquifer Mineralogy

Bulk XRD analysis results indicate samples from the San Andres Limestone consisted primarily of calcite and/or dolomite (97 percent), with a small amount of quartz (1 percent) and less than five percent of unidentifiable components. Samples from the Glorieta Sandstone contained much lower carbonate mineral content (6 to 16 percent) and consisted primarily of quartz (62 to 82 percent) with lesser amounts of kaolinite and potassium feldspar. Optical microscopy results for these samples were very consistent with respect to major mineral constituents. Microscopy also revealed the presence of minor constituents which could not be detected using XRD analysis. These include pyrite in association with relatively minor iron oxides in both the San Andres Limestone and Glorieta Sandstone.

The carbon contents are comprised primarily of inorganic carbon (carbonate), with minor organic carbon, and are highest in the San Andres Limestone samples, as would be expected for carbonate rocks. The total sulfur content consisted of either sulfate-sulfur or sulfide-sulfur (pyrite), while the sulfur content of the Glorieta Sandstone is largely dominated by sulfide-sulfur. The presence of organic carbon and pyrite in a number of samples may tend to impart reducing conditions within the San Andres Limestone and Glorieta Sandstone aquifers, depending on the relative rates of oxygen depletion versus oxygen replenishment from surface recharge.

1.3.2.6.2.4 San Andres-Glorieta Aquifer Water Quality

Analytical results of groundwater sampling indicate the groundwater is a calcium-sulfate type with a tendency toward higher proportions of calcium and sulfate relative to magnesium and bicarbonate with depth. The total dissolved solids (TDS) concentrations ranged from 860 to 1,960 mg/L and increased with depth. A redox profile was identified under which conditions become more reducing with depth. An inverse relationship between ferrous iron and dissolved oxygen illustrates that higher ferrous iron is associated with low dissolved oxygen concentrations in all wells. Field oxidation-reduction potential measurements expressed as Eh were found to be a reliable indicator of the overall redox conditions. For example, higher dissolved oxygen concentrations were indicative of relatively oxidizing conditions as reflected by the corresponding higher measured Eh values. Conversely, higher ferrous iron concentrations were indicative of relatively reducing conditions as indicated by correspondingly lower Eh values. Redox profiles were also apparent in the distribution of dissolved nitrogen species, where the oxidized form of nitrogen (nitrate) was only detectable in highest elevation samples, while the reduced form (ammonia) dominated at depth. Anoxic sulfidic conditions were also apparent at depth where measurable sulfide was detected.

1.3.2.6.2.5 San Andres-Glorieta Aquifer Geochemical Modeling

Analytical results of groundwater sampling of the San Andres-Glorieta Aquifer were used as input to the geochemical speciation model PHREEQC (Parkhurst and Appelo, 2013) to calculate mineral saturation index values and the forms of uranium, molybdenum, and selenium present in the groundwater. This information can be used to assess the potential for direct precipitation and/or adsorption of constituents during transport. Constituents (e.g., uranium), whose respective minerals (e.g., uraninite) have positive saturation index values indicating oversaturation, can potentially precipitate in the aquifer and be retarded in transport, while constituents with negative saturation index values would tend to stay in dissolved form and, therefore, be less likely to be retarded by precipitation during transport.

Saturation index values indicated equilibrium with respect to calcite and dolomite, consistent with the observed mineralogy. The majority of the samples were also oversaturated or near-equilibrium with the ferrous-bearing carbonate minerals rhodochrosite and/or siderite, but with a tendency toward undersaturation at higher Eh values. The presence of low ferric concentrations also resulted in oversaturation with respect to ferrihydrite and goethite. Oversaturation with respect to these iron oxide minerals is consistent with the identification of trace goethite and iron oxides identified using optical microscopy.

In neutral and slightly alkaline environments, powellite ($CaMoO_4$) is the primary mineral phase with the potential to control molybdenum concentrations. However, the San Andres-Glorieta groundwater samples are highly undersaturated with respect to powellite and therefore, molybdenum would not be expected to precipitate in this environment. In the relatively deep samples and in select shallow samples with low Eh, conditions range from equilibrium to oversaturation for iron selenide (FeSe) and/or amorphous selenium, which may act to maintain low selenium concentrations in the San Andres-Glorieta aquifer. Measurable uranium was present in the groundwater samples, although a high degree of uraninite undersaturation was calculated, indicating that conditions are adequately oxidizing to prevent the precipitation of uraninite. The solution speciation results indicated that virtually 100 percent of the dissolved molybdenum exists as the free molybdate ion (MoO_4^{2-}), 100 percent of the dissolved selenium exists as the reduced selenate [selenium (IV)] ion ($HSeO_3^-$ and SeO_3^{-2}), and 100 percent of the dissolved uranium exists in the form of oxidized uranium (VI) complexed with calcium and carbonate ($Ca_2UO_2(CO_3)_3$ and $CaUO_2(CO_3)_3^{-2}$).

1.3.2.6.2.6 San Andres-Glorieta Aquifer Implications for Constituent Transport

The pH and Eh conditions in the San Andres-Glorieta aquifer are such that uranium occurs primarily in its oxidized form as mobile uranium-calcium-carbonate complexes, which are only weakly attenuated by reactive mineral surfaces. The range in pH-Eh conditions measured in the San Andres-Glorieta aquifer showed that the samples lie within the range of stability for oxidized uranium-carbonate complexes, rather than within the uranium (IV) stability field. Similarly, molybdenum and selenium also exist in solution as oxyanions which are only weakly adsorbed under neutral pH conditions. Potential adsorbing minerals which have been identified in the San Andres-Glorieta aquifer include unspecified iron oxides (likely ferrihydrite) and goethite, a more crystalline form of iron oxide. Thus, the primary transport control for uranium, molybdenum, and selenium in the San Andres-Glorieta aquifer would be largely indistinguishable from that of the alluvial aquifer.

The measured iron content of the San Andres Limestone samples ranged from 0.0934 to 0.413 percent as iron (HDR, 2021), with an average of 0.27 percent as iron. These values approximate the same range in ferrihydrite estimated from selective chemical extraction of alluvial aquifer samples that are 0.01 to 0.38

percent as iron (WME, 2021). Considering this range in alluvial ferrihydrite content, a surface complexation mixing model (SCCM) was previously utilized to predict the adsorption behavior of certain constituents in the alluvial aquifer. Freundlich adsorption constants for uranium and molybdenum, were subsequently derived using a conservatively low ferrihydrite content of 0.05 percent as iron to account for the expected lower adsorption efficiency in the actual groundwater system. Because both the forms of dissolved uranium and the content of the adsorbing phase (ferrihydrite) in the San Andres-Glorieta aquifer are essentially identical to those of the alluvial aquifer, constituent transport within the San Andres-Glorieta aquifer can also be appropriately and conservatively modeled using the Freundlich parameters previously developed for the alluvial aquifer (HMC, 2020e).

1.3.2.6.3 Geochemical Behavior and Attenuation of Constituents

Section 2.2 identifies the specific constituents that are the subject of this ACL Application. As discussed in Section 5.1, the ACL values for the constituents for which the transport model is not specifically calibrated were calculated using the ratio of maximum source area groundwater concentrations (C_{POC}) to maximum predicted POE concentrations (C_{POE}) from modeling of a completely geochemically-conservative theoretical tracer (see Section 4). This is a conservative approach to the development of ACLs because, in reality, all constituents plus chloride and sulfate will exhibit some degree of attenuation during groundwater transport. This section discusses the general geochemical behavior and factors affecting transport and attenuation of the constituents addressed in this ACL Application.

1.3.2.6.3.1 <u>Chloride and Sulfate</u>

The anions chloride (Cl^-) and sulfate (SO_4^{2-}) are common in most groundwaters and have been studied extensively. These constituents are generally considered to behave conservatively during groundwater transport and are often referred to as indicator constituents with respect to identifying uranium milling impacts to groundwater (NRC, 2003a). Elevated chloride and sulfate were present in the historic discharges to the Large Tailings Pile (WME, 2020b) and therefore groundwater in the License boundary has exceeded the License groundwater protection standards of 250 mg/L for chloride and 1,500 mg/L for sulfate.

Although chloride and sulfate are generally considered to behave conservatively during groundwater transport, they may be attenuated to some degree when compared to a completely conservative, theoretical tracer. For example, anions (e.g., Cl^-) can be electrostatically attracted to positively-charged mineral surfaces in the same way that cations (e.g., K^+) are attracted to negatively-charged surfaces. The capacity for a given mineral to adsorb anions generally increases with increasing acidity (decreasing pH), which contributes to positively-charged surfaces, depending on the mineralogy being considered. It has been shown that the capacity of clay minerals to adsorb anions with decreasing pH is much greater for minerals which possess a pH-dependent charge (e.g., kaolinite) compared to those with a permanent charge (e.g., montmorillonite). Kaolinite has been shown to adsorb chloride from solution up to a pH of 7, whereas chloride was not retained by montmorillonite above a pH of 4; for kaolinite, the divalent sulfate ion was adsorbed to a greater extent compared to monovalent chloride, as would be expected based on electrostatic forces alone (Bohn et al., 1985).

Sulfate is generally more reactive than chloride. In addition to retention by electrostatic attraction, sulfate also has the ability to form surface complexes with soil various iron/aluminum oxide and clay minerals (e.g., Chao et al., 1962; Sokolova and Alekseeva, 2008), as well as various pure mineral surfaces, such as ferrihydrite, goethite, kaolinite (Dzombak and Morel, 1990; Rao and Sridharan, 1984; Rietra et al., 1999). Several important factors controlling sulfate adsorption onto mineral surfaces include the pH and ionic

strength of the solution, sulfate concentration, mineralogy, and organic matter content. Significant adsorption of sulfate by various soil minerals typically occurs at around pH = 5.5 with a maximum adsorption at pH = 4 (Sokolova and Alekseeva, 2008), although infinitesimal amounts of sulfate would still be retained at higher pH values.

1.3.2.6.3.2 Ammonia, Nitrite, and Nitrate

The alkaline carbonate leaching process for recovering uranium used ammonia (NH_3) to control pH (Skiff and Turner, 1981). Ammonia is a reduced form of nitrogen (nitrogen -III) which is typically added to solution as anhydrous ammonia gas [$NH_3(g)$] during industrial applications. Anhydrous ammonia reacts with water to form the ammonium ion (NH_4^+) with the release of OH- which can act to raise pH:

$$NH_3(g) + H_2O(l) \rightarrow NH_4^+(aq) + OH^-(aq)$$

Ammonium (nitrogen -III) is stable under reducing conditions but may be oxidized to nitrate (nitrogen +V) by nitrifying bacteria in soils and groundwater. During the nitrification process, ammonium is first converted to nitrite (NO_2^-) (nitrogen +III) catalyzed by the Nitrosomonas bacteria (Alexander, 1977):

$$NH_4^+(aq) + 1.5\ O_2(g) \rightarrow NO_2^-(aq) + 2H^+(aq) + H_2O(l)$$

Nitrite is an unstable intermediate and typically does not accumulate (Rivett et al., 2008), but rather is further oxidized to nitrate (NO_3^-) (nitrogen +5) catalyzed by the Nitrobacter bacteria (Alexander, 1977):

$$NO_2^-(aq) + 0.5O_2(g) \rightarrow NO_3^-(aq)$$

As a result, the historic tailings discharge contained measurable ammonia-N and with nitrate-N above the License groundwater protection standards (10 mg/L to 15 mg/L); recent geochemical investigations have shown that the redox conditions within the Large Tailings Pile range from oxic to suboxic, such that dissolved nitrogen in the tailings solution also occurs primarily as ammonia-N with lesser amounts of nitrate-N (WME, 2020a). Alluvial groundwater becomes primarily oxidizing downgradient of the Large Tailings Pile, where ammonia-N is largely below detection and nitrate becomes the dominant form of nitrogen.

Nitrate does not interact strongly with mineral surfaces and therefore it is not significantly attenuated by adsorption processes. However, there are a number of biogeochemical processes controlling nitrate attenuation in groundwater. As a general rule, denitrification has been identified as the dominant nitrate attenuation process in groundwater (Rivett et al., 2008). Under anoxic conditions, denitrifying bacteria are able to couple organic carbon oxidation with nitrate reduction to produce gaseous nitrogen N2(g):

$$5CH_2O(s) + 4NO_3^-(aq) \rightarrow 2N_2(g) + 4HCO_3^-(aq) + CO_2(g) + 3H_2O(l)$$

Denitrification results in a loss of nitrate to nitrogen gas as the final end-product. However, the alluvial groundwater contains measurable dissolved oxygen and therefore conditions are not generally favorable for denitrification (Rivett et al., 2008). Other potential nitrate depletion mechanisms include: (1) Dissimilatory nitrate reduction to ammonium, (2) assimilation of nitrate into microbial biomass, and (3) nitrate removal by deeply-rooted vegetation (phreatophytes). These mechanisms are generally insignificant relative to denitrification under anoxic conditions, but together with groundwater mixing, may play a more important role in the attenuation of nitrate under oxic conditions in the alluvial aquifer.

1.3.2.6.3.3 Arsenic

Arsenic accumulation in roll front deposits may be associated with pyrite in unaltered sandstones and/or iron oxides in altered sandstones (Harshman and Adams, 1980). As a result, historic tailings solutions contained arsenic at concentrations exceeding the Criterion 5C standard of 0.05 mg/L and the New Mexico Drinking water standard (0.01 mg/L per NMAC 20.6.2.3103.A; WME, 2020b). The two main redox states of arsenic, which commonly occur in groundwater are arsenite (arsenic +III) and arsenate (arsenic +V) (Cullen and Reimer, 1989; Masscheleyn et al., 1991). In reducing environments, dissolved arsenic mainly occurs as arsenite, or may precipitate as insoluble arsenic sulfide minerals (orpiment, realgar). However, under predominantly oxidizing conditions, arsenate is the dominant form of arsenic in solution. Under the pH conditions of most groundwater systems, arsenate will be present as the negatively-charged oxyanions $H_2AsO_4^-$ and $HAsO_4^{2-}$. Both arsenate and arsenite may be adsorbed by a variety of aquifer materials, including iron oxides, aluminum oxides, and phyllosilicate (clay) minerals. Adsorption to iron oxides (particularly ferrihydrite) is particularly important in controlling arsenic concentrations due to the ubiquitous nature of iron oxides in the environment and the high strength of arsenate adsorption onto iron oxide surfaces (Dzombak and Morel, 1990; Waychunas et al., 1993). Arsenate adsorption onto iron oxides is maximized at low pH and begins to decrease with increasing pH above a pH of 7 (Pierce and Moore, 1982; Goldberg, 2002).

1.3.2.6.3.4 Boron

Elevated boron concentrations have been reported to be associated with former uranium ore milling sites, and in some cases attributed solely to natural occurrences which produce elevated background concentrations (DOE, 1996; OECD, 2002; DOE, 2005; DOE, 2020a). Sedimentary rocks tend to have the highest concentrations of naturally-occurring boron (Parker, 1967), where boron can be found as a constituent of axenite, tourmaline, ulexite, colemenite, and kernite (Gupta et al., 1985). Newman (1962) also identified abnormally high concentrations of boron in some principal host sandstones of the Colorado Plateau. Consequently, boron concentrations in alluvial groundwater in the vicinity of the Large Tailings Pile have been shown to exceed 0.75 mg/L.

The dominant forms of dissolved boron in groundwater are boric acid, $B(OH)_3$, and borate ion, $B(OH)_4^-$. Boric acid is a weak acid with a relatively high pKa value (9.24 in fresh water), so that it has limited dissociation under neutral and low pH values (Kochkodan et al., 2015). Therefore, the unionized boric acid B(OH)3 species would be the predominant form in the alluvial aquifer. Boron containing minerals are either very insoluble (tourmaline) or very soluble (hydrated boron minerals) and generally do not control the solubility of boron in soil solutions (Goldberg, 1993). Rather, the boron concentrations in soil solution are controlled by adsorption reactions, which are most affected by pH and mineralogy. Boron adsorption to soils has been shown to increase in the pH range of 3 to 9 with decreasing adsorption at higher pH values (Goldberg, 1997). Numerous studies have also investigated boron adsorption onto various crystalline and amorphous iron and aluminum oxide minerals. As summarized by Goldberg (1997), boron adsorption increased with increasing pH up to an adsorption maximum at pH 6 to 8 for aluminum oxides and pH 7 to 9 for iron oxides. Above the adsorption maxima, boron adsorption decreased with increasing pH for both mineral types. Layer silicate clays may also serve as important adsorbates for boron, with maximum adsorption occurring around pH 8 and the order of adsorption capacity being kaolinite less than montmorillonite less than illite (Goldberg, 1997). Humic acids associated with natural organic matter also have the capacity to adsorb boron with maximum adsorption around pH 9 (Goldberg, 1997; Meyer and Bloom 1997).

1.3.2.6.3.5 Cadmium

Cadmium is known to be associated with sandstone-hosted uranium roll front deposits, and although little information exists on its mode of occurrence, cadmium likely occurs as an impurity (typically 0.2 to 0.4 percent) in sphalerite (ZnS; Alloway, 1991; Finch, 1967; Frondel, 1958). Hence, there is potential for cadmium accumulation in uranium mill tailings. Consistent with these associations, cadmium concentrations in excess of the 0.01 mg/L Criterion 5C standard have been measured in the tailings placed in the Large Tailings Pile (WME, 2020b). The chemical behavior of cadmium in groundwater is determined by the presence of other organic and inorganic ions in solution and the groundwater pH (Gardiner, 1974; McComish and Ong, 1988; Powell et al., 2011). In water, cadmium typically exists in divalent form as free cadmium cation (Cd^{2+}) and its hydrolysis products (e.g., $Cd(OH)^{+}$, $Cd(OH)_2^0$) and/or as solution complexes with nitrate, carbonate, sulfate, and phosphate. Cadmium may also exist as solution complexes with naturally-occurring dissolved organic acids.

Both precipitation/dissolution and adsorption/desorption reactions have the potential to control cadmium concentrations in natural waters (Rai and Zachara, 1984). Under acidic conditions, cadmium is not strongly attenuated. Under pH-neutral and alkaline conditions, however, cadmium attenuation can occur through the precipitation of otavite ($CdCO_3$; Santillan-Medrano and Jurinak, 1975) or by coprecipitation with iron oxyhydroxides (Gerth, 1990). In addition to cation exchange on clay minerals, cadmium is also strongly attenuated by adsorption to iron oxides, where the strength of adsorption increases with increasing pH (Langmuir, 1997). Cadmium concentrations in natural waters are therefore generally low under pH-neutral to alkaline conditions and future cadmium mobility will be very low in the alluvial aquifer.

1.3.2.6.3.6 Fluoride

Fluoride is widely distributed in the earth's crust and is highly reactive. Because fluoride (F^-) and the hydroxyl ion (OH^-) have similar ionic radii, fluoride can replace OH- in mineral structures. Replacement of the OH^- group by fluoride in hydroxyapatite [$Ca_5(PO_4)_3OH$] produces fluorapatite [$Ca_5(PO_4)_3F$], one of the most common fluorine minerals, along with fluorite (CaF_2) and cryolite (Na_3AlF_6) (NAS, 1971). The occurrence of fluoride-bearing minerals can be grouped into halides, oxides, carbonates, borates, sulfates, phosphates, and silicates (Koritnig, 1978). Some of the most common fluoride-bearing minerals include biotite, muscovite, apatite, and hornblende, which may constitute a portion of the gangue mineralogy in association with uranium ore deposits. Therefore, uranium mill tailings can potentially contain elevated fluoride concentrations, depending on the gangue mineralogy of the ore deposit. Results from selected Large Tailings Pile monitoring wells between 2018 and 2020 indicated an average fluoride concentration of 3.4 mg/L, with a maximum concentration of 26 mg/L (WME, 2020a), which exceeds the NMAC Human Health Standard for fluoride of 1.6 mg/L.

Fluorite precipitation has been shown to control dissolved fluoride concentrations in soils containing calcium carbonate (calcite) (Rai and Zachara, 1984), and calcite has also been identified in the alluvial aquifer at the GRP (WME, 2020a). A more common attenuation mechanism for fluoride is adsorption to iron and aluminum oxyhydroxides, the surface charges for which are pH-dependent (Meeussen et al., 1996). However, a number of studies have shown that fluoride is easily leached from both contaminated and uncontaminated soils, indicating that fluoride is only weakly adsorbed to mineral surfaces under neutral and alkaline pH conditions (Polomski et al., 1982; Reddy and Gloss, 1993). The earlier work of Hingston et al. (1972) has shown that fluoride is specifically adsorbed onto goethite (FeOOH) and gibbsite [$Al(OH)_3$], but only below the zero point of charge of the mineral when the surface is positively charged; the pH of maximum fluoride adsorption was found to be approximately 3.2. Meeussen and others (1996) were able

to successfully model fluoride transport through goethite-coated sand by modeling fluoride adsorption, where fluoride adsorption was greatest at pH =4.0, and only a single ligand exchange reaction was needed to describe the displacement of OH^- from the mineral surface by fluoride.

1.3.2.6.3.7 Molybdenum

Enrichment of molybdenum is common in sandstone-hosted uranium deposits, where molybdenum typically occurs as molybdenum sulfide (MoS_2; Bullock and Parnell, 2017; Nash et al., 1981; Rosenzweig, 1961). Tailings disposed in the Large Tailings Pile and the Large Tailings Pile tailings solution both contain molybdenum at concentrations exceeding the License groundwater protection standard for the alluvium (0.1 mg/L). Subsequent oxidation of molybdenum (-II) as MoS_2 releases molybdenum (+VI) to solution, which is dominated by the molybdate ion (MoO_4^{2-}) above pH 5 (Smedley and Kinniburgh, 2017). In both native soils and mining-affected groundwater environments, under neutral to alkaline pH conditions, molybdenum concentrations can be controlled by precipitation of powellite ($CaMoO_4$; Frascoli and Hudson-Edwards, 2018; Lindsay, 1979). Powellite precipitation has been proposed as a mechanism controlling the concentrations of molybdenum in the immediate vicinity of the Large Tailings Pile (WME, 2020b).

Molybdenum is also known to be weakly adsorbed by the surfaces of various mineral oxides, carbonates, clay minerals, and iron oxides. In particular, adsorption of molybdenum onto the surface of iron and aluminum oxides has received considerable attention due to the ubiquitous occurrence of iron and aluminum oxides in soils and aquifer materials. Iron oxides have been identified as the most important sorbent for reactive metals in the alluvial aquifer and tend to adsorb more molybdenum compared to aluminum oxides and clay minerals (Goldberg et al., 1996; Jones, 1957). Studies have shown that molybdate adsorption onto ferrihydrite is at a maximum between a pH of 4 and 5, and decreases rapidly with increasing pH, with minimal molybdenum adsorption above a pH of 7 to 8 (Goldberg et al., 1996; Goldberg, 2009).

1.3.2.6.3.8 Combined Radium-226 and 228

Radium (principally the radium-226 isotope) is produced from the radioactive decay of uranium-238 and hence occurs naturally in uranium ore. Radium-226 is also radioactive and decays by alpha particle emission to produce radon gas (radon-222). As a consequence, the tailings from operation of the Homestake mill contained radium-226 concentrations exceeding the Criterion 5C (5 pCi/L combined radium-226 and 228; WME, 2020b). Disposal of those tailings in the Large Tailings Pile resulted in elevated radium concentrations in the alluvium directly below the Large Tailings Pile. The potential attenuation mechanisms for radium in groundwater are (1) ion exchange with clay minerals, (2) specific adsorption to mineral surfaces (iron oxides), (3) coprecipitation with barite ($BaSO_4$) and/or gypsum ($CaSO_4 \cdot 2H_2O$), and (4) direct precipitation (IAEA, 2014). Although radium sulfate ($RaSO_4$) and radium carbonate ($RaCO_3$) can potentially precipitate directly from solution, radium concentrations in waters associated with uranium mining are usually not high enough to reach saturation with these pure radium solids (Langmuir and Riese, 1985).

Radium mobility in the alluvial groundwater is therefore likely limited by a combination of ion exchange, adsorption, and coprecipitation. This is supported through bulk mineralogical characterization of alluvial solids, which has identified the presence of clay minerals (kaolinite, smectite) and iron oxides (hematite, ferrihydrite; Arcadis, 2018; WME, 2020a). In addition, the presence of barite in alluvial solids has been confirmed (WME, 2020a) and represents a significant potential sink for radium in groundwater (Bosbach

et al., 2010). On a mass basis, the concentrations of radium in groundwater beneath the Large Tailings Pile would be miniscule compared to the mass of uranium. For example, a radium-226 activity concentration of 1 pCi/L is equivalent to mass concentration of only 1 x 10^{-9} mg/L. The low relative mass of dissolved radium and consequent high radium attenuation capacity of the alluvium results in a much lower mobility of radium compared to uranium. Elevated radium activities have historically been primarily confined to the area beneath the Large Tailings Pile. Currently, combined radium-226 and 228 activities in all alluvial wells remain below the License groundwater protection standard, indicating the alluvium essentially contains an infinite capacity to attenuate radium from the Large Tailings Pile seepage.

1.3.2.6.3.9 Selenium

Selenium enrichment is common within sandstone-hosted uranium roll front deposits (Bullock and Parnell, 2017; Nash et al., 1981) where it may occur as iron selenide ($FeSe_2$) or as an impurity (up to 3%) in pyrite (FeS_2) (Coleman and Delevaux, 1957). As a result, concentrations of selenium as high as 14.7 to 51.2 mg/L have been reported for tailings disposed in the Large Tailings Pile and Small Tailings Pile (WME, 2020b) and in select Large Tailings Pile monitoring wells (WME, 2020a). In oxidizing environments, dissolved selenium occurs primarily as selenium +VI in the form of selenate (SeO_4^{2-}), where the primary attenuation mechanism is adsorption to iron oxides (Dzombak and Morel, 1990; WME, 2020b). However, selenate adsorption is very weak under neutral to alkaline conditions and is more weakly adsorbed compared to uranium (Kaplan and Serne, 1995; Goldberg, 2014). In the presence of sulfate, the extent of selenium adsorption is even further reduced due to competition for adsorption sites (Dhillon and Dhillon, 2000). Evidence for the high mobility of selenate is the elevated selenium concentrations (up to 3.4 mg/L) measured in downgradient domestic wells prior to groundwater restoration (Kaufmann et al., 1976). The relative extent of the oxidized portion of the selenium plume was equally and effectively reversed by groundwater restoration source control activities; subsequently, geochemical conditions within and beneath the Large Tailings Pile have since limited further migration of selenium.

Tailings seepage and alluvial groundwater beneath the Large Tailings Pile is more reducing compared to the outlying oxidizing alluvial groundwater. In the Large Tailings Pile seepage, dissolved selenium occurs as educed selenium +4 in the form of selenite (SeO_3^{2-}). Reduced solid-phase forms of selenium (elemental selenium and iron selenide) have also been identified in the tailings solids (WME, 2020a). Selenite is more strongly adsorbed to mineral surfaces relative to selenate (Goldberg, 2012), and precipitation of the reduced solid-phase forms also act to reduce selenium solubility. Reducing conditions within the Large Tailings Pile are driven by the decay of organic matter, where the rates of oxygen consumption are greater than the rates of oxygen replenishment, as controlled by infiltration of dissolved oxygen and diffusion into the Large Tailings Pile. The dramatic decreases in dissolved selenium in both the Large Tailings Pile and underlying alluvial groundwater since the 1970s indicate that conditions have become more reducing over time. Increasingly reducing conditions may have been further enhanced by changes in hydraulics of the Large Tailings Pile. For example, during early milling operations with a much smaller thickness in the Large Tailings Pile, seepage was likely occurring from the coarse sands and would have reported more directly to the alluvium. As the thickness of the tailings increased, a larger fraction of the solution passing through the pile was likely exposed to the finer slimes, where reducing conditions favorable for precipitation of insoluble elemental selenium would be more quickly established.

1.3.2.6.3.10 Thorium-230

Thorium-230 is produced from the radioactive decay of uranium-238 and decays by alpha emission. It is a precursor to radium-226. Thorium-230 has been detected in the tailings from the former operations at the

Homestake mill (WME, 2020b) at levels above the License groundwater protection standard for the alluvium (0.3 pCi/L). Like combined radium-228+228, elevated thorium-230 in the alluvium only occurs in close proximity to the Large Tailings Pile. The mobility of thorium in groundwater is restricted at pH values > 6 due to precipitation of insoluble thorium hydroxide [Th(OH)4], thorium oxide (ThO_2), and, potentially, thorium sulfate [$Th(SO_4)_2$] when sulfate concentrations are elevated (Ryan and Rai, 1987; Langmuir, 1997). Thorium is also strongly adsorbed by clays, iron oxides, and organic matter which cause thorium to concentrate in soil and sediments. Studies have shown that maximum thorium adsorption (95 to 100%) onto various mineral and organic constituents occurs above a pH of approximately 5.5 to 6.5 (Langmuir and Herman, 1980; LaFlamme and Murray, 1987). As a result, dissolved thorium-230 concentrations in natural waters rarely exceed 0.08 pCi/L (Langmuir and Herman, 1980). This is consistent with the 2019 measured thorium-230 concentrations of 0.01 to 0.1 pCi/L in alluvial groundwater beneath the Large Tailings Pile, just beyond the edge of the plume (HMC and Hydro-Engineering, 2020). Similar to radium, the low relative mass of dissolved thorium-230, and the alluvium's consequent high thorium attenuation capacity, results in much lower mobility than uranium.

1.3.2.6.3.11 Uranium

Two types of uranium ore were processed at the former Homestake Mill: (1) sandstone-hosted ore (80 to 85 percent of the mill feed) and (2) limestone-hosted ore (15 to 20 percent of the mill feed (Skiff and Turner, 1981). The ore grade ranged from 0.04 to 0.3 percent where uranium mineralization occurred as a combination of oxidized and reduced uranium minerals (coffinite, uraninite, tyuyamunite, carnotite). As a result of incomplete extraction of uranium during the milling process, uranium concentrations in tailings and in the Large Tailings Pile exceed the uranium License groundwater protection standards (0.03 mg/L to 0.18 mg/L) (WME, 2020a; WME, 2020b).

The most important uranium oxidation states in nature are the uranous (uranium +IV) and the uranyl (uranium +6) states (Langmuir, 1997). The uranous form is stable in waters with a low redox potential (Eh) and pH and tends to be controlled by precipitation of uraninite (UO_2) under most natural conditions. Uraninite precipitation will act to maintain dissolved uranium concentrations well below the License groundwater protection standards as long as reducing conditions are maintained. The uranyl form is stable under oxidizing conditions (high redox potential) and tends to be much more mobile than the uranous form due to the relatively higher solubility of uranium (+6) minerals (e.g., carnotite). Under acidic (pH less than 5) oxidizing conditions, and in the absence of carbon dioxide, the free uranyl ion (UO_2^{2+}) is the dominant species in solution, whereas the monomeric hydrolysis species (e.g., $UO_2(OH)^+$, $UO_2(OH)_2^0$) begin to dominate at higher pH. However, in most groundwater systems where elevated carbon dioxide is present, uranyl forms strong carbonate complexes (e.g., $(UO_2)_2CO_3(OH)^{3-}$, $UO_2(CO_3)_3^{4-}$) which become much more abundant relative to the uranyl hydrolysis species. The carbonate complexes are important because they increase the solubility of uranium minerals, facilitate uranium (+IV) oxidation, and limit the extent of uranium adsorption in oxidizing waters, thus increasing uranium mobility (Langmuir, 1997). The uranyl species also forms stable complexes with calcium, fluoride, magnesium, phosphate, and sulfate which can affect uranium transport behavior (Langmuir, 1978; Dong and Brooks, 2006).

Adsorption-desorption reactions are an important consideration for uranium behavior in natural environments. Because of the relatively low solubility of the uranous solids (e.g., uraninite), adsorption is generally not considered an important attenuation mechanism under reducing conditions. However, uranyl is generally more soluble and tends to be controlled by adsorption reactions in oxidizing groundwater systems. Because of their common occurrence in soils and sediments and strong sorptive behavior toward

uranium +VI, iron oxyhydroxides (e.g., ferrihydrite, goethite) are generally the most important potential sorbents for uranium, with organic matter second in importance (Langmuir, 1997). The pH of maximum uranyl adsorption of uranyl ions on ferrihydrite has been observed in the pH range 5 to 8 (Hsi and Langmuir, 1985; Waite et al., 1994). Adsorbed uranium +VI can be reduced to uranium +IV as uraninite or coffinite by mobile reductants (such as Fe^{2+}) or can be reduced directly by organic matter. Adsorbed uranium +VI can also be desorbed by an increase of alkalinity at constant pH or by raising the pH. Such changes increase the extent of uranyl carbonate complexing, which are poorly adsorbed, causing desorption and remobilization of uranyl species (Langmuir, 1997).

1.3.2.6.3.12 Vanadium

Vanadium enrichment is common within sandstone-hosted uranium roll front deposits where it may occur as vanadium (+III) (vanadium mica, roscoelite, montroseite) and vanadium (+IV) (vanadium montmorillonite, vanadium chlorite, paramontroseite) (Nash et al., 1981). As a result, vanadium concentrations in tailings and in a number of Large Tailings Pile monitoring wells exceed the current License groundwater protection standard (0.02 mg/L) (WME, 2020a; WME, 2020b). The transport characteristics of vanadium in groundwater are highly dependent on redox conditions. Dissolved vanadium can exist as either vanadium (+IV) or vanadium (+V) (Lee, 1983). In oxidizing environments and under near-neutral conditions, vanadium exists primarily as vanadium (+V) in the form of the vanadate ion ($H_2VO_4^-$) (Wehrli and Stumm, 1989). Vanadate behaves very similar to phosphate in aqueous and biological systems and is known to be adsorbed and incorporated into clay mineral structures and iron oxide coatings (Evans and Landergren, 1974). Humic and fulvic acids, which constitute many natural organics, also have a strong affinity for vanadium, in the presence of which these materials can reduce dissolved vanadate to vanadyl, which favors vanadium complexation by organic substances (McBride, 1980; Wehrli and Stumm, 1989). The presence of organic substances has been shown to further enhance the adsorption of vanadium to iron oxides (Peng and Korshin, 2011). Mineralogical characterization of the alluvial aquifer has identified the presence of clay minerals (kaolinite, smectite), iron oxides (hematite, ferrihydrite), and organic matter which can effectively act to reduce dissolved vanadium concentrations in groundwater (Arcadis, 2018; WME, 2020a). Based on the historic observed lack of notable migration from the Large Tailings Pile and the strong attenuation capacity of the alluvial aquifer, the future mobility of vanadium should continue to be restricted and remain significantly less mobile compared to uranium.

1.3.2.6.4 Conceptual Geochemical Model

In the current conceptual geochemical model, an active source term is contained within a dissipating mound of tailings water in the Large Tailings Pile, where the rates of seepage will continue to decrease over time (Figure 1.3-39). The sodium-sulfate tailings seepage contains elevated pH, TDS, and COC concentrations, with redox conditions ranging from oxic to suboxic. Uranium exists primarily as oxidized uranium (+VI) complexed with carbonate ($UO_2(CO_3)_2^{2-}$) while molybdenum is mainly present as the oxidized molybdate (MoO_4^{2-}) ion. Dissolved selenium in the tailings is predicted to occur as both the oxidized [selenium (VI)] selenate (SeO_4^{2-}) ion and the reduced [selenium (IV)] selenite (SeO_3^{2-}) species. As tailings seepage migrates into the underlying alluvial aquifer, it mixes with alluvial groundwater from upgradient. As the tailings-influenced groundwater moves downgradient, the concentrations of conservative indicator constituents (chloride, sulfate) are controlled by dilution and dispersion. The dissolved uranium becomes dominated by the uranyl-calcium-carbonate complexes ($CaUO_2(CO_3)_3^{2-}$, $Ca_2UO_2(CO_3)_3$) and selenate becomes the main form of selenium upon mixing with the more oxidizing calcium-sulfate type alluvial groundwater. Molybdenum continues to migrate as the free molybdate ion.

Potential attenuation mechanisms for the constituents in the alluvial aquifer include mineral precipitation, adsorption by various clay minerals, and adsorption by amorphous iron hydroxide (ferrihydrite). Direct precipitation of constituents is not considered to be an important attenuation mechanism in the alluvial aquifer due to the extent of undersaturation with respect to the oxidized mineral forms (e.g., carnotite, calcium molybdate, metal selenates). However, HMC (2018b) has recognized the presence of reduced microenvironments in the alluvial aquifer, which could produce locally reducing conditions. Selenium is more easily reduced relative to uranium and molybdenum, and thus could also potentially migrate as selenite or precipitate as elemental selenium in these localized zones. The relative importance of the two remaining attenuation mechanisms (adsorption to clays or ferrihydrite) focuses on the two constituents (uranium and molybdenum) whose modeled transport results are presented in this ACL Application.

The affinity for adsorption to minerals is controlled by the forms of dissolved uranium and molybdenum in the groundwater, and the surface charge of the mineral, both of which are pH dependent. Uranium is mainly present as negatively charged calcium- and carbonate-complexes under site pH conditions and would only exist as positively-charged species (UO_2OH^+, UO_2^{2+}) below pH of 6 (Figure 1.3-40). Similarly, molybdenum occurs primarily as the negatively charged MoO_4^{2-} ion (Figure 1.3-41). Clay minerals are negatively charged above pH of 5 (Appelo and Postma, 2013), producing a swarm of positively charged cations (Na+, Ca^{2+}) at their surface, where the concentrations of negatively charged anions are the lowest. A diffuse layer of ions extends from the clay mineral surface into the solution, with cations at higher concentrations and anions at lower concentrations compared to the solution (Figure 1.3-41). Major cations (Na^+, Ca^{2+}) are held rather weakly to the clays by electrostatic force, whereas metal oxyanions bond more strongly with oxygen on mineral surfaces. However, under site conditions (pH greater than 7), the anionic forms of uranium and molybdenum are essentially excluded from interacting with negatively charged clays.

Alternatively, iron oxide surfaces will be neutral or positively charged under most groundwater pH conditions (Appelo and Postma, 2013). Oxyanion adsorption involves both an electrostatic attraction and chemical bonding to the mineral surface, and adsorption of uranium and molybdenum by ferrihydrite is expected under site conditions. In the conceptual geochemical model, adsorption by ferrihydrite [$Fe(OH)_3$] is therefore considered to be the primary mechanism for partitioning of uranium and molybdenum in the alluvial aquifer (Figure 1.3-39). The extent of adsorption is not 100 percent and will vary depending on the specific constituent and local geochemical conditions, such that a fraction of the uranium and molybdenum remains mobile. Due to its widespread nature, studies have shown ferrihydrite to exert more control on the attenuation of uranium compared to clays. For example, uranium adsorption data compiled by the EPA (1999a) indicates that soil containing higher percentages of iron oxides, mineral coatings, and/or clay minerals will exhibit higher adsorption capacities compared to soil solely dominated by quartz and feldspars (Figure 1.3-42). Some investigators have also shown that adsorption capacities for soil of mixed mineralogy are not necessarily correlated with clay content, but rather uranium appeared to be associated with mineral surface coatings of variable pH (consistent with ferrihydrite occurrence; EPA, 1999a). Consequently, the use of surface complexation models (SCCMs) utilizing the adsorptive behavior of uranium on ferrihydrite are almost universally used to model fate and transport of uranium in groundwater systems (e.g., Zhu et al., 2002; Curtis et al., 2009; Johnson et al., 2016; NRC, 2003c; NRC, 2006a).

1.4 Groundwater Protection Standards

NRC groundwater protection regulations for uranium mills are set forth in Appendix A to 10 CFR Part 40. Criteria 5A-5D and Criterion 13 incorporate the basic groundwater protection standards imposed by the

Environmental Protection Agency in 40 CFR Part 192, Subparts D and E (48 FR 45926; October 7, 1983). Criterion 6(7) identifies that non-radiological hazards associated with the licensed waste must also be addressed. Criterion 7 identifies the requirement for detection monitoring, compliance monitoring, and corrective action monitoring programs. Criterion 11 identifies that title to the byproduct material and land, including any interests therein (other than land owned by the United States or by a state) used for the disposal of any byproduct material or that is essential to ensure the long-term stability of such disposal site, must be transferred to the United States or the State in which such land is located, at the option of such State. Criterion 12 identifies that the final disposition of tailings, residual radioactive material, or wastes at milling sites (including those in groundwater) should be such that ongoing active maintenance is not necessary to preserve isolation.

NRC has also established site-specific groundwater standards in the materials license SUA-1471. Condition 35B of the License identifies the NRC groundwater protection standards. These values and their respective bases are included in Table 1.1-1. It is noted that the constituents, boron, chloride, sulfate, and total dissolved solids (TDS) are not listed in Criterion 13 of 10 CFR Part 40, Appendix A nor in Appendix I to 40 CFR part 192, and therefore, are not subject to the requirements of 10 CFR Part 40, Appendix A Criterion 5B(2). These constituents are not typically considered hazardous at other Title II uranium mill tailings facilities. Thus, no ACLs will be proposed for these constituents. However, boron, chloride, and sulfate are discussed in the document because the State of New Mexico has water quality standards for these constituents, and the NRC License has standards for chloride and sulfate. HMC proposes to remove chloride and sulfate from License Condition 35B upon NRC approval of the ACLs for the ten identified constituents. TDS is not addressed as a hazardous constituent because adverse health effects from the broad category of TDS cannot reasonably be determined: associated specific hazards are highly dependent on the individual ions that make up the TDS values, and those individual ions are addressed independently. Chloride, sulfate, and TDS are retained as monitoring parameters in the proposed monitoring program.

1.5 Proposed Alternate Concentration Limits

This section summarizes the development of the proposed ACLs, which are presented with additional detail in Section 5.1 of this ACL Application. Section 2.2 of this ACL Application screens groundwater and Large Tailings Pile concentrations and identifies 10 constituents to be addressed, most of which are not laterally extensive, and three of which are not currently included in License Condition 35B.

Assessment of corrective action alternatives, presented in Sections 4.2 through 4.5 of this ACL Application, identify the Proposed Action as approval of ACLs. Two groundwater model types were developed; a set of calibrated base-case models were developed to assess corrective action alternative performance and a set of bounding-case models were developed by modifying the base-case models to conservatively assess groundwater constituent concentrations at the POE for the proposed ACL values. The base-case flow and transport models have been calibrated for both uranium and molybdenum, the two groundwater constituents that exceed License groundwater protection standards at the furthest lateral distance from GRP sources. A selenium predictive model run was developed to calculate ACLs and incorporates site-specific attenuation mechanisms. All other constituents addressed in this ACL Application, which exhibit lower relative source concentrations and/or extend over substantially less area, were modeled by applying results from a single individual constituent that transports conservatively (without any geochemical retardation) as a surrogate analyte. The model design and predicted transport behavior of this surrogate analyte is intended to

conservatively bound the potential future transport of all other constituents (other than uranium and molybdenum) addressed in this ACL Application, which have some, although varying, degrees of geochemical retardation in transport. The calibrated groundwater flow and transport models, referred to as base-case models, are used to assess the groundwater corrective action alternatives described in Sections 4.2 and 4.3 of this ACL Application and support selection of the Proposed Action.

The proposed ACLs are set above the current (2022-2025) measured maximum groundwater concentration of each analyte at the POC area wells. Demonstration that these current maximum groundwater constituent concentrations will result in concentrations below the groundwater protective limits at the POE for 1,000 years is accomplished using conservative groundwater flow and transport models of the Proposed Action. The conservative models of the Proposed Action were developed from the base-case calibrated models by adjusting major input parameters to reflect the most conservative end of their reasonable ranges so that the model outcomes would predict greater constituent transport than the calibrated-base case models. These modified models are referred to herein as bounding-case models.

The modification applied to the bounding-case models were used to provide additional assurance that the maximum current groundwater concentrations and conservative estimates of long-term source and transport conditions will remain protective at the POE and address potential uncertainties associated with modeling future contaminant sources, contaminant transport properties, long-term groundwater use demand, and long-term contaminant and hydrologic inputs. A summary of input parameter adjustments made to the calibrated models for the bounding-case models is presented in Sections 4 and5 of this ACL Application, and referenced appendices present the detailed calculation of the proposed ACLs.

1.5.1 Groundwater Constituents

The constituents identified in this ACL Application include those identified in the current License Condition 35B as well as additional constituents that HMC is addressing as if they constituted hazardous constituents, as described in Section 2.2. The identified constituents are:

- Metals
  - arsenic, cadmium, molybdenum, selenium, vanadium
- Radionuclides
  - uranium, combined radium-266 and radium-228, and thorium-230.
- Non-metal, non-radiological constituents
  - nitrate and fluorine (fluoride)

These constituents are the focus of the analyses in the ACL Application. No organic compounds, polychlorinated biphenyls, or pesticides have been used at the GRP or identified in samples from the tailings. Chloride, sulfate, and total dissolved solids (TDS), are identified in License Condition 35B and in the State of New Mexico Discharge Permit DP-200, but are not considered hazardous and are not listed as hazardous constituents in Appendix A to 10 CFR Part 40, and thus do not require an ACL. HMC therefore proposes to remove them from the GRP License Condition 35B upon NRC approval of the ACLs for the ten identified constituents. Chloride, sulfate, and TDS are retained as monitoring parameters in the proposed monitoring program and are discussed in Section 5.2 of this application for this reason.

Boron is not listed in Criterion 13 of Appendix A to 10 CFR 40 and, therefore, does not meet the definition of a hazardous constituent in Criterion 5B(2). As a result, no ACL will be established for it. Boron is discussed in this document because it has been identified as above the State of New Mexico irrigation standard, but it will not be retained as a water quality monitoring constituent.

1.5.2 Proposed Points of Compliance and Points of Exposure

Six POC wells are proposed and further discussed in Section 5. ACLs are calculated to assure that groundwater constituent concentrations will remain below protective standards at groundwater points of exposure (POEs). The proposed long-term control boundary constitutes the POE for all aquifers. Figure 1.5-1 shows the proposed POE control boundary used in this ACL Application. There are no current exposures to impacted groundwater due to several factors, including HMC ownership of the substantial majority of the land within the control boundary, an alternative water supply provided to all properties with legal access to groundwater within the control boundary, an annual well survey documenting no groundwater use from existing permitted wells in the control boundary, and a New Mexico Office of the State Engineer order prohibiting new or replacement wells in areas with impacted groundwater.

HMC has obtained ownership of approximately 86% of the surface estate and 77% of the subsurface estate of the land area within the anticipated long-term care boundary, continues its good faith and serious efforts to obtain all surface and subsurface estates within the anticipated long-term care boundary, and intends to comply with regulatory requirements governing acquisition and transfer of property within the control boundary. Documentation demonstrating HMC's serious and good faith efforts being made to acquire the remaining estates is available for NRC staff review onsite. All wells not required for the approved groundwater monitoring plan within the proposed control boundary will be plugged and abandoned once HMC acquires land ownership and there will be no groundwater use allowed on any land within the proposed control boundary. The Long-Term Care Boundary is proposed by the DOE and approved by NRC. It may or may not be commensurate with the proposed control boundary, which is the area this Licensee will be responsible for controlling access to and use of groundwater while it holds the License.

There are 542 parcels of land within the proposed control boundary, HMC currently owns 507 of them, which comprises over 86 percent of the land area within the control boundary (See Figure 1.2-57). Of the parcels not yet owned by HMC, only 20 parcels have permitted groundwater access in areas with groundwater quality currently exceeding the License groundwater protection standards, all other parcels with permitted groundwater access do not currently overlie groundwater in any hydrologic unit exceeding the License groundwater protection standards. All parcels with permitted groundwater access to impacted formations are connected to an alternate water supply and do not currently use groundwater from those wells. A state prohibition on new wells in this area does not allow the State Engineer's office to permit new wells in this area. HMC does not and will not permit groundwater use on surface and subsurface estates it owns within the control boundary and will plug and abandon all permitted wells not required by the license when new estates are acquired by HMC.

Per NRC guidance in NUREG-1620, Section 4.3.3.2.5 (Exposure Assessment), HMC proposes to establish the POE associated with the proposed ACLs beyond the GRP license area boundary. HMC has made, and will continue to make, good-faith efforts to acquire land between the license area boundary and the POE, and commits to transfer property ownership within the proposed long term control boundary to the DOE as

long-term custodian as part of the license termination process. DOE is currently planning for the site to be transferred to Legacy Management in 2035 (DOE, 2026).

1.5.3 Calculation of ACLs

Proposed ACLs are above current (2022-2025) measured groundwater constituent concentrations at the proposed POC area wells (Table 1.5-1). Proposed ACLs are demonstrated to be protective using bounding-case model runs performed for two constituents, uranium and a hypothetical, conservative (i.e., non-sorptive, non-reactive) constituent. Predictive model runs were also conducted for molybdenum and selenium for use in calculation of ACLs. Proposed ACLs are lower than the maximum POC concentration that would remain protective at the POE, affording time and opportunity for investigation and potential corrective action if POE and/or POC concentrations were to increase to near protective limits. Calibrated groundwater transport models were developed based on best estimate site-specific input parameters and measured target head and groundwater concentration targets. These models are termed base-case models. The base-case model for uranium groundwater transport was used to evaluate the three identified corrective action alternatives.

Bounding case predictive simulations for future transport of uranium and a hypothetical conservative constituent with a unit source concentration were performed for the proposed action (Alternative 3; ACLs and monitoring) to identify the potential cumulative impacts of "worst case" model parameter inputs on POE concentrations by selecting input values for key parameters from the outer bounds of the reasonable ranges of values that promote greater future extent of mass transport and greater mass and concentrations in groundwater.

Predicted Bounding-case transport modeling results demonstrate with reasonable assurance a) all future hazardous constituent concentrations at all downgradient POE will remain protective for 1,000 years and b) proposed ACLs will not result in groundwater concentrations at any POE above protective standards for 1,000 years. Figure 1.5-1 shows the proposed long-term control boundary (LTCB) which constitutes the POE for all aquifers.

1.5.4 Proposed Implementation and Groundwater Monitoring

The proposed Groundwater Compliance Monitoring Plan, described in detail in Section 5.2 includes annual monitoring for all 10 identified constituents (see Section 2.2 and Appendix 2.2-A for identification of constituents addressed in this ACL Application) and the field parameters (static groundwater level, pH, temperature, electrical conductivity, dissolved oxygen, oxidation reduction potential [ORP]). The proposed Groundwater Compliance Monitoring Plan includes monitoring at (i) six monitoring locations within the tailings (collection sumps); (ii) six POC wells in alluvium; (iii) six groundwater locations directly below the Large Tailings Pile; (iv) two upgradient wells in the alluvium; and (v) 90 downgradient monitoring wells across the affected hydrologic units. Water sample collection will be performed annually in accordance with GRP standard operating procedures (SOPs). Data from this monitoring will be analyzed and assessed in accordance with the GRP Groundwater Compliance Monitoring Plan and Quality Assurance Plan (QAP) and reported annually per the proposed amendment to License Condition 15. Groundwater level measurements are proposed to be collected quarterly at all wells for the first year following cessation of groundwater collection and injection to monitor changes in groundwater gradients and annually thereafter.

1.5.5 ALARA Demonstration

The as low as reasonably achievable (ALARA) requirement identified in 10 CFR 40 Appendix A is based on the necessary minimum condition that concentrations at the POE be protective, meaning exposure point concentrations meet and remain at or below the specified radiological dose limits and other groundwater protection standards identified in the License. Under 10 CFR 40, Appendix A, licensees seeking ACLs must demonstrate that the exposure concentrations have been reduced to levels that are ALARA or that ACLs are ALARA.

Establishing if exposure concentrations have been reduced to levels that are ALARA or that ACLs are ALARA is a process and does not prescribe a specific value for all licensees or conditions. Rather, it is an analysis conducted to assess corrective action alternatives and their respective associated costs and benefits to determine whether further reductions to concentrations below the protective limits at the POE are reasonably achievable.

NUREG-1757 (NRC, 2022a) guides the assessment of costs and benefits of identified corrective action alternatives. Specifically, it provides that, when analyzing the reasonable achievability of an alternative's further reduction of POE groundwater constituent concentrations below protective limits, an alternative is not reasonably achievable if its costs are more than one order of magnitude--or ten times--the monetized benefits of the additional reduction in dose.

As presented in Section 4 of this ACL Application and supported by the groundwater flow and transport modeling presented in Appendix 4.2-B, long-term groundwater restoration is not reasonably achievable. Alternatives to the Proposed Action, which provide reasonable assurance of control of access to and use of groundwater within the control boundary and of maintaining groundwater constituent concentrations below protective standards at and beyond the control boundary, are identified and evaluated for technical feasibility in Sections 4.2 and 4.3. A cost/benefit analysis is provided in Section 4.4 and an analysis of corrective action performance is provided in Appendix 4.1-A to support demonstration that the past several decades of corrective actions together with the Proposed Action have reduced groundwater concentrations to ALARA. This analysis addresses the direct and indirect costs and benefits of groundwater corrective action alternatives based on the guidance in the NRC ACL Guidance (NRC, 1996), NUREG-1620 (NRC, 2003b) and NUREG-1757 Volume 2, Rev 2 (NRC, 2022a). The current and projected resource value of the groundwater prior to contamination and timeliness of remedy completion identified by NRC in NUREG-1620 are added to the list of benefits. The value of the groundwater irrevocably lost as untreatable wastewater from collected groundwater treatment is added to the list of costs. The ALARA demonstration identifies the following.

- The present value of the pre-contaminated groundwater resource for the next 1,000 years, based on estimates of future demand, ranges between $0.147 million and $3.76 million.
- The present value of monetized benefit from averted dose for human exposure to groundwater containing uranium for the entire potentially affected population for the next 1,000 years ranges from $81,568 (Alternative 1) to $ 1.57 million (Alternative 3).
- The present value cost of the alternatives ranges from $20.65 million (Alternative 3) to $248.8 million (Alternative 1).
- The monetized cost/benefit ratios (high estimate and low estimate) identify that the monetized costs of reducing POE groundwater constituent concentrations below protective limits are more than an order of magnitude higher than the projected monetized costs and the non-monetized benefits are not sufficiently large to change the scale of the cost/benefit ratios:

- Alternative 1 Cost/Benefit Ratio: 65 to 103
- Alternative 2 Cost/Benefit Ratio: 55 to 70
- Alternative 3 Cost/Benefit Ratio: 7.4 to 25

Based on the guidance from Section N.4 of Appendix N to NUREG-1757 (NRC, 2022a), further reduction of groundwater constituent concentration through corrective alternatives is not reasonably achievable because the costs are more than ten times the benefits.

1.5.6 Proposed License Amendment

Based on the data and analyses presented in this ACL Application, HMC respectfully requests the following amendments to the current License Conditions 15, 35, 36 and 42, as follows in redline/strikeout.

15. The results of all effluent and environmental monitoring required by this license and regulation shall be reported ~~semi-~~annually, by March 31 ~~and September30~~. All groundwater monitoring data shall be reported per the requirements in License Condition 35.

35. The licensee shall implement a groundwater compliance monitoring program separate from the requirements in License Condition 15. The Licensee shall:

A. Implement the groundwater monitoring shown in the Groundwater Compliance Monitoring Plan submitted by the licensee on June 30, 2026~~, November 20, 2017 (ML18018A102), as updated by the licensee in correspondence dated October 8, 2019 (ML19281C055)~~.

B. The following groundwater protection standards are established for the POC wells C2, D1, M3, SB, SZ and X ~~each designated aquifer/zone~~ as described in the table below ~~Ground-Water Hydrology for Support of Background Concentration at the Grants Reclamation Site (Hydro-Engineering, December 2001) and Background Water Quality Evaluation of the Chinle Aquifers (Homestake Mining Company and Hydro-Engineering, October 2003)~~:

Constituents	*Alluvial Aquifer*	*Chinle Mixing Zone*	*Upper Chinle Non-*	*Middle Chinle Non-Mixing Zone*	*Lower Chinle Non-*
~~Selenium (mg/L)~~	~~0.32~~	~~0.14~~ *	~~0.06~~ *	~~0.07~~ *	~~0.32~~ *
~~Uranium (mg/L)~~	~~0.16~~	~~0.18~~ *	~~0.09~~ *	~~0.07~~ *	~~0.03~~ *
~~Molybdenum (mg/L)~~	~~0.1~~	~~0.1~~ *	~~0.1~~ *	~~0.1~~ *	~~0.1~~ *
~~Sulfate (mg/L)~~	~~1500~~	~~1750~~ *	~~914~~ *	~~857~~ *	~~2000~~ *
~~Chloride (mg/L)~~	~~250~~	~~250~~ *	~~412~~ *	~~250~~ *	~~634~~ *
~~TDS (mg/L)~~	~~2734~~	~~3140~~ *	~~2010~~ *	~~1560~~ *	~~4140~~ *
~~Nitrate (mg/L)~~	~~12~~	~~15~~	*	*	*
~~Vanadium (mg/L)~~	~~0.02~~	~~0.01~~	~~0.01~~	*	*
~~Thorium-230 (pCi/L)~~	~~0.3~~	*	*	*	*
~~Ra-226+228 (pCi/L)~~	~~5~~	*	*	*	*
~~* - ground-water protection standards not necessary for the constituents in the indicated zones~~					

Constituents	All	Chi	Upp	Mid	Low
~~Selenium (mg/L)~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~
~~Uranium (mg/L)~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~
~~Molybdenum (mg/L)~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~
~~Sulfate (mg/L)~~	~~1~~	~~1~~	~~9~~	~~8~~	~~2~~
~~Chloride (mg/L)~~	~~2~~	~~2~~	~~4~~	~~2~~	~~6~~
~~TDS (mg/L)~~	~~2~~	~~3~~	~~2~~	~~1~~	~~4~~
~~Nitrate (mg/L)~~	~~1~~	~~1~~			
~~Vanadium (mg/L)~~	~~0~~	~~0~~	~~0~~		
~~Thorium-230 (pCi/L)~~	~~0~~				
~~Ra-226+228 (pCi/L)~~	~~5~~				
~~* - ground-water protection standards not necessary for the constituents in the indicated zones~~					

Constituents	***Alluvial Aquifer***	***Chinle Mixing Zone***	***Upper Chinle Non-Mixing Zone***	***Middle Chinle Non-Mixing Zone***	***Lower Chinle Non-Mixing Zone***
Arsenic (mg/L)	*0.3*	*	*	*	*
Cadmium (mg/L)	*0.03*	*	*	*	*
Fluoride (mg/L)	*9*	*	*	*	*
Molybdenum (mg/L)	*116*	*	*	*	*
Nitrate+Nitrite as N (mg/L)	*41*	*	*	*	*
Selenium (mg/L)	*4.2*	*	*	*	*
Uranium (mg/L)	*50.0*	*	*	*	*
Vanadium (mg/L)	*0.3*	*	*	*	*
Thorium-230 (pCi/L)	*11*	*	*	*	*
Radium-226+228 (pCi/L)	*51*	*	*	*	*
* *groundwater protection standards not necessary for the constituents in the indicated zones*					

~~*C. Implement the corrective action program described in the September 15, 1989 submittal, as modified by the reverse osmosis system described in the January 15, 1998 submittal, excluding all sampling and reporting requirements for Sample Point 1, with the objective of achieving the concentrations of all constituents listed in License Condition 35B. Composite samples from Sample Point 2 (SP2) will be taken monthly and analyzed for the constituents listed in License Condition 35B; the results of these analyses will be reported in the semi-annual and annual reports required by License Conditions 15 and 42.*~~

~~*D. Operate evaporation ponds, EP1, EP2 and EP3, and enhanced evaporation systems located in each pond as described in the June 8 and 28, 1990; July 26, August 16, August 19, September 2 and 15, 1994; October 25, 2006, February 7, 2007, July 18, 2007, and March 17, 2008, submittals. Monitoring and*~~

~~*mitigation measures for EP3 contained in the HMC Environmental Report dated January 30, 2007, are incorporated into this LC by reference.*~~

~~*E. Operate the zeolite water treatment systems located on the Large Tailings Pile as described in the December 11, 2017 (ML17361A006), February 22, 2018 (ML18066A583), and May 17, 2019 (ML19149A366), submittals, including all monitoring and mitigation requirements specified therein.*~~

~~*F. Submit by March 31 of each year, a performance review of the corrective action program that details the progress towards attaining groundwater protection standards.*~~

42. An annual report will be submitted to the NRC that includes (1) a description of any changes, tests, or experiments approved by a SERP including a summary of the safety and environmental evaluations, (2) the ALARA audit report, (3) land use survey, (4) monitoring data, ~~*(5) corrective action program report, and (6)*~~ *(5) the effluent and environmental monitoring reports.*

2 HAZARD ASSESSMENT

The hazard assessment describes the characteristics of both primary and secondary sources of groundwater contamination at the GRP (Section 2.1), identifies the relevant constituents (Section 2.2), and evaluates the risk to human health and the environment at the POE (Section 2.3).

2.1 Source and Contamination Characterization

This section describes the characteristics of various sources of constituents entering into groundwater at the GRP. The primary sources of contaminants at the GRP are the Large Tailings Pile, Small Tailings Pile, and debris pits located south of the Large Tailings Pile, where former milling equipment was buried (Figure 1.2-60). Potential secondary sources include the impacted alluvium and fine-grained bedrock units underlying the Large Tailings Pile. The sources and contaminant characterization are based primarily on several studies, which are either included by reference or appended to this document.

2.1.1 Large Tailings Pile - Primary

The Large Tailings Pile is an unlined impoundment covering about 200 acres and contains approximately 21 million tons of uranium mill tailings. Seepage from the Large Tailings Pile represents the largest source of contaminant loading to the alluvial groundwater at the GRP.

2.1.1.1 Large Tailings Pile Tailings Solids Characterization

The tailings solids in the Large Tailings Pile are heterogeneous and generally consist of alternating and interfingering layers of poorly graded sands, silts, and clays, with fine grained fractions concentrated in the center portions of the two Large Tailings Pile surface ponds, which were used to manage Large Tailings Pile tailings solids and liquids. Surface tailings tend to be loose and oxidizing, with increasing moisture and evidence of reducing conditions with depth (dark coloration, odor of H_2S). Their chemical composition is dominated by aluminum, calcium, iron, potassium, and silicon, and the primary constituent concentrations (uranium, molybdenum, selenium) are elevated relative to native soil and highly variable, with Large Tailings Pile solids concentrations (dry-weight basis) ranging from: a) 38 to 118 mg/kg uranium, b) 4 to 19 mg/kg molybdenum, and c) 79 to 192 mg/kg selenium.

Detailed mineralogical testing using both X-ray diffraction analysis and scanning electron microscope (SEM) has shown that various clay minerals, calcite, quartz, and minor pyrite, are the main minerals present. Although tailings pore water was calculated to be undersaturated with respect to selenium and uranium minerals, SEM revealed selenium in association with iron on the surface of pyrite and as elemental selenium mineral inclusions. Uranium was associated with calcium and vanadium, consistent with an oxidized mineralogy (tyuyamunite, carnotite). Selective chemical extraction suggests uranium may be associated with carbonates, organic matter, and iron oxides (WME, 2020a).

No solid forms of molybdenum were identified through SEM; however selective chemical extraction indicates most of the molybdenum in the tailings is either water soluble or occurs in an unidentified residual (stable) form, with lesser amounts extracted from the exchangeable and organic/sulfide phases (WME, 2020a). This indicates that a fraction of the molybdenum is available for future transport by long-term Large Tailings Pile infiltration and seepage.

Static testing using acid-base accounting showed the tailings contain an excess acid-neutralizing (buffering) capacity. In 20-week duration kinetic tests using humidity cells, uranium, molybdenum selenium, vanadium, and sulfate displayed early concentration spikes in a few Large Tailings Pile tailings samples, but the overall decreasing trends did not indicate significant residual sources of constituents that would be released from the tailings upon future long-term weathering (WME, 2020a). The isolated spikes were likely due to delayed flushing-diffusion from the finer-grained material (as observed for uranium in a slime sample) or oxidation of molybdenum sulfides, elemental selenium, and pyrite (FeS_2). Plots of cumulative mass released for uranium, molybdenum, selenium, and vanadium showed little to no increase after 20 weeks, indicating that the capacity of the tailings to release additional constituents had become exhausted by the end of the test (WME, 2020a; Figure 2.1-1). However, the number of pore volumes needed to exhaust the tailings is large and is significantly more than the anticipated infiltration through the pile over the next 1000 years. Evaluation of major ion concentration trends in the humidity cell testing leachates indicate that rinsing of soluble constituents, dissolution of calcite, and oxidation of sulfide minerals (primarily pyrite) are the primary mechanisms controlling the long-term chemistry of weathered tailings solids leachate (WME, 2020a). Therefore, increases in current Large Tailings Pile seepage concentrations from weathering or geochemical alternation of tailings solids over the intermediate to long-term are not indicated by these data.

2.1.1.2 Large Tailings Pile Pore Water Geochemical Characterization

This section summarizes the geochemical characterization of the tailings pore water. The tailings solution consists of a high-pH (approximately 9 to 10) sodium-sulfate and sodium-carbonate water, with elevated concentrations of TDS, uranium, molybdenum, and the indicator constituents chloride and sulfate (WME, 2020a). Redox conditions are important in controlling the solubility and behavior of constituents in the tailings and have been evaluated by assessing dissolved oxygen (DO) content and measured redox potential (Eh). Because field Eh measurements are often unstable unless the system is completely anoxic (devoid of DO) and dominated by iron, sulfur, and manganese, the tailings characterization study (WME, 2020a) included analysis for additional analytes to assess the redox status of the tailings pore water, including the iron (Fe^{2+}/Fe^{3+}), nitrogen (NH_4^+/NO_3^-), and sulfur (H_2S/SO_4^{2-}) redox pairs. This evaluation indicated that Eh values computed from the NH_4^+/NO_3^- redox couple (67 to 250 mV) provides the closest match to field-measured Eh values (26 to 464 mV). The low DO concentrations in some wells completed in tailings are consistent with the consumption of dissolved oxygen by organic matter decay, producing localized reducing conditions. The redox classification scheme developed for groundwaters indicates the tailings pore waters can be classified as ranging from oxic to suboxic, although the presence of measurable sulfide (H_2S) suggests the existence of some anoxic sulfidic zones as well.

Tailings pore water speciation calculations were subsequently conducted using the geochemical model PHREEQC with Eh calculated from the NH_4^+/NO_3^- couple to define redox conditions (WME, 2020a). The results indicate that dissolved uranium and molybdenum occur primarily in their oxidized forms [uranium (+VI), molybdenum (+VI)], while selenium is present as both selenium (+VI) and selenium (+IV). Molybdenum is predicted to exist primarily as the molybdate ion (MoO_4^{2-}), uranium as the uranyl tetracarbonate species ($UO_2(CO_3)_3^{4-}$), and selenium as selenite (SeO_3^{2-}) with only minor amounts of selenate (SeO_4^{2-}), all of which are generally mobile in the environment. Calculated saturation index (SI) values suggest there are no discrete uranium, molybdenum, or selenium minerals controlling the overall concentrations of these constituents in the tailings. The tailings are undersaturated with respect to the common low solubility reduced uranium (+IV) minerals [uraninite, $UO_2(c)$; amorphous uranium oxide,

UO_2(am)], and the oxidized uranium (+VI) minerals (carnotite, tyuyamunite, and uranium phosphate). The tailings pore water is also mostly undersaturated with the common molybdenum and selenium minerals, such as calcium molybdate ($CaMoO_4$) and elemental selenium [Se(am)]. Section 2.1.1.2 further addresses potential constituent concentrations in the Large Tailings Pile.

The NRC sampled the Large Tailings Pile liquid from each of two ponds located at that time on the top of the Large Tailings Pile. These ponds are identified by NRC as the East Pond (sample location H-1) and the West Pond (sample location H-2), although no map showing these locations has been identified. Sampling took place on April 6, 1987, to support identification of the hazardous constituents for uranium mill tailings in general, and for the License. The NRC analyzed the samples for dissolved and total concentrations of 31 metals, 18 other non-metal compounds, major ions, three radionuclides, as well as 99 organic compounds. Results from both the 1987 NRC sampling and HMC sampling of Large Tailings Pile fluid for the period 1997 through June 2021 are used to support identification of all GRP constituents addressed in this ACL Application (discussed further and tabulated in Section 2.2 of this ACL Application).

Overall, NRC samples of the tailings in 1987 identified total uranium concentrations ranging from 10.2 mg/L to 24.2 mg/L and dissolved uranium concentrations from 9.5 mg/L to 22.1 mg/L. HMC sampling of the tailings from 1997 through June 2021 measured uranium total concentrations from 0.014 mg/L to 13.9 mg/L from 27 samples and dissolved uranium concentrations from 0.049 mg/L to 131 mg/L, with an average dissolved concentration of 13.89 mg/L from over 1,400 samples.

NRC sampling of the tailings in 1987 identified total molybdenum concentrations ranging from 73 mg/L to 100 mg/L and dissolved molybdenum concentrations ranging from 39 mg/L to 58 mg/L. HMC sampling of the tailings from 1997 through June 2021 measured total molybdenum concentrations ranging from 6.64 mg/L to 9.56 mg/L and dissolved molybdenum concentrations ranging from 0.046 mg/L to 188.9 mg/L. The average dissolved concentration for molybdenum was 34.0 mg/L based on over 1,300 samples. Graphs of uranium and molybdenum concentrations in tailings sumps through time are presented in Section 3 of the 2024 Annual Performance Report (HMC and Hydro-Engineering, 2025). These results are discussed further and tabulated in Section 2.2 of this ACL Application. It is noted that average concentrations from the samples described above may not be representative of the actual average tailings seepage concentration given that these samples were taken from the ponds atop the tailings pile and not porewater from within the tailings material itself.

Calculation of average tailings impoundment water uranium concentration began in 2006 and calculation of average tailings impoundment water molybdenum concentration began in 2010; these values have been presented in each subsequent Annual Performance Report. Section 3.3.5 of the 2024 Annual Performance Monitoring Report (HMC and Hydro-Engineering, 2025) presents the most recent calculation of the average tailings concentrations as well as plots of measured Large Tailings Pile tailings water concentrations through time. The calculated current average Large Tailings Pile saturated tailings water concentrations are 5.06 mg/L uranium and 12.85 mg/L molybdenum (Table 2.1-1). These concentrations are taken to be representative of the average current and long-term Large Tailings Pile tailings water seepage concentrations. The average Large Tailings Pile tailings water concentrations are representative of current conditions as residual tailings solution concentrations are relatively stable (HMC and Hydro-Engineering, 2025).

2.1.1.3 Large Tailings Pile Seepage Rates Characterization

A Large Tailings Pile seepage model (the reformulated mixing model [RMM]) was previously developed to assess drain-down and long-term changes in both tailings seepage flow rates and constituent mass loading (Hydro-Engineering, 2019). The reformulated mixing model assessments of past Large Tailings Pile seepage rates were developed based on vadose modeling using the VADOSE/W code. Subsequently, a drain-down model (DDM) was developed that incorporates the Brooks and Corey method (Brooks and Corey, 1964) to estimate past seepage rates and mass loading beginning in 2012 as well as future seepage and Large Tailings Pile toe drain rates and constituent concentrations (Hydro-Engineering, 2020a; Hydro-Engineering, 2020b).

Seepage estimates developed from the reformulated mixing model for the period 2002 through 2011 and from the drain down model for the period 2012 through 2019 are used in the predictive groundwater flow and contaminant transport models, and discussed in Sections 3 and 4, to simulate flow from the Large Tailings Pile into the local groundwater system. Simulated Large Tailings Pile seepage rates for each model stress period in the base-case calibrated model are presented in Table 2.1-2. The calculated long-term seepage rate for the entire Large Tailings Pile footprint, equilibrated with long-term infiltration through the approved final reclamation cover (Hydro Engineering, 2025), is estimated to be 0.04 gallons per minute.

A conservative bounding-case estimate for long-term tailings seepage was also developed to support conservative modeling of contaminant transport for calculation of ACLs. This bounding-case estimate assumes that the long-term infiltration rate through the final reclamation cover is 2.4 gallons per minute, a value sixty times higher than the base-case estimate. This rate of infiltration is demonstrably conservative for an engineered tailings cover as this represents about four percent of an annual precipitation rate of 10 inches per year for the roughly 100-acre Large Tailings Pond top surface area, which is twice as high as the conservatively assumed recharge rate of 2% in the groundwater model (see recharge discussion in Sections 3 and 4).

The Large Tailings Pile seepage rates as modeled for future conditions are presented in further detail in Section 3.1.1.2 and Section 5.1 of this ACL Application.

2.1.1.4 Large Tailings Pile Rebound Evaluation

Flushing activities at the Large Tailings Pile ceased in 2015. Several studies were subsequently conducted to evaluate the potential for diffusive mass transfer of constituents from fine-grained tailings materials (sometimes referred to as tailings slimes) into the coarse tailings fraction (sometimes called tailings sands), and from the coarse tailings into the Large Tailings Pile pore water (diffusive rebound) following flushing. An initial tailings rebound study (Arcadis, 2012) was conducted in three phases: (1) a gas tracer study to understand local hydraulic and solute transport properties, (2) direct monitoring of constituent concentration trends in the Large Tailings Pile porewater, and (3) laboratory evaluation of constituents leaching from tailings solids. This study concluded that no future significant diffusive mass transfer and subsequent rebound of constituents is expected to occur.

From 2018 through 2020, a multi-faceted supplemental evaluation of tailings rebound was conducted by: (1) extending the *in situ* post-flush monitoring period for existing wells previously used for that purpose in the Arcadis (2012) study (Figure 2.1-2), (2) expanding the spatial extent and representativeness of *in situ* post-flush monitoring by installing additional wells with short screen lengths (5 feet) in sands and slimes,

(3) revising the tailings monitoring analyte list to include major cations/anions plus redox parameters, and (4) conducting a controlled diffusive rebound static column study using undisturbed tailings samples from the Large Tailings Pile (WME, 2020a).

Results from the supplemental Large Tailings Pile rebound investigation indicated that a few select tailings sumps and former Arcadis rebound monitoring wells have demonstrated increasing constituent concentrations since flushing ceased but the increases are minor compared to pre-flushing concentrations and none have returned to pre-flushing concentration (WME, 2020a; also see Figures 2.1-3 through 2.1-9 of this ACL Application). However, monitoring results from the short-screen wells indicate either decreasing or overall stable concentrations of constituents in Large Tailings Pile pore water (Figure 2.1-10). In addition, results from the controlled static column study provided no indication of diffusive rebound over a one-year test period (Figure 2.1-11 and Figure 2.1-12). The volume-weighted concentrations of uranium, molybdenum, and selenium in the Large Tailings Pile have also been decreasing since flushing ceased, providing no indication of diffusive concentration rebound in the Large Tailings Pile as a whole (WME, 2020a).

In summary, the characterization of the Large Tailings Pile tailings solids and pore water indicate:

- The Large Tailings Pile has low DO with Eh values computed from the NH_4^+/NO_3^- redox couple provide the closest match to field-measured Eh values. Tailings conditions range from oxic to suboxic with pockets of anoxic conditions
- Uranium and molybdenum occur primarily in their oxidized forms [uranium (+VI), molybdenum (+VI)], while selenium is present as both selenium (+VI) and selenium (+IV); molybdenum is predicted to exist primarily as the molybdate ion (MoO_4^{2-}), uranium as the uranyl tetracarbonate species ($UO_2(CO_3)_3^{4-}$), and selenium as selenite (SeO_3^{2-})
- Rinsing of soluble constituents, dissolution of calcite, and oxidation of sulfide minerals (primarily pyrite) are the primary mechanisms controlling the long-term chemistry of weathered tailings solids leachate
- Tailings contain an excess acid-neutralizing capacity and no significant residual sources of constituent release from the tailings upon future long-term weathering are indicated
- No future significant diffusive mass transfer and subsequent rebound of constituents is expected to occur

2.1.1.5 Bounding Source Large Tailings Pile Source Term Estimation

The mass of uranium and molybdenum released from the humidity cell tests on samples of unsaturated tailings sands and slimes (fine) materials (WME, 2020b) were used in conjunction with observed concentrations to estimate bounding concentration values for the large Tailings Pile unsaturated zone, to support bounding-case input concentrations for the predictive transport model runs of the Proposed Action (see Section 5.1 of this ACL Application). One pore volume of the Large Tailings Pile (2.38×10^9 L) was estimated using the known mass of tailings (21 million tons, or 1.91×10^{10} kg), an assumed bulk density of 1,600 kg/m^3, and an assumed average porosity of 0.20 (Table 2.1-1). Using the median and maximum release rates of uranium and molybdenum from humidity cell tests together with the mass of tailings, the median and maximum pore volume concentrations can be calculated. The calculated median and maximum uranium concentrations (2.3 mg/L and 89.9 mg/L, respectively) are of similar magnitude to the observed average and maximum concentrations (5.06 and 20.4, respectively; Table 2.1-1), indicating some

consistency between humidity cell test-measured release rates and observed conditions within the Large Tailings Pile.

A uranium concentration of 45 mg/L was chosen to represent a reasonable upper bound average concentration for the long-term tailings seepage. The value of 45 mg/L for uranium is well above the calculated median pore volume concentration of 2.3 mg/L, lower than the calculated maximum pore volume concentration of 89.9 mg/L, but approximately nine times the current average saturated concentration of 5.06 mg/L measured in 2024 (Table 2.1-1; also see Section 3.3.5 of HMC and Hydro-Engineering, 2025). Using 45 mg/L uranium is a reasonable maximum value for the average tailings seepage concentration for model sensitivity analysis. For molybdenum, a concentration of 25 mg/L was selected to represent a reasonable upper bound average concentration for the unsaturated zone. The value of 25 mg/L for molybdenum is also between the median and maximum calculated values and approximately two times the current saturated zone average concentration of 12.85 mg/L (Table 2.1-1). These average values are generally consistent with the current average concentrations of uranium and molybdenum in tailings sump samples (HMC and Hydro-Engineering, 2025), which tend to be higher than water sampled from wells completed in tailings, as discussed in more detail in Section 4.1 of this ACL Application. These values are also consistent with laboratory column test results for Large Tailings Pile and Small Tailings Pile column test samples (WME, 2020b).

However, these upper-bound values, derived from bulk tailings calculations and composited tailings water sample values from wells and drains, are not likely representative of volumetrically weighted average concentration values for current and long-term tailings seepage concentrations that are lower.

An upper bound on Large Tailings Pile long-term seepage rates is assumed to be sixty times the base-case seepage rate of 0.04 gallons per minute or 2.4 gallons per minute (Hydro-Engineering, 2020a). This represents infiltration of approximately 4.6 percent of an annual average precipitation, assuming annual precipitation levels of 10 inches per year, through the final reclamation cover (assumed 100-acre area). That infiltration rate is extremely high for an engineered soil cover and is higher than the infiltration rates modeled for native ground surfaces (see recharge discussions in modeling reports presented in Appendices 3.1-A and 4.2-B).

2.1.2 Small Tailings Pile – Primary Source

The Small Tailings Pile is an unlined impoundment covering about 40 acres and contains approximately 2 million tons of uranium mill tailings. Compared to the Large Tailings Pile, the footprint of the Small Tailings Pile is relatively small, and the Small Tailings Pile is completely unsaturated. This condition is confirmed by data from 14 boreholes into and through the Small Tailings Pile. These data are documented in the 2018 geochemical characterization (WME, 2020a), the 2019 supplemental geochemical characterization (WME et al., 2020), and a geotechnical investigation in the Small Tailings Pile (Stantec, 2019). Due to the absence of saturation, the direct contribution of constituent loading to groundwater from the Small Tailings Pile is considered minor relative to the Large Tailings Pile and not a substantive long-term source of groundwater constituents. For use in the groundwater model, the source term from the STP was assumed to be the same as the areal recharge from the model domain for 20.34 acres of the STP, excluding the footprint of Evaporation Pond 1. The concentration of the seepage from the STP was assumed to be 40 mg/L.

Geochemical characterization of the Small Tailings Pile solids indicated the same general chemical and mineralogical occurrence of constituents and dominant mineral forms as the Large Tailings Pile, although the Small Tailings Pile solids did contain comparatively lower total sulfur and sulfide-sulfur content, and also possess excess acid-neutralizing capacity (Figures 2.1-13 and 2.1-14; WME, 2020a). High flushing induced during humidity cell testing produced early concentration spikes of uranium and molybdenum during the first week of testing slime samples (WME, 2020a), after which the leachate concentrations displayed a simple rinse-out behavior. As observed for the Large Tailings Pile samples, the capacity of the tailings to release additional constituents had become exhausted by the end of the test, and rinsing of soluble constituents, dissolution of calcite, and oxidation of sulfide minerals (primarily pyrite) are the primary weathering mechanisms (WME, 2020a).

2.1.3 Debris Pits

The Homestake mill and associated structures were decommissioned and demolished between 1993 and 1995. Debris were buried on-site in eight pits (Figure 1.2-60). Because the former mill debris has been effectively contained and isolated from the surrounding environment, it is not considered to be a future source of constituents to groundwater.

2.1.4 Tailings Impacted Alluvium - Secondary Source

Impacted alluvium, especially those underlying the Large Tailings Pile and Small Tailings Pile, serve as secondary sources of constituents to alluvial groundwater. In 2019, a number of borings were extended through the alluvium to bedrock directly below the tailings piles, and samples of the underlying alluvium were collected for geochemical analyses (WME et al., 2020). The samples were analyzed for forms of iron, manganese, aluminum, calcium, magnesium, potassium, sodium, and other constituents addressed in this ACL Application, using total analysis and selective chemical extractions. Samples of alluvium from below the Large Tailings Pile and Small Tailings Pile were also subjected to six small-scale column tests to assess the potential of the underlying alluvium as a secondary source.

The textural compositions of the underlying alluvium ranged from sand (90 percent sand with 5 percent clay) to clay (70 percent clay and 13 percent sand). When compared to concentrations measured in upgradient soil, impacts to the alluvium are observed to depths of approximately 20 feet below ground surface based on the relatively elevated sulfate, chloride, uranium, selenium, vanadium, and radium-226 concentrations to that depth. In several borings however, molybdenum concentrations in the underlying alluvium were elevated at greater depths when compared to upgradient soil concentrations. A positive correlation existed between clay content and both total/soluble uranium, indicating that fine-grained materials have the potential to store greater mass and release higher dissolved uranium concentrations compared to coarse-grained materials. Results from selective chemical extraction were consistent with the observed correlation between clay content and both total/soluble uranium, where significant fractions of uranium and molybdenum in the underlying alluvium are water soluble, even in samples containing appreciable clay. Selenium, however, is associated more with organic matter and/or sulfides due to localized reducing conditions encountered in and below the tailings, limiting future selenium solubility.

The column test results showed that shallow alluvial soil directly beneath the Large Tailings Pile and Small Tailings Pile (typically less than 20 feet deep) contain some constituents that can be easily mobilized upon contact with fluids (e.g., uranium, molybdenum, selenium, vanadium) at concentrations above the range of upgradient and/or distant down gradient alluvial soil (WME et al., 2020). Most or all of the mobile

constituent concentrations could be attributed to soluble or weakly sorbed species that are subject to washout, as represented by high chloride and sulfate concentrations, and the tendency of the trace metal leaching curves to follow the chloride and sulfate trends. The column effluent behavior, especially for conservative constituents such as chloride, indicates a role of diffusive dual domain transport (discussed in Section 3.1.1) on long-term effluent concentrations. Higher effluent concentrations are observed during initial flushing due to displacement of residual porewater, dissolution of soluble salts, and desorption. Although effluent concentrations approach those of the influent with continued rinsing, they remain slightly elevated relative to the influent even beyond 10 pore volumes (WME et al., 2020). The increases in chloride and sulfate measured in batch tests were of similar magnitude to each other, consistent with diffusion of constituents from micropores associated with fine-grained material into the primary porosity of the sample. It was also noted that the amount of chloride and sulfate mobilized was significantly greater in the columns constructed with Small Tailings Pile soil than those with Large Tailings Pile soil. This could have resulted from soil under the Large Tailings Pile receiving seepage that was diluted as a result of the Large Tailings Pile flushing program, while the Small Tailings Pile did not undergo such a flushing treatment. Therefore, the study data indicate that alluvial materials impacted by tailings seepage act as a long-term secondary source of groundwater impacts through both dissolution of soluble or weakly sorbed species on solids as well as by diffusion of contaminants from fine-grained clay and silt pore space into the primary porosity of the water-yielding unit.

2.1.5 Source and Contamination Characterization Summary

The primary potential source of groundwater contaminants is seepage from the Large Tailings Pile. This seepage includes drainage from tailings and from infiltrating water. A secondary source to groundwater is derived from mass that resides in lower permeability silts, silty sands, and fine sands in the alluvium and mass that is sorbed onto aquifer solids. Characterization of these sources is described in the sections above and the referenced appendices to this ACL Application, as well as materials previously submitted to NRC and referenced above. The Debris Pits that contain the mill debris, the Small Tailings Pile, which is unsaturated and largely covered by the lining of Evaporation Pond 1, and the Land Application Irrigation area are not substantive current or long-term sources of groundwater constituents. Drain down and long-term seepage from the Large Tailings Pile, as well as release of contaminants from the silty sands, silts, and silty sands are long-term sources of contaminants to groundwater. Sensitivity modeling of these individual source terms, discussed in Section 3, indicates that base-case long-term seepage from the Large Tailings Pile, alone in isolation of existing contamination, is not predicted to result in groundwater concentrations of uranium above the License groundwater protection standard in the future. The heterogenous nature of the alluvial materials along with sorption are the primary contributors to the persistence of higher concentrations observed at the site.

2.1.5.1 Tailings Seepage - Primary Source

Tailings solids were characterized using mineralogical analysis, assessment of tailings acid base accounting, cation exchange capacity and total organic carbon content, relative constituent mobility (based on selective extraction leach tests), and assessment of tailings weathering and long-term constituent mobility using humidity cell tests. Tailings solids tend to be loose and oxidizing near the surface of the Large Tailings Pile, with increasing moisture and evidence of reducing conditions with depth. Tailings solids contain an excess acid-neutralizing capacity, and no significant residual sources of constituent release from the tailings upon future long-term weathering are indicated. Rebound of Large Tailings Pile

concentrations to pre-flushing concentrations are not indicated by the extensive mineralogical and geochemical data and are not observed in the bulk tailings monitoring data since flushing was terminated in 2015 (see Section 2.1.1.2).

Tailings pore water was characterized by sampling and analysis of constituent concentrations and trends in the Large Tailings Pile porewater, laboratory evaluations of constituent leaching from tailings solids, gas tracer studies to understand local hydraulic and solute transport properties, PHREEQC speciation modeling for dissolved forms of uranium, selenium, and molybdenum in the tailings water, and controlled diffusive rebound column study using undisturbed tailings samples from the Large Tailings Pile (see Section 2.1.1.1). The Large Tailings Pile is actively draining while the Small Tailings Pile is not saturated. The Large Tailings Pile pore waters have low dissolved oxygen concentrations and pore water constituent concentrations are generally present in their oxidized forms, which are relatively mobile ionic species. The Large Tailings Pile characterization data indicate that average intermediate and long-term tailings seepage concentrations are anticipated to be 5.1 mg/L uranium and 13 mg/L molybdenum, which is not substantially different than current tailings average conditions. The upper bound on long-term average Large Tailings Pile uranium and molybdenum seepage concentrations are conservatively estimated to be 10 mg/L for uranium and 25 mg/L for molybdenum.

Modeling of Large Tailings Pile seepage drain down and long-term rates identify that the Small Tailings Pile is not saturated while the Large Tailings Pile is still draining and is estimated to have a long-term base-case seepage rate of 0.04 gallons per minute for the entire Large Tailings Pile footprint. An upper bound long-term seepage rate of 2.4 gallons per minute is identified for the Large Tailings Pile. As discussed earlier, in spite of the lack of saturation in the STP, an assumed seepage rate is based upon the areal recharge assumed for the model domain over the portion of the pile not covered by Evaporation Pond 1.

2.1.5.2 Back Diffusion - Secondary Source

Assessment of this secondary source term was performed in 2019 using a number of borings in the alluvium directly below the tailings piles, with alluvium samples tested for major ions, metals, and constituent concentrations using selective chemical extraction methods as well as column tests. A positive correlation existed between clay content and both total/soluble uranium was identified, indicating that fine-grained materials have the potential to store greater mass and release higher dissolved uranium concentrations compared to coarse-grained materials. Results from selective chemical extraction were consistent with these observations. Further, column test effluent behavior, especially for conservative constituents such as chloride, indicates a role of diffusive dual domain transport (discussed in Section 3.1.1) on long-term effluent concentrations. However, it should be noted that this secondary source term primarily affects the duration of contaminant migration and persistence in the environment and does not have a reasonable potential to provide higher long-term concentrations than currently measured.

2.2 Constituents of Concern

To ensure the proposed ACLs are comprehensive and all constituents that may reasonably pose a present or potential hazard are addressed, HMC has performed a thorough and systematic review of constituents in the ores, mill process, and the 11e.(2) Byproduct Material in the Large Tailings Pile and groundwater. The general review process included the following steps and is supported by a detailed review and associated data provided in Appendix 2.2-A.

- Assess source term concentrations in the Large Tailings Pile for an extensive list of constituents, considering process knowledge of ore compositions as well as process chemicals and reagents.
- Compare those Large Tailings Pile concentrations to License Condition 35B and other potential standards where the License or Criterion 5C do not specify numerical standards.
- Retain those constituents that are identified in the License or Criterion 5C and are present in groundwater above the lowest promulgated standard identified in Table 1.1-1 where the License or Criterion 5C do not specify numerical standards.
- Assess groundwater concentrations for the retained constituents in the uppermost aquifer at and beyond the points of compliance (POCs) with respect to the License groundwater protection standard or the lowest promulgated standard identified in Table 1.1-1, where the License or Criterion 5C do not specify numerical standards.
- Where groundwater data are available for constituents not retained from the Large Tailings Pile screening step above, assess those groundwater concentrations with respect to the Table 1.1-1 standards, where the License or Criterion 5C do not specify numerical standards to verify that available groundwater conditions are consistent with the screening of those constituents.
- Those constituents identified in the groundwater at or beyond the POC above the lowest promulgated standards where the License or Criterion 5C do not specify numerical standards, are considered constituents to be addressed under this ACL Application.

The decision process by which constituent data were reviewed and retained as constituents to be addressed is discussed in Appendix 2.2-A. Appendix 2.2-A also includes the data sets for tailings and a summary of the groundwater data for the constituents from the Large Tailings Pile data assessment.

This review identified three additional constituents, arsenic, cadmium, and fluoride not addressed in License Condition 35B. Arsenic, fluoride, and cadmium are listed constituents in Criterion 13 of Appendix A to 10 CFR 40. While the State of New Mexico has promulgated standards for boron, chloride and sulfate, these constituents are not hazardous and are not identified as hazardous constituents under 10 CFR Part 40 Appendix A Criterion 13 or Criterion 5C and thus have been omitted from consideration for ACLs. Chloride and sulfate are retained as monitoring parameters in the proposed monitoring program. These 10 constituents identified for ACLs from this review are included in Table 2.2-1, which summarizes the results of the constituent review process.

2.3 Health and Environmental Risks of Constituents

Hazardous constituents have been identified in groundwater at the GRP at concentrations greater than levels established in the License, as described in Section 2.2, above. This hazard assessment addresses the identified constituents listed in Table 2.2-1 and discussed below.

None of the individual groundwater constituents have a reasonable potential to cause damage to structures due to the depth of (typically greater than 35 feet) and lack of groundwater contact with structures. The concentrations of the tailings constituents where private wells are located are not sufficiently high to be corrosive or detrimental to those well materials. The concentrated brine water in the evaporation ponds may have some potential to be corrosive but are contained in ponds lined with materials that are compatible with those constituents and concentrations.

Groundwater depths are below rooting depths of crops and burrowing animals so there is no potential for direct exposure or damage to wildlife and vegetation. Only one well permitted for irrigation has been identified in the area of current or potential future groundwater impact and this well draws groundwater from the San Andres-Glorieta aquifer, which is not impacted and is predicted to not be impacted in the future. Therefore, there is no potential for damage to crops from the groundwater contaminants.

2.3.1 Arsenic

Information in this section is adapted from the Agency for Toxic Substances and Disease Registry (ATSDR) Toxicological Profile for Arsenic (ATSDR, 2007). Arsenic is widely distributed in the Earth's crust at a concentration of ~3.4 ppm. Environmental arsenic is mostly found in minerals and only to a small extent in its elemental form. Arsenic is mainly obtained as a byproduct of the smelting of copper, lead, cobalt, and gold ores. Arsenic is largely immobile in agricultural soil and tends to concentrate and remain in upper soil layers for long periods. Arsenic has a long history as a control for pests.

Terrestrial plants may accumulate arsenic by root uptake from the soil and certain species may accumulate substantial levels, but when grown on highly polluted soil or soil naturally high in arsenic, the arsenic level taken up by the plants is comparatively low. Inorganic arsenic has been recognized as a human poison for centuries. Oral doses greater than 60 mg/Lin water can result in death. Lower levels of inorganic arsenic, ranging from about 300 to 30,000 µg/L in water may result in irritation of the stomach and intestines, with symptoms such as stomachache, nausea, vomiting, and diarrhea. Other effects that might occur from swallowing inorganic arsenic include decreased production of red and white blood cells, which may cause fatigue, abnormal heart rhythm, blood-vessel damage resulting in bruising, and impaired nerve function causing a “pins and needles” sensation in hands and feet (ATSDR, 2007).

A characteristic effect of long-term oral exposure to inorganic arsenic is a pattern of skin changes that include patches of darkened skin and the appearance of small “corns” or “warts” on the palms, soles, and torso, and are often associated with changes in the blood vessels of the skin. Skin cancer may also develop. Ingestion of arsenic has been reported to increase the risk of cancer in the liver, bladder, and lungs (ATSDR, 2007).

Direct skin contact with high concentrations of inorganic arsenic compounds may irritate the skin causing some redness and swelling. It does not appear that skin contact is likely to lead to any serious internal effects (ATSDR, 2007).

Inorganic arsenic is recognized by the International Agency for Research on Cancer (IARC, 2012) as a carcinogen based on evidence in humans. Studies have also suggested that chronic oral exposure to arsenic may result in the development of respiratory tumors and increased incidence of lung cancer. The principal route of exposure to arsenic for the general population in the United States is likely to be the oral route, primarily in food and in drinking water.

2.3.2 Boron

Boron is a widely occurring element in minerals found in the earth’s crust. It is the 51st most common element found in the earth’s crust and is found at an average concentration of 8 mg/kg (approximately 0.0008 percent). Boron will combine with oxygen to form borates, of which boric acid is an example (ATSDR, 2010a).

Exposure to large amounts of boron over short periods of time can affect the stomach, intestines, liver, kidney, and brain and might eventually lead to death. Studies of dogs, rats, and mice indicate that the male reproductive organs are affected if large amounts of boron are ingested for short or long periods of time (ATSDR, 2010a). Adverse developmental effects have been identified for acute- and intermediate-duration exposures, but not reported for chronic-duration exposures.

Neither the International Agency for Research on Cancer (IARC, 2006) nor EPA (IRIS, 2007) have data for the carcinogenicity classification of boron and boron compounds.

Criteria recommended for the protection of sensitive species include less than 0.3 mg boron/L in crop irrigation waters, less than 1.0 mg boron/L for aquatic life, less than 5.0 mg boron/L in livestock drinking waters, less than 30 mg boron/kg in waterfowl diets, and less than 100 mg boron/kg in livestock diets (Eisler, 1990).

2.3.3 Cadmium

The information below is taken from the ATSDR Toxicological Profile for Cadmium (ATSDR, 2012b). Cadmium is a metal found in the earth's crust often associated with zinc, lead, and copper ores. Pure cadmium is a soft, silver-white metal. Cadmium chloride and cadmium sulfate are soluble in water.

Cadmium and cadmium compounds may travel through soil, but the metal's mobility depends on factors such as pH and amount of organic matter. Cadmium binds strongly to organic matter and will be immobile in soil and be taken up by plant life, eventually, entering the food supply. Cadmium will exist in water as the hydrated ion or as ionic complexes with other inorganic or organic substances. Soluble forms migrate in water, while insoluble forms are immobile and will deposit and adsorb to sediments.

Cadmium availability to organisms in the environment is dependent on a number of factors including pH, Eh, and chemical speciation. Plant uptake of cadmium decreases as soil pH increases. Respiration and ingestion are the main routes of cadmium absorption for mammals. Factors that are reported to affect dietary cadmium absorption from the GI tract include age, sex, chemical form, levels of protein, levels of calcium and the presence of other elements (EPA, 2005a).

In humans, very high cadmium levels ingested in water or food may severely irritate the stomach and lead to vomiting, diarrhea, and sometimes death. Ingesting chronic lower levels of cadmium can lead to a build-up of cadmium in the kidneys, which, if high enough will damage the kidneys. Long-term exposure to lower levels of cadmium can also cause bones to become fragile and break easily (ATSDR, 2012b).

According to the Integrated Risk Information System (IRIS), accessed May 2021, there is no quantitative estimate of carcinogenic risk from oral exposure to cadmium. Therefore, no estimate of potential carcinogenic risk is discussed here.

2.3.4 Chlorine

As a fundamental chemical element, chlorine is not only abundant in the Earth's crust (ranking 18th in the list of elements), but it is also ubiquitous in our soil, rivers, lakes, trees, plants and, of course, oceans. Like other common elements (carbon, hydrogen, oxygen, nitrogen, sulfur, phosphorous) that are present in all

living things, chlorine and the other halogens (bromine, iodine and, to a lesser extent, fluorine) are present as well. Although only 30 natural organochlorines had been discovered by 1968, this number has grown to over 1,000.

Chlorides are dissolved from rocks and soils. The chlorides of calcium, magnesium, sodium, and potassium are readily soluble. Drainage from salt springs and sewage, oil fields, and other industrial wastes may add large amounts of chloride to streams and groundwater reservoirs. Small quantities of chloride have little effect on the use of water. Sodium chloride imparts a salty taste, which may be detectable when the chloride exceeds 100 ppm, although in some water, 500 ppm may not be noticeable. High concentrations of chlorides can present a health hazard to children and other young mammals (NGWA, 2017). However, no acute-, intermediate-, or chronic-duration oral minimal risk levels (MRLs) were derived for chlorine by ATSDR. Chlorine is not listed in the EPA Ecotox knowledgebase (EPA, 2022b).

2.3.5 Fluorine

Information in this section is taken from the ATSDR Toxicological Profile for Fluorides, Hydrogen Fluoride and Fluorine (ATSDR, 2003b). Fluoride is a natural component of the earth's crust and soil. Small amounts of fluoride are present in water, air, plants, and animals. Fluorine is a gas at room temperature, is the most electronegative element, and is very reactive. Fluoride is the ionic form of fluorine. Fluoride salts, generically referred to as fluorides, are naturally occurring components of rocks and soil. Sodium fluoride is a fluoride salt commonly used in toothpaste for the prevention of dental cavities. Sodium fluoride and other fluoride compounds, such as fluorosilicic acid and sodium hexafluorisilicate, are used in the fluoridation of public water.

The main human health concern regarding fluoride is likely to be from excessive chronic oral exposure in drinking water. Due to the deposition of significant amounts of fluoride in bone, the primary target system for intermediate and chronic exposures of both humans and several laboratory animal species is the skeletal system (including teeth). Both beneficial and detrimental dental and skeletal effects have been observed in humans. Fluoride has been shown to decrease the prevalence of dental cavities and, has been used for the treatment of osteoporosis.

Data on the potential of fluoride to induce reproductive and/or developmental effects is inconclusive. A significant association between high levels of fluoride in municipal drinking water (3 mg/L and greater) and decreases in fertility rates was found in a study of birth records found. Another study found decreases in serum testosterone levels in men with skeletal fluorosis (fluoride concentration in water was 3.9 mg/L). However, design limitations of these studies, particularly the use of poorly matched controls, limits the usefulness of these studies.

IARC (1987) labeled fluorides as "*non-classifiable as to their carcinogenicity [ability to cause cancer] in humans.*" While IARC noted that the studies "*have shown no consistent tendency for people living in areas with high concentrations of fluoride in the water to have higher cancer rates than those living in areas with low concentrations*," it was also noted that the evidence was inadequate to draw conclusions one way or the other.

Numerous epidemiological studies have examined the issue of a connection between fluoridated water and cancer. Most studies have not found significant increases in cancer mortality or site-specific cancer incidence (ATSDR, 2003b).

Ecotoxicity values for sodium fluoride are limited to aquatic species such as daphnia, minnows, bluegill and trout (NIH, 2022). Neither fluorine nor fluorides are listed in the EPA Ecotox knowledgebase (EPA, 2022b).

2.3.6 Molybdenum

Molybdenum is a naturally occurring element found extensively in the environment and typically in abundance within various ore bodies and natural mineral deposits. Molybdenum is primarily found as a compound of oxide or sulfide, and it does not occur naturally in a pure metallic form.

Molybdenum is considered an essential trace element, with low levels required for good health in humans and animals. It occurs naturally in all plants and animals. An intake of 45 micrograms of molybdenum per day (µg/day) is recommended for adults (ATSDR, 2017a). Molybdenum compounds appear to have low toxicity in humans (Institute of Medicine, 2001) and while a range of health effects in laboratory animals has been observed, observation of these effects in humans remains limited.

A study of individuals in Armenia, with an estimated daily intake of 10 to 15 mg/day molybdenum, reported aching joints, headaches and gout-like symptoms (NIH, 2020). No human dermal exposure studies were identified by the ATSDR (2017a), so information regarding dermal toxicity of molybdenum comes from a limited number of acute-exposure animal studies. No dermal effects were observed in rates following a 24-hour dermal application for 280 or 1,200 mg molybdenum/kg (ATSDR, 2017a). At the concentrations often found in groundwater, dermal exposure to molybdenum does not appear to pose any health risks.

Due to the limited human toxicity data available, the tolerable upper intake level for molybdenum in healthy individuals is based on levels associated with the impaired reproduction and fetal development in rats and mice. For healthy adults the recommended tolerable upper intake level for molybdenum is 2 mg/day.

A number of studies with limited scope and laboratory animals have examined the oral toxicity of molybdenum. The studies evaluated the toxicity of several molybdenum compounds, predominantly sodium molybdate, ammonium heptamolybdate, and ammonium tetrathiomolybdate (ATSDR, 2017a). There are no entries in the EPA Ecotox data base for molybdenum (EPA, 2022b).

There are limited data on the hepatotoxicity of molybdenum in humans. Mendy and others (2012) found a significant association between urinary molybdenum levels and the risk of having a self-reported liver condition, but the study did no establish causality between molybdenum exposure and damage to the liver. In laboratory animals, the liver does not appear to be a sensitive target of molybdenum toxicity, although effects have been seen at higher doses.

No studies were located by ATSDR (2017a) regarding systemic effects in humans or animals following dermal exposure to molybdenum.

A study of acute exposure via oral intake in humans over a 10-day period estimated a no-observed-adverse-effect level (NOAEL) of 0.022 mg/kg/day and resulted in no alterations in urinary uric acid levels. No

intermediate or chronic period studies in humans were reported by ATSDR (2017a). As stated in ATSDR (2020), "*During the development of toxicological profiles, MRLs are derived when ATSDR determines that reliable and sufficient data exist to identify the target organ(s) of effect or the most sensitive health effect(s) for a specific duration for a given route of exposure to the substance. MRLs are based on non-cancer health effects only and are not based on a consideration of cancer effects.*" The oral minimal risk level for intermediate (15-364 days) duration ingestion of molybdenum with a target of renal damage is estimated to be 8E-03 mg/kg/day. According to ATSDR (2017a), "*No studies were located regarding cancer in humans and animals following oral exposure to molybdenum*."

2.3.7 Nitrate

Nitrate is a naturally occurring chemical compound. It can be found in soil and water and is formed as the product of organic material decomposition, or mass produced for use as fertilizer. Nitrate is highly soluble and completely dissociates in water. Nitrate, as a part of the earth's nitrogen cycle, is ubiquitous in the environment and people are exposed to it primarily through the ingestion of food and drinking water.

The International Agency for Research on Cancer (IARC) determined that there is inadequate evidence for the carcinogenicity of nitrate in food or drinking water. Exposure to large amounts of nitrate from drinking water sources has been reported to cause methemoglobinemia in infants. Young infants (less than six months of age) appear to be particularly sensitive to the effects of nitrate on hemoglobin after consuming formula prepared with drinking water that contained nitrate at levels higher than recommended limits.

There are no entries in the EPA Ecotox database for nitrate (EPA, 2022b).

The ATSDR (2017b) reports that information regarding health effects in humans or animals due to dermal exposure to nitrate, over any duration, is not considered necessary because the general population is not likely to be dermally exposed to nitrate at levels that might cause adverse health effects.

A minimal risk level (MRL) is defined as an estimate of daily human exposure to a substance that likely will not cause an appreciable risk of adverse effects (noncarcinogenic) over a specified duration of exposure. Minimal risk levels can be derived for acute, intermediate, and chronic duration exposures for inhalation and oral routes. Appropriate methodology does not exist to develop minimal risk levels for dermal exposure. For nitrate, a minimal risk level of 4 mg/kg/day has been derived for chronic-duration oral exposure (365 days or more) to nitrate (ATSDR, 2017b).

The State of New Mexico lists the human health drinking water standard of 10 mg/L for nitrate (as nitrate-nitrogen), and the current License groundwater protection standards for the GRP range from 10 mg/L to 15 mg/L nitrate, which corresponds to the established alluvial groundwater background concentration.

2.3.8 Selenium

Information in this section is taken from the Toxicological Profile of Selenium compiled by the Agency for Toxic Substances and Disease Registry (ATSDR, 2003a). Selenium is a naturally occurring substance that is found in the earth's crust in variable concentrations, most often in rocks and soil. Pure selenium, presented as metallic gray to black crystals, is often referred to as elemental selenium or selenium dust. Selenium is usually not found in the environment in its elemental form, selenium [0], but is usually combined with other substances, such sulfide minerals or with silver, copper, lead, and nickel minerals. Selenates (selenium[+VI]) and selenites (selenium[+IV]) are water soluble. Some selenium compounds are gases.

Selenium is an essential trace element in humans and animals and is a biologically active part of a number of important proteins, particularly enzymes involved in antioxidant defense mechanisms (e.g., glutathione peroxidases), thyroid hormone metabolism (e.g., deiodinase enzymes), and redox control of intracellular reactions (e.g., thioredoxin reductase). It can have either nutritional or possibly toxic effects, depending upon the level of intake. Most people in the United States are unlikely to suffer from selenium deficiency. Although excessive intake of selenium can cause adverse health effects, these are generally observed at doses more than five times greater than the Recommended Dietary Allowance (RDA). Because of greater bioavailability, water-soluble selenium compounds are probably more toxic that elemental selenium by any exposure pathway.

No studies have been found regarding death in humans after inhalation of elemental selenium or selenium compounds. ATSDR (2003a) states "*In studies of human occupational exposures, it appears that the respiratory tract is the primary site of injury after inhalation of selenium dust or selenium compounds, but gastrointestinal (possibly due to swallowed selenium) and cardiovascular effects, as well as irritation of the skin and eyes, also occur. Little of the available information for humans, however, relates health effects exclusively to measured concentrations of the selenium dust or compounds because of the possibility of concurrent exposures to multiple substances in the workplace*." Further, cancer has not been found in epidemiological studies of inhalation of elemental selenium or selenium compounds.

There have been no incidents of human mortalities in the United States resulting from either intermediate or chronic oral exposures to selenium or selenium compounds. Some early studies that reported selenium to be carcinogenic in mammals were flawed. No association between selenium intake and the incidence of cancer in humans or animals has been found in the majority of studies. One study showed an increase in melanoma for a cohort of individuals exposed to selenite in a municipal water supply in Italy. Several studies of nutritional selenium supplements found a significant reduction in overall cancer mortality and lung cancer incidence. Epidemiological studies of the association between selenium concentration in forage crops indicated an inverse association between selenium levels and cancer occurrence, with some exceptions.

Skin rashes, burns and contact dermatitis is reported for acute exposure to selenium dioxide.

The current recommended tolerable upper intake level (UL) for selenium in adults is 0.4 mg/day. The tolerable upper intake level is defined as the highest level of daily nutrient intake that is likely to post no risk of adverse health effects to almost all individuals in the population.

According the ATSDR (2003a), following publication of several flawed studies published as late as 1971, the majority of subsequent studies in humans and animals have shown no association between selenium intake and cancer incidence or a "*clear chemopreventive association*." The International Agency for Research on Cancer (IARC) notes that selenium is not classifiable as to its carcinogenicity to humans. EPA agrees, with the exception of selenium sulfate, which it classifies as probably a human carcinogen.

2.3.9 Sulfate

Sulfate is a naturally occurring chemical compound found in nearly all groundwater and surface water sources. Its presence in water sources is primarily due to atmospheric deposition, dissolution of sulfate minerals and oxidation of sulfide minerals.

No health-based drinking water standards exist for sulfate as the existing data does not indicate a level of sulfate likely to cause adverse human health effects (WHO, 2004). Drinking of water with concentrations above 600 mg/L sulfate have been demonstrated to cause laxative effects in adults, with infants and children possibly susceptible to diarrhea at water sulfate concentrations above 600 mg/L. (ATSDR, 2009). The EPA established a secondary maximum contaminant level for sulfate of 250 mg/L due to odor and taste issues at these concentrations, and the state of New Mexico's water quality criteria for sulfate is 600 mg/L. Sulfate in drinking waters is typically considered a nuisance, due to taste, odor and mineral deposition, and does not pose a significant health risk. EPA classified sulfates as a national secondary contaminant with a maximum contaminant level (MCL) of 250 mg/L based on salty taste or so-called organoleptic effects (EPA, 1990).

NMED has a domestic water supply standard of 600 mg/L for sulfates, but no standard based on health. Therefore, since there is no health hazard that pertains to sulfate exposure, sulfates will not be considered further in the hazard assessment.

2.3.10 Vanadium

Information in this section is taken from the Toxicological Profile of Vanadium compiled by the Agency for Toxic Substances and Disease Registry (ATSDR, 2012a). The element vanadium is abundant in the earth's crust with an average concentration of 100 ppm. It exists in a variety of oxidation states ranging from -II- to +V, but +III, +IV (vanadyl) and +V (oxidized vanadates) are the most common. Weathering of rock and soil erosion are the two major natural release mechanisms for vanadium to enter into water.

Studies of occupational exposure, human experimental exposure, and laboratory animal experiments, indicate that the primary targets of toxicity are the respiratory tract following inhalation exposure and the gastrointestinal tract, hematological system, and developing organism following oral exposure. There have been no studies to examine the carcinogenic potential of vanadium in humans. IARC has classified vanadium pentoxide a possibly carcinogenic (group 2B), but that was based on only evidence in animals and not human experience. Neither the Department of Health and Human Services (HHS) nor EPA have classified the carcinogenicity of vanadium.

The ATSDR (2012a) reports that limited dermal exposure studies were identified in humans or animals, and absorption by this route is generally considered to be very low. No increases in the occurrence of dermatitis were observed in a cohort of vanadium pentoxide workers, and no histological alterations of the skin were observed in rats and mice following intermediate to chronic duration exposures to vanadium pentoxide.

According to ATSDR (2012a), studies of cancer in humans or animals after oral exposure vanadium were not found. However, some studies designed to assess other effects found no increase in tumor frequency in rats or mice chronically exposed to vanadyl sulfate in drinking water. The document notes that while those oral studies were negative for cancer, because of small sample size, they were inadequate for evaluating carcinogenicity. Regardless, for this petition, no estimate of cancer risk for vanadium ingestion has been calculated.

Estimates of exposure levels posing minimal risk to humans (minimal risk levels) for noncancerous effects have been made for vanadium. Minimal risk levels do not consider carcinogenic effects. A chronic duration (less than one year) inhalation minimal risk levels of 0.0001 mg/m^3 has been derived for vanadium

pentoxide dust. This level is based on mouse and rat experimental data. Several laboratory animal studies of chronic toxicity following oral exposure and most did not find adverse effects. No studies of toxicity in humans for chronic oral exposure have been identified. ATSDR (2012a) reported that no studies were located regarding human death following oral exposure to vanadium.

2.3.11 Combined Radium-226 and Radium-228

Radium is a naturally occurring radioactive material formed during the radioactive serial decay of uranium and thorium. Numerous isotopes of radium exist. The isotopes of radium-226 and radium-228 are the most prevalent in the environment as they are formed from the decay of the most naturally abundant isotopes of uranium and thorium: uranium-238 and thorium-232. Both radium-226 and radium-228 undergo radioactive decay and emit energy in the form of alpha particles and gamma rays, decaying to form radon gas.

Radium and the radiation it emits are ubiquitous in the environment. At the concentrations in the environment that are considered normal, there is no clear evidence of any harmful health effects due to long-term exposure. However, exposure to higher levels of radium over long periods of time may result in in harmful effects including anemia, cataracts, fractured teeth, cancer (especially bone cancer), and death (ATSDR, 1990). As radium is chemically analogous to calcium, it will typically accumulate in bone following intake. In general, the adverse effects of radium are believed to be the consequence of the radiation emitted by the element itself and by its daughter products.

No studies were located regarding the following health effects in humans or animals following oral exposure to radium. Again ATSDR (1990) discussing dermal effects states: *"No studies were located regarding the following health effects in humans or animals after dermal exposure to radium. It is important to note, however, that the radium dial painters had chronic dermal exposure to radium on their lips and tongues. Although no recognition of this fact has been located in the literature, it is noteworthy that no local effects on exposed skin have been described in the available case studies of these workers*."

Information on the lethal effects of radium due to acute oral exposure is lacking. Many deaths, especially from bone cancer, have occurred in humans following long-term oral exposure to radium-226 and radium-228. Radium dial painters in the early 20th century ingested large enough amounts of radium over multiple years and contracted anemia, jaw necrosis and osteogenic sarcomas. No studies of effects from dermal exposure to radium were located regarding health effects in humans or animals.

Potential doses from ingestion of radium-226 and radium-228 can be calculated using EPA dose conversion factors tabulated in Federal Guidance Report No. 11 (EPA, 1988). Estimates of potential cancer morbidity and mortality may be made using coefficients listed in Federal Guidance Report No. 13 (EPA, 1999b).

2.3.12 Thorium-230

Thorium is a radioactive element that occurs naturally in the environment; thus, background levels occur in air, water, and soil. The most likely sources of exposure of the general population to thorium are from inhalation of air and ingestion of food and drinking water containing thorium. Thorium-230 is a decay product of uranium-238 and a precursor to radium-226, decaying by alpha emission with a half-life of 77,000 years.

Toxicokinetic, radiological, and health effects data for thorium have not determined whether its toxicity is attributable to radiological, chemical, or combined radiological and chemical properties. Exposure to thorium compounds in amounts large enough to pose a serious chemical health risk would be expected to pose a radiation health risk as well, particularly within lungs where insoluble thorium compounds may be retained and in other tissues where absorbed thorium is retained (e.g., liver, bone). Alpha particles from thorium-230 are the greatest concern, especially if the thorium is inhaled or ingested. Alpha particles will not penetrate skin and can only travel short distances, on the order of a few cell diameters, if emitted within the body.

The effects of dermal exposure to thorium are not well studied and it appears no human studies of dermal toxicity exist. Animal studies of the effects of dermal exposure are limited to a single study involving rats. Thorium nitrate (15 nCi/kg/day) was applied to the scrotal skin of rats for 15 days resulting in mild edema of the seminiferous tubules and sperm desquamation; the rapid onset of the symptoms suggests these effects were due to chemical toxicity rather than a radiological effect (ATSDR, 2019).

ATSDR (2019) did not publish minimal risk levels for thorium, as such, due to "*insufficient data for MRL derivation*." Investigators have evaluated the carcinogenicity of thorium in two cohorts of 3,039 thorium workers, most of whom were laborers or operators involved in thorium extraction. No association was found between thorium exposure and deaths from all cancers or from specific types of cancers, compared to mortality rates for US white males. A smaller subset of 592 workers with exposure to thorium dust had an elevated risk from all cancer and pancreatic cancer, but those results were likely confounded by smoking, which was not controlled for.

Potential doses from ingestion of thorium-230 may be calculated using EPA dose conversion factors tabulated in Federal Guidance Report No. 11 (EPA, 1988). Estimates of potential cancer morbidity and mortality for thorium-230 may be made using coefficients listed in Federal Guidance Report No. 13 (EPA, 1999b).

2.3.13 Uranium

Uranium is assumed to be carcinogenic due to its radioactive emissions but is primarily regulated due to its nephro-toxicological effects. As stated in ATSDR (2013), "*Current evidence from animal studies suggests that the toxicity of uranium is mainly due to its chemical damage to kidney tubular cells following exposure to soluble uranium compounds and the respiratory tract following chronic inhalation exposure to insoluble uranium compounds. Other potential targets of toxicity include the reproductive system and the developing organism. There are limited data on the renal toxicity of uranium following inhalation exposure in humans. A number of studies found no alterations in mortality due to renal disease in uranium workers. An autopsy study of long-time workers exposed to low levels of uranium did not find evidence of renal injury years after exposure termination*."

No deaths have been reported in humans as a result of dermal exposure to uranium compounds. In laboratory animal studies deaths due to renal failure were observed following dermal exposure to highly concentrated uranium compounds. Potential doses from ingestion of various uranium isotopes may be calculated by using EPA dose conversion factors tabulated in Federal Guidance Report No. 11 (EPA, 1988). Estimates of potential cancer morbidity and mortality from exposure to uranium isotopes may be made using coefficients listed in Federal Guidance Report No. 13 (EPA, 1999b).

3 EXPOSURE ASSESSMENT

The following presents an assessment of the potential human and environmental exposures and the hazards associated with the conditions resulting from implementation of corrective action alternatives.

The future uses of groundwater and the access to groundwater present the only source for potential human and environmental exposure to hazardous constituents from the GRP. Water from an impacted well is considered to be the only mechanism for a resident to incur a potential adverse health effect from the GRP. Similarly, the most reasonable scenario for environmental exposure is represented as groundwater pumped from the same well assumed to supply water to a resident.

A groundwater flow and contamination transport model is presented below, used to predict the fate and transport of constituents in groundwater and predicted exposure point concentrations under the considered corrective action alternatives.

3.1 Transport and Pathway Assessment

Groundwater flow and contaminant transport modeling have been performed to support assessment of potential exposures and hazards associated with the corrective action alternatives evaluated herein and to support development of the proposed ACLs. The modeling and supporting reports addressing model calibration and model predictions have been developed based on applicable ATSM International (ASTM) Standards (ASTM, 2006; ASTM, 2008) and in accordance with NRC guidance (Neuman and Wierenga, 2003). Calibration of the groundwater flow and contaminant transport model is discussed below, the detailed report documenting model design and calibration is provided in Appendix 3.1-A while development of the alternatives is presented in Section 4.2. Evaluation of the alternatives with the predictive flow and transport model is addressed in Section 4.3.

The following sections summarize development of the GRP numerical groundwater model, model groundwater flow calibration, geochemical modeling and transport model parameterization, and groundwater transport model calibration for uranium and molybdenum. All other constituents are modeled using a surrogate constituent that is assumed to transport conservatively (no retardation in transport). This modeling is based on refinements of models previously developed for NRC and EPA (HMC, 2020d) with a specific focus on both additional and/or improved geochemical modeling, groundwater flow and transport calibration, and predictive fate and transport modeling. The model includes simulation of the following key hydrogeologic components of the site conceptual model:

- Groundwater flow and hydraulic heads within the Alluvial and San Andres-Glorieta aquifers and three Chinle formation water-yielding units (Upper, Middle, and Lower Chinle) beneath the GRP.
- Fate and transport of constituents (i.e., uranium, molybdenum, selenium, and a surrogate conservative solute that is considered as a bounding surrogate for the other constituents not specifically modeled).

Groundwater collection, injection, and hydraulic containment are key components for groundwater flow and transport model development for the GRP. In general, source and plume control measures have reduced the concentrations of constituents in tailings and the areal extent of observed contaminant plumes. Figure 3.1-1 shows the extent of the uranium plume in the alluvial groundwater for years 1999 and 2024 where

total affected areas with uranium concentrations above 0.16 mg/L in the alluvial groundwater have decreased by approximately 40 percent over 20 years from 1,108 acres to 692 acres.

The following are key Hydrogeologic Site Conceptual Model elements specific to the GRP previously discussed in Section 1.2.2.8 that were generally translated into the model:

- The GRP is located in the southern (lower) portion of the San Mateo Creek Basin.
- Aquifers of Quaternary and Permian age are present at the GRP.
- Principal aquifers with groundwater flow at the GRP include the alluvium and the San Andres-Glorieta while the upper, middle, and lower water-yielding units of the Chinle Formation (Triassic age) are considered local sources of groundwater.
- In general, there is little evidence of inter-aquifer flow in the San Mateo Creek Basin, which is due to the presence of low-permeability aquitards between the principal aquifers. However, where bedrock units subcrop beneath saturated alluvium, some inter-unit flow occurs with the alluvial groundwater generally flowing into the underlying units.
- Local groundwater flow in the alluvium generally flows parallel to the downgradient surface in San Mateo Creek Basin, the Rio Lobo, and the Rio San Jose, but bifurcates around a bedrock high located south of the Large Tailings Pile.
- Groundwater flow in the Chinle Formation water-yielding units is generally to the north-northeast, except where influenced by faulting, subcrop locations, or ongoing restoration operations. Groundwater flow in the underlying San Andres-Glorieta aquifer is to the east-southeast.
- Remedial activities at the GRP have included groundwater collection and injection in both the alluvium and Chinle sandstones, affecting local groundwater flow conditions.
- The presence of fault zones has restricted and redirected local groundwater flow in the Chinle water-yielding units under the GRP.
- Local groundwater flow conditions have been well characterized through decades of data collected from hundreds of monitoring wells on the GRP.

3.1.1 Model Development

This section presents the basis and approach for design and parameterization of the groundwater flow and contaminant transport model used to assess groundwater corrective action alternatives, which are addressed in Sections 4.1 through 4.3 of this ACL Application.

3.1.1.1 Model Structure

The groundwater flow and transport model structure is based on a three-dimensional (3-D) geologic model developed using Leapfrog™, a geologic modeling software that captures stratigraphy and faulting at both the local scale around the GRP and regionally within the San Mateo Creek Basin. The geologic model includes existing local geologic model surface outcrops, stratigraphic layer thicknesses, fault structures, dip directions, and dip angles to produce layer cake representation of the primary stratigraphic units in the southern poriton of the San Mateo Creek Basin in the vicinity of the GRP (HMC, 2012), as well as information from site geologic logs and regional well information (well depths and units penetrated). The groundwater model layering is based on stratigraphic information collected during recent geological investigations that established the contact elevations between the San Andres-Glorieta and Lower Chinle Shale in the area south of the GRP beneath the Rio San Jose alluvium (HDR, 2021). Overall, more than

1,400 well logs were used to inform the basin-scale three-dimensional geologic model in addition to 14 geologic maps for the region. A detailed report of design and calibration of the groundwater flow and transport model is presented in Appendix 3.1-A and includes data source references for the geologic information used to develop the structural basis for the model.

The geologic model was then used to create 11 appropriate hydrostratigraphic layers with unstructured grids using USG-Transport, which is a version of the popular United States Geological Survey family of MODFLOW groundwater flow modeling codes (Panday et al., 2013; Panday, 2025). The upper two model layers represent saturated alluvium, except where saturated basalt overlies the alluvium. In those regions, the basalt is represented by model Layer 1 and the underlying alluvium is represented by model Layer 2. The base of model Layer 1 was defined by the top of the alluvium where the basalt is present, and an extrapolation of the pre-basalt land surface elsewhere in the model domain. The basalt in the model domain originated from the El Tintero cinder cone on the order of 57,000 to 79,000 years ago, with a best estimate of 68,000 years ago (Sims et al. 2007; Laughlin et al., 1993). The nominal thickness of the basalt in the model domain is about 100 feet. In this report, the saturated basalt and the underlying saturated alluvium, where they exist, are referred to as the "alluvial aquifer" for simplicity of terminology as obviously basalt is not alluvium.

The San Andres-Glorieta is represented by two layers within the model. Layer 10 represents the upper 20 feet of the San Andres Limestone that visual inspection of core and laboratory analyses of rock samples from GRP field investigations demonstrated had low primary and secondary porosity relative to deeper intervals of the formation. Below the upper 20 feet, the San Andres-Glorieta contained numerous intervals with open holes and void spaces, and core samples exhibit significantly higher porosity values (HDR, 2021). This San Andres/Glorieta below the upper 20 feet is layer 11 in the model. Table 3.1-1 summarizes the hydrostratigraphic units, model layer numbers, and references the data sources for the layer hydrogeologic characteristics.

The Model extent encompasses the principal aquifers (alluvial aquifer and SAG aquifer) in the immediate GRP area along with three water-yielding units and four confining units associated with the Chinle Formation , with local grid refinement implemented in the immediate vicinity of the GRP for improved local resolution. The equivalent square grid spacing ranges from 5,012 by 5,012 feet near the model margins, which is appropriate to simulate representative regional flow conditions, to 53 feet by 53 feet where the smaller areas are appropriate for simulation of both constituent transport and fluxes from the numerous GRP wells associated with the collection (groundwater withdrawal)/injection system. The variably spaced grid contains a total of 590,504 active model cells over 11 vertical layers.

Figure 3.1-2 illustrates the unstructured mesh for the portion of the model domain surrounding the GRP. Head target data, predicted head data, and additional maps illustrating model domain areas including boundary conditions, recharge, hydraulic conductivity, and aquifer storage values are presented in Appendix 3.1-A.

3.1.1.2 Model Boundary Conditions

Model boundary conditions are a mechanism to control, add, or remove flow from the model extent (such as recharge, collection, injection, upgradient inflow, downgradient outflow, no-flow). The boundary conditions and hydrologic stresses, summarized below and addressed in detail in Appendix 3.1-A, include the following:

- groundwater recharge from precipitation
- Seepage from the Large and Small Tailings Piles
- groundwater collection and injection
- general head boundaries (GHBs)
- Background groundwater recharge from precipitation was applied to the highest active model layer through the USG-Transport Recharge (RCH) package. Groundwater recharge is modeled as approximately two percent of the long-term average annual precipitation at GRP. Precipitation information obtained from the Parameter-Elevation Regressions on Independent Slopes Model ([PRISM] PRISM, 2004) for the GRP, and the NOAA 1991-2000 average annual precipitation at the Grants Milan Municipal Airport (USC00293682) were the bases for the estimate of long-term average precipitation. The normal annual precipitation at the Grants Milan Municipal Airport weather station (USC00293682) was 9.67 inches based on data from 1991 through 2020 (NOAA, 2026). The PRISM calculated average annual precipitation data at the LTP from 1991 through 2020 was 9.34 inches and was 9.14 inches from 2001 through 2024. The recharge rate specified was 0.18 inches per year. Recharge in the model is constant both spatially and temporally within the calibration period.

Seepage from the Large Tailings Pile represents a source of both recharge and chemical mass loading to the local groundwater system. Historical Large Tailings Pile seepage rates were developed using a calibrated VADOSE/W seepage model. These seepage rates were then incorporated into a separate seepage model (the reformulated mixing model [RMM]) to assess long-term changes in both seepage flow rates and constituent mass loading beginning in 2000 (Hydro-Engineering, 2019). Subsequently, a drain down model (DDM) was developed that applies the Brooks and Corey method to estimate past seepage rates and mass loading beginning in 2012 based on historical site-specific data as well as future seepage and Large Tailings Pile seepage rates, toe drain collection rates, and constituent concentrations (Brooks and Corey, 1964; Hydro-Engineering, 2025). Seepage estimates developed from the reformulated mixing model for the period 2002 through 2011 and from the drain down model for the period 2012 through 2024 (Hydro-Engineering, 2025) are used as input for the groundwater model to simulate flow from the Large Tailings Pile into the local groundwater system. Figure 3.1-3 illustrates the modeled Large Tailings Pile seepage rates, which were as high as 200 gallons per minute in 2014, 4.6 gpm in 2024, and are estimated to reach a long-term steady-state rate of 0.036 gallons per minute.

Groundwater withdrawals and injections include ongoing injection and groundwater collection (also termed extraction) associated with the groundwater corrective action at the GRP as well as pumping from the San Andres-Glorieta aquifer by the Village of Milan and City of Grants for municipal uses and formerly by the Tri-State Generation and Transmission Escalante Generation Station (Tri-State). Groundwater corrective action volumes, rates, and locations of injection and collection at the GRP have varied over time and groundwater collection volumes from wells are measured on an aggregate basis, not well-specific basis (HMC and Hydro-Engineering, 2025). Therefore, past collection and injection rates at specific locations in the alluvial aquifer and Chinle Formation were approximated for years 2002 through 2024 (HMC and Hydro-Engineering, 2025). These rates are provided in Appendix A to Appendix 3.1-A and were simulated in the model using the USG-Transport Well (WEL) package.

The primary pumping from the of San Andres-Glorieta aquifer, in addition to remedial activities during the calibration period, was associated with the Tri-State Generation & Transmission Escalante Generation

Station (Tri-State), as well as the Village of Milan and City of Grants municipal withdrawals. Municipal and Tri-State groundwater pumping data were obtained from DOE (2020) for years 2012-2018. However, Tri-State groundwater pumping ceased in August 2020 and that power generating facility was taken permanantly offline. For portions of the historical calibration period where detailed well pumping data are unavailable, averaged annual reported rates were applied to occur from model Layer 11 (lower of the two San Andres-Glorieta model layers), where the aquifer exhibits greater transmissivity relative to the upper 20 feet of the formation (HDR, 2021). Pumping rates for the San Andres-Glorieta aquifer used for model flow calibration are summarized in Table 3.1-2. General head boundary conditions (discussed below) were used to simulate regional groundwater flow in the San-Andrews Glorieta, to simulate groundwater flow in the alluvium upstream of the Bluewater Mill Site, and to simulate initial conditions for the San Mateo Creek alluvium at the northeastern model extent boundary (see Figure 3.1-4 for locations)

3.1.1.3 Model Calibration Period

The model simulates a transient calibration for the period of 2002 through 2024 using variable length stress periods. The variation in stress period length is a result of availability and confidence in estimated extraction and injection data accuracy over the given time interval. A steady state solution was developed for late 2001 that provides initial conditions for the transient calibration model. Each year from 2002 through 2012 contains a single 12-month stress period, while 2013 and through 2016 contain six-month stress periods and one-year stress periods from 2017 through 2024. Model calibration over 23 years with variable temporal stresses (e.g., extraction and injection rates) lends confidence that the flow and transport model reasonably simulates GRP hydrologic and hydrogeochemical processes to support predictive modeling.

3.1.1.4 Aquifer Physical Properties

Aquifer physical properties of the hydrostratigraphic units that control groundwater flow include hydraulic conductivity (vertical and horizontal), the specific yield, and the specific storage. Original zonation of model hydraulic properties parameterization was based on the Leapfrog™ three-dimensional geologic model discussed earlier in this section. Distributions and calibrated values of hydraulic conductivity assigned in the model within the vicinity of the GRP closely match inferred values from the aquifer tests for the alluvial aquifer and Chinle water-yielding units (HMC, 1981; HMC, 1996). Input storage values (specific yield and specific storage) were manually adjusted within typically observed ranges to better match observed groundwater-level data and interpreted flow directions in accordance with standard manual model calibration practices (Anderson, et al., 2015). Table 3.1-3 shows the hydraulic conductivity and storage values for each hydrostratigraphic unit in the calibrated flow model.

Figures included in Appendix 3.1-A provide the hydraulic conductivity, specific yield and specific storage values associated with each respective hydrostratigraphic model.

During calibration of the model, it was determined that overall model calibration improved if the San Mateo Fault was represented using the MODFLOW-USG-Transport Horizontal Flow Barrier (HFB) package. The Horizontal Flow Barrier hydraulic characteristic values were assigned in all Horizontal Flow Barrier package locations in layers 2 through 11 using the average hydraulic conductivity values assigned to the hydrostratigraphic unit of adjacent model cells, which were then scaled by the relative overlap of the model layers on either side of the fault. Fault zone width was assumed to be five feet. Where faults completely offset a model layer, the Horizontal Flow Barrier hydraulic characteristic was assigned a minimum value

of 1.0×10^{-11} feet/day. Barriers to horizontal groundwater flow are based on the geologic model and include fault offsets between principal hydrostratigraphic units at both the regional scale and locally beneath the GRP (Figure 1.2-17, Figure 1.2-18, Figure 1.2-21, and Figure 1.2-22).

3.1.2 Groundwater Flow Model Calibration

Model calibration for the 2002-2024 period focused on four primary objectives:

- Reasonable simulation of wetting and drying of alluvium associated with remediation activities at the GRP
- Simulation of observed groundwater elevations especially for the alluvial aquifer in the vicinity of the GRP
- Simulation of observed groundwater flow directions in the GRP area
- Development of a groundwater flow solution that allowed calibration to observed uranium and molybdenum concentrations

Model parameters were adjusted to obtain agreement with observed conditions. The final calibration represents a good balance between the calibration objectives, as certain parameter modifications may have improved the model's ability to simulate one condition (such as improved simulation of groundwater elevations) while degrading the model's match in other areas (such as degraded matches to observed constituent concentrations).

The head target data set consists of 397 locations in the alluvium (Layer 1: 23,468 observations), 44 locations in the Upper Chinle water-yielding unit (Layer 4: 3,317 observations), 68 locations in the Middle Chinle water-yielding unit (Layer 6: 2,239 observations), 27 Lower Chinle water-yielding unit locations (Layer 8: 654 observations), and 27 San Andres-Glorieta aquifer locations (Layer 11: 11,974 observations). Figures 3.1-5 through 3.1-8 provide groundwater flow target locations used for calibration. Figure 3.1-10 illustrates the predicted versus measured 2024 groundwater heads for the alluvial aquifer from the calibrated model. Additional figures showing 2007, and 2015 predicted versus measured groundwater heads as well as time versus head data plots for specific target wells are provided in Appendix 3.1-A.

Simulated heads in the calibrated model generally match observed groundwater elevations based on statistics related to model residuals (the difference between simulated and observed groundwater levels), inspection of target location hydrographs, comparison of historic and modeled groundwater elevation contours, and comparison of water balance calculations. Standard calibration statistics include the residual mean, absolute residual mean, root mean squared error (RMS error, which gives greater weight to larger residuals), and the scaled root mean squared error (root mean squared error divided by the total change in measured head, a measure of how well the model simulates groundwater flow gradients). Table 3.1-4 provides a summary of these statistics for the 15-year period 2010 through 2024 for the overall model and for only the alluvial aquifer since the calibration for the alluvium is especially critical for estimation of remediation timeframes at the GRP. The initial years of the calibration period are not used for the statistics as these years serve as a spin-up period following the initial steady-state simulation for year 2001.

Although there are no regulatory or industry defined statistical ranges for a well-calibrated model, regional models typically strive for percentage error metrics (e.g., scaled root mean squared error) of less than 10 percent whereas local scale models attempt for a scaled statistic less than 5 percent. The model has regional characteristics, and thus a scaled root mean squared (RMS) error of 2.7 percent is both much less than 10

percent and indicative of a well calibrated model. The slightly negative mean residual (-0.33 feet) indicates that there is minimal bias where the solution slightly overestimates heads (negative values indicate overestimation) and the absolute residual mean suggests that the groundwater flow solution is typically within 4.4 feet of the observed value. Both the model and the model report included in Appendix 3.1-A have been developed based on applicable ASTM International (ASTM) Standards (ASTM, 2006; ASTM, 2008) and in general accordance with NRC guidance (Neuman and Wierenga, 2003).

For the alluvial aquifer, the calibration process also aimed to minimize both the residual mean and a scaled residual mean squared error of less than 5 percent, which is lower than generally accepted standards for regional model calibration. The residual mean for the alluvial aquifer is -0.86 feet which indicates that simulated alluvial heads are, on average, slightly high while the absolute residual mean shows that the solution is typically within 3.8 feet of observed alluvial groundwater elevations. The scaled root mean squared error statistics is 3 percent (Table 3.1-4).

Figure 3.1-10 presents a scatter plot comparing simulated and observed groundwater elevations. For all layers, simulated groundwater elevations relative to target values generally fall near the 1:1 line, indicative of good calibration. Simulated water elevation contours for the alluvial aquifer for all years, reasonably match contours based on measured data for those periods, as do hydrographs of modeled versus measured groundwater elevations. These contours and hydrographs for all simulated targets locations and all groundwater elevation target values are presented in Appendix 3.1-A.

The simulated water balance and rates of inflows and outfllows to each hydrostratigraphic unit underlying the alluvial aquifer for the calibration period are presented in Table 3.1-5 for years 2002-2024. Inflows to the alluvial aquifer are predominantly from injection followed by storage, and recharge (which includes Large and Small Tailings Pile seepage). Outflows from the alluvial aquifer are predominantly flows to the San Andres-Glorieta aquifer and alluvial groundwater collection, which occurs as part of ongoing remedial activities.

Given the overall objective to simulate remediation timeframes for the GRP, the model is considered sufficiently calibrated to observed water levels and the general hydraulic gradients. Groundwater levels are simulated to within approximately 3.8 feet on average in the alluvial aquifer, with simulated levels being slightly higher than those observed. The overall model scaled root mean squared error is 2.7 percent, whereas the alluvial aquifer scaled root mean squared error is 3.0 percent, representing good calibration.

3.1.3 Transport Model

The numerical transport portion of the model is constructed using the USG-Transport code to simulate solute advection, dispersion, as well as geochemical attenuation through adsorption and dual-porosity processes. Transport simulations were performed using the total variation diminishing (TVD) approach for advection because it is mass conservative, virtually free of numerical oscillation, and minimizes numerical dispersion (Zheng and Bennett, 2002; Panday, 2025). The transport modeling includes simulation of dispersion and attenuation in the alluvial aquifer and bedrock units through Freundlich non-linear adsorption isotherms which are based on site-specific data and geochemical modeling. The dual-porosity transport accounts for constituent diffusion between open pore space and fractures (the mobile domain) and the less permeable alluvial silts and clays or rock matrix (the immobile domain), as illustrated in Figure 3.1-11, which can both slow transport as well as act as a long-term secondary source of contaminant mass for transport.

HMC has conducted specific studies to assess geochemical conditions within the tailings and the alluvial groundwater system to (1) estimate the source terms, (2) characterize the subsurface geochemical properties, and (3) identify contaminant attenuation mechanisms in groundwater transport according to NUREG-1620 (NRC, 2003a). The study objectives were to (1) characterize the solid-phase geochemistry of tailings and alluvium, together with geochemical conditions in the tailings solution and alluvial groundwater, and (2) better understand the factors controlling source conditions and transport of three primary constituents, uranium, molybdenum, and selenium (WME, 2020a). Based on these findings, a site conceptual geochemical model was developed (CGM; WME, 2020b), as presented in Section 1.2. In addition, geochemical characterization of the tailings is presented in Section 2.1 of this ACL Application. The detailed reports of the geochemical characterization of the GRP system are included in Appendix 3.1-A.

The numerical parameters quantifying uranium, molybdenum, and selenium attenuation processes in the current groundwater model were established using the conceptual geochemical model in conjunction with site-specific geochemical data as summarized below and detailed in Appendix 3.1-A. Remaining constituents identified in Section 2.2, which have either lower concentrations in the tailings and/or less aereal extent in the groundwater, are modeled using conservative assumptions (i.e., no retardation) to bound their transport behavior rather than constituent-specific transport parameters, as discussed in more detail in Section 4.3.

3.1.3.1 Transport Parameter Development

The transport of uranium and molybdenum are modeled using Freundlich isotherms developed from analysis of site-specific data using geochemical reaction code PHREEQC (Parkhurst and Appelo, 2013). PHREEQC was used to model surface complexation behavior of uranium, molybdenum, and selenium on ferrihydrite to predict the adsorption behavior as a function of key geochemical parameters (e.g., pH, carbonate concentration). The resulting surface complexation and mixing model (SCMM) was developed using site-specific data from which the Freundlich isotherm provided the best fit (see Equation 3-1):

$$x/m = K_f C^{(1/n)} \qquad \text{[Equation 3-1]}$$

where x/m is the weight of adsorbate per unit weight of adsorbent (mg/g), C is the equilibrium concentration of the adsorbate (mg/L), K_f is an empirical partition coefficient at equilibrium (L/g), and n is an empirical coefficient (INEEL, 2002).

The SCMM utilizes the MINTEQv4.dat database developed by the EPA (1998) because it contains an extensive compilation of thermodynamic data for uranium. This database was modified to contain additional thermodynamic data for the aqueous uranium (VI) alkaline-earth metal (Ca, Mg) complexes, which have been recognized as playing an important role in the environmental chemistry of uranium. The SCMM combines surface complexation reactions with geochemical mixing of groundwater to calculate uranium and molybdenum partition coefficient values (K_f) using the Freundlich isotherm. Adsorption curves showing the adsorbed concentration (mg/kg) versus the equilibrium solution concentration (mg/L) were prepared and the data evaluated as the linear form of the Freundlich isotherm (Equation 3-2):

$$\log x/m = 1/n \log C + \log K \qquad \text{[Equation 3-2]}$$

The linear form of the Freundlich isotherm (Equation 3-2) produces a slope of 1/n and an intercept of log K from which the empirical partition coefficient (K_f) can be derived. The values for K_f and 1/n can be

used in conjunction with aquifer porosity and bulk density to calculate the effective uranium retardation relative to the velocity of groundwater (the retardation factor) as a function of solute concentration. All groundwater solution compositions and aquifer mineral component inputs to the geochemical surface complexation and mixing model are based on site-specific data (WME, 2020a). The properties of the adsorbing surface in the geochemical surface complexation and mixing model were defined to be consistent with those of ferrihydrite. The amount of ferrihydrite was conservatively assumed to be 0.05 percent as iron based on selective extraction results (WME, 2020a; WME, 2020b). However, because prior visual estimates of alluvial iron content (up to 3 percent) were higher than those detected using diffraction XRD analysis (HMC, 2018), two additional ferrihydrite contents were evaluated, the average content for alluvial sands (0.529 percent or 5,290 ppm as iron) and the overall average for alluvium samples (1.0855 percent or 1,885 ppm as iron; HMC, 2018). The PHREEQC input files for uranium and molybdenum simulations in the SCMM are provided in Appendix H to Appendix 3.1-A.

Figures 3.1-12 and 3.1-13 illustrate the effective retardation factor versus concentration relationships that are obtained from the Freundlich parameters used to simulate sorption for uranium and molybdenum. Sorption does not remove mass from the aqueous system during transport but rather simply retard its transport. As discussed further later in this section, the model was well calibrated using the selected Freundlich parameters.

3.1.3.2 Transport Model Parameterization

Using the calibrated groundwater flow model, constituent transport models were developed to simulate fate and transport of uranium, molybdenum, selenium and a surrogate conservative solute, as described below. First, for uranium and molybdenum an initial groundwater concentration plume for 2001 was developed from historical data. Then, transport parameters such as porosity, bulk density and dispersivity were established based on site-specific data (see Appendix 3.1-A). Geochemical parameters established from site-specific data and reactive geochemical modeling, discussed above, were incorporated into the model for uranium and molybdenum, and diffusion coefficients and mass transfer rates were established for modeling constituent diffusion into and out of the immobile domain for the flow systems related to fine grained sediments and the bedrock matrix of the Chinle and San Andres-Glorieta hydrostratigraphic units.

Initial concentrations for the transport model transient calibration were interpolated to the model grid using 2001 and 2002 interpreted groundwater constituent plume map contours and 2001 and 2002 analytical data from groundwater sampling (Hydro-Engineering, 2002; Hydro-Engineering, 2003). This was performed for both uranium and molybdenum in the alluvial aquifer, Upper Chinle, Middle Chinle, and Lower Chinle. Initial plume areas were slightly modified as needed to improve calibration. All areas of unimpacted groundwater in Chinle units, San Andres Limestone, and the San Andres-Glorieta aquifer were assigned concentrations equal to the ambient conditions summarized in Table 3.1-6. Reinjection and infiltration concentrations associated with GRP remedial activities were set equal to 0.04 mg/L for uranium and 0.074 mg/L for molybdenum based on averages values from analytical sampling data of RO Plant effluent and fresh-water supply wells averaged over the period of 2002-2017 (HMC and Hydro-Engineering, 2018).

Other transport parameterization included values for porosity, bulk density, and dispersivity. The velocity of the constituents of interest in groundwater are directly related to the effective porosity of the porous medium (connected void area available for transmission of groundwater flow and solute transport). In the alluvium, where the specific yield was assigned a value of 0.20 , and the effective porosity in the mobile

domain was assigned a value of 0.25. The effective porosity values assigned to the mobile domain in theChinle water-yielding units was 0.2, to the Chinle shales was 0.09, and to the SAG was 0.20.

Dispersivity quantifies the degree to which mechanical dispersion of constituent occurs in advection of groundwater. During the model calibration process, a range of dispersivity values were used (Table 3.1-7). Dispersivity was noted to be a relatively insensitive parameter in the model results. The USG-Transport option to include cross-dispersion terms in solution of the transport equations is also employed. The use of the total variation diminishing solution for transport simulations generally minimizes unwanted artificial numerical dispersion. Additionally, a widely accepted and broadly used approach to minimizing numerical dispersion is to employ model grid spacing that has a dimensionless Peclet number (grid cell spacing divided by dispersivity) under a value of 4 (Voss, 1984). The refined portion of the Voronoi mesh grid was constructed targeting a nominal cell width of 62.5 feet. For the refined portion of the model grid the Peclet number is 1.18 (62.5 feet divided by 53 feet).

The groundwater system was conceptualized as a dual-domain system within the active area of the model domain where transport of constituents from the vicinity of the GRP Site would be expected to occur and beyond. The dual domains are a mobile domain and an immobile domain. The mobile domain is conceptualized as that portion of the model cell where water is actively flowing (fracture zones or higher permeability lenses) and transport is governed by advection and dispersion. The immobile domain is conceptualized as the portion of a model cell where groundwater is stagnant or moving very slowly relative to the mobile domain and diffusion is the primary transport process. In developing the transport model, the fraction of each cell that is the mobile domain and the fraction that is the immobile domain is specified. Uniform fractions were specified in the model layers.

In the alluvium the mobile domain is the coarser grained sediment and the immobile domain is the clays and silts (Figure 3.1-11). The mobile fraction and immobile fraction were estimated from Nuclear Magnetic Resonance NMR) logs run on boreholes advanced as part of the dual-domain investigation (HDR, 2024). The average mobile fraction in the alluvium for the boreholes advanced was 0.87, which is the sum of mobile and capillary porosity as interpreted from the NMR logs. In the bedrock and the basalt, the mobile domain was conceptualized as fracture zones and the immobile domain was conceptualized as the competent bedrock and basalt. The USG-Transport dual-porosity transport code requires input values for the effective porosity of the mobile domain, the porosity of the immobile domain, first-order mass transfer rate coefficient, and optional sorption parameters for the immobile domain. The immobile domain porosity values were set to the values summarized on Table 4 in Appendix 3.1-A.

The mass transfer coefficient characterizes the exchange of mass between the mobile and immobile domains and can be described by a geometry-based general equation as presented in Table 3.1-8. Mass transfer rates were estimated for the alluvium and the bedrock units with the value for all bedrock units (Chinle and San Andres-Glorieta). This equation, the specific parameters used, and their bases are summarized in Table 3.1-8. An analysis of the sensitivity of predictive transport model results to a one order of magnitude increase in the mass transfer coefficientshowed little sensitivity of results to the input mass transfer coefficient values.

Sorption was simulated in the immobile domain using the same Freundlich non-linear isotherm parameters as in the mobile domain and remaining alluvial aquifer system. For the alluvial aquifer, immobile domain concentrations were set equal to the mobile domain concentrations. For the Chinle water-yielding units, the immobile domain concentration was set as ten percent of the difference between the mobile domain

concentrations and the background concentration plus the background concentration. This reflects limited diffusion into the immobile domain, which constitutes 80 percent of the unit volume, in the period from 1958 until 2021.Recent geochemical investigations (WME, 2020a) indicate that groundwater concentrations of molybdenum beneath and adjacent to the Large Tailings Pile are controlled by precipitation of the mineral powellite ($CaMoO_4$) near the Large Tailings Pile. As a result, the concentrations of molybdenum in the alluvial groundwater are limited to between 0.1 to 1 mg/L in the direct vicinity of the Large Tailings Pile. To account for powellite precipitation in the model, USG-Transport Prescribed Concentration Boundary (PCB) package cells were defined to encompass the area of powellite precipitation and restricts the downgradient molybdenum source concentration to 0.70 mg/L. The remaining fraction of dissolved molybdenum continues to migrate through the alluvium primarily as molybdate (MoO_4^{2-}), which was simulated using the non-linear Freundlich isotherm.

3.2 Surrogate Conservative Constituent Model Development

A hypothetical and conservative constituent model was developed to provide a technical basis for conservatively estimating potential future concentrations of other constituents for which the model was not calibrated, as presented in detail in Appendix 3.1-A. A unit concentration approach was undertaken for this analysis to simulate travel times and compare simulated output concentrations relative to input source concentrations. The input source concentrations in Large Tailings Pile seepage recharge were set at a value of 1.0 (surrogate mass per volume concentration units) so that model output concentrations can be intuitively interpreted as fractions of the source concentration. Note that this approach assumes that the source concentration of Large Tailings Pile seepage recharge does not change through time. Because the surrogate constituent is assumed to behave in a non-reactive manner, adsorption-based attenuation was not simulated. Diffusion-based dual-porosity processes were assumed to apply to this surrogate constituent, and the molecular diffusion-based mass transfer rate coefficient used for uranium was applied to the surrogate constituent because sensitivity analyses in Appendix 3.1-A indicate model predictions are relatively insensitive to order of magnitude increases and decreases of the mass transfer rate coefficient.

It should be noted that the model cannot be reasonably calibrated to a surrogate conservative constituent, so this analysis assumes that values of other groundwaer flow model input parameters (e.g., hydraulic conductivity of geologic materials and dispersivity), developed during calibration of the model to uranium and molybdenum are reasonable to use for a surrogate conservative constituent. In addtition, the initial groundwater concentration conditions (2024) for the surrogate conservative constituent predictive runs were based on two precursor simulations that were used to establish a hypothetical constituent groundwater distribution in 2024 (see Figures 3.2-1 and 3.2-2. For COCs that are strongly adsorbed including arsenic, cadmium, vanadium, thorium-230 and radium 226+228, the simulated 2024 concentrations were adjusted to be consistent with measured concentrations of these strongly adsorbed COCs exceeding background levels in 2024 only beneath the LTP and an approximate 100-foot buffer around the LTP. The adjustment was to set initial concentrations for the predictive simulation to zero outside of a buffer around the LTP, and inside the buffer to use the 2024 concentrations simulated with the two precursor simulations. For COCs with minimal adsorption (fluoride and nitrate), the initial conditions for the predictive simulation were the values calculated for 2024 with the two precursor simulations.

The two predictor simulations were structured as follows. First, a 44-year simulation was performed to represent the historical period from the begining of uranium milling activities to the beginning of the historical period of the model (1958-2001) in which the recharge seepage concentration from the Large

Tailings Pile set to a value of 1.0 while recharge in other areas of the model was assumed to have zero concentration. This initial precursor model condition was then followed by a second initialization simulation for the historical calibration period model representing 2002-2024. For this second precursor period, Large Tailings Pile seepage recharge rates were unchanged from the historical calibration model, and the Large Tailings Pile seepage recharge concentrations were set to 1.0 to represent the input source of the surrogate constituent. Precipitation-based recharge rates over the remainder of the model domain were unchanged, and the concentrations in this recharge were set to zero. Groundwater collection and injection activities were simulated at the same volumetric rates as in the historical calibration model for uranium and molybdenum, and injection unit concentrations were set to 0.0002 (i.e., 0.02 percent of the input source concentration). These precursor simulations result in a 2024 distribution of the surrogate constituent 0.01 unit concentration in groundwater (Figure 3.2-1) that is broader than the current distributions of the other constituents, as illustrated in the maps contained in Appendix 3.1-A.

By using the calibrated groundwater flow model inputs, assuming completely non-reactive transport for other constituents that have some non-zero amount of geochemical retardation in aqueous transport, and by using an initial plume distribution that exceeds the actual initial plume distributions of the individual constituents, the results of the surrogate model can be used to conservatively estimate (overestimate) the transport and future exposure point concentrations of the constituents not individually modeled. Predictive simulations using the surrogate conservative constituent model and use of the predicted POE concentrations to calculate concentrations of other constituents and related ACLs are presented in Section 5.1 of this ACL Application.

3.3 Transport Model Calibration Results

Transport model calibration results for uranium and molybdenum were evaluated based upon qualitative comparison of simulated contours and well chemographs to observed data. Results for uranium transport, followed by molybdenum, are described below. Transport calibration target locations for both uranium and molybdenum are provided on Figures 3.3-1 through 3.3-4. Predictive simulations using the calibrated uranium and molybdenum models and use of the predicted maximum POE concentrations to calculate ACLs are presented in Section 5.1 of this ACL Application.

3.3.1 Uranium Transport Calibration Results

Uranium concentrations simulated by the transport model generally compare well with analytical data. The uranium analytical data used in the calibration data set include 322 total locations with 6,379 total observations; 248 alluvial locations with 5,053 observations; 30 Upper Chinle locations with 547 observations; 31 Middle Chinle locations with 553 observations; and 13 Lower Chinle locations with 226 observations. (Figures 3.3-1 through 3.3-4).

Figures 3.3-5 through 3.3-8 provide contour maps of comparisons of simulated uranium contours for the alluvial aquifer and Chinle units in 2024 versus interpreted contours developed from analytical data and previously presented in the GRP 2024 annual monitoring reports (HMC and Hydro-Engineering, 2025). Appendix 3.1-A also provides contour map figures of comparisons of simulated uranium contours for the alluvial aquifer and Chinle water-yielding units for 2007and 2015. The simulated uranium contours in the alluvium and the Upper and Middle Chinle sandstone units are consistent with observed values and reflective of interpreted contours in the vicinity of the GRP, indicating acceptable transport calibration. Further, time series chemographs for well target locations in all aquifers indicate reasonable matching of

concentration levels and trends over the 23 year calibration period, as illustrated by chemographs for all target locations, provided in Appendix E to Appendix 3.1-A. All transport target data are provided in table format in Appendix F to Appendix 3.1-A.

The San Andres-Glorieta aquifer predicted groundwater uranium concentrations were below the 0.03 mg/L State of New Mexico drinking water standard for the entire simulation period (i.e., no greater than 0.0164 mg/L). The slight change in San Andres-Glorieta concentrations is due to the difference in initial ambient concentrations between the lowermost Chinle Shale unit (Layer 9; 0.02 mg/L) and that of the upper San Andres Limestone (Layer 10; 0.005 mg/L) and San Andres-Glorieta aquifer (Layer 11; 0.005 mg/L) coupled with a downward flow gradient. This result is consistent with the conceptual model that alluvial groundwater recharges the San Andres-Glorieta where it subcrops below the saturated alluvium.

Overall, the transport model reasonably simulates observed uranium distributions and changes at the GRP for all four groundwater units (alluvium, Upper Chinle, Middle Chinle, and Lower Chinle).

3.3.2 Molybdenum Transport Calibration Results

Figures 3.3-9 Uthrough 3.3-11 provide contour map figures of comparisons of simulated moybdenum contours for the alluvial aquifer and Chinle units in 2024 versus interpreted contours developed from analytical data and previously presented in the GRP 2024 annual monitoring report (HMC and Hydro-Engineering, 2025). Appendix 3.1-A also provides contour map figures of comparisons of simulated molybdenum contours for the alluvial aquifer and Chinle units for 2007 and 2015. The molybdenum analytical data used in the calibration data set include 1329 total locations with 2,585 total observations; 106 alluvium locations with 2,075 observations; 15 Upper Chinle locations with 348 observations; 7 Middle Chinle locations with 147 observations; and 1 Lower Chinle location with 15 observations. Because molybdenum concentrations for samples obtained from the Lower Chinle have remained below GRP groundwater protection standards no, contour maps are presented for this unit.

For year 2024, the transport model simulates molybdenum distribution with width and distance of transport; the modeled groundwater molybdenum plume extent is generally equal to or greater than the interpreted contours from measured data, and reasonably matched observed concentration trends at target locations. All concentrations simulated for the San Andres-Glorieta aquifer were below the License groundwater protection standard of 0.1 mg/L for the entire simulation period (i.e., no greater than 0.0186 mg/L) and reflect the same recharge processes discussed above for the uranium calibration.

An additional check of the transport model performance relative to observed conditions was undertaken to compare simulated mass removal from the alluvial aquifer through remedial extraction wells compared to estimates of mass removal developed based on historical reporting presented in the 2024 Annual Monitoring Report (HMC and Hydro-Engineering, 2025). Figures 3.3-12 and 3.3-13 illustrate the estimated and predicted uranium mass removal for the entire GRP on an annual basis and cumulatively. The mass removal estimates were developed based on groundwater extraction rates and measured groundwater uranium concentrations, as documented in a technical memorandum provided as Appendix G to Appendix 3.1-A. The deviation in 2018 where the simulated uranium mass removed is greater than the estimated was likely the result of the 2018 estimate being calculated from anomalously low RO Plant influent uranium concentration sampling results. These comparisons provide a strong line of evidence based on mass flux that the model is well-calibrated in addition to the standard calibration to observed groundwater level and concentration analytical time series data.

3.3.3 Summary and Conclusions

A transient groundwater flow and transport model has been calibrated to a data set that spans a 23 year period between years 2002 and 2024 with dynamic inputs (e.g., aquifer pumping, water injection, tailings seepage, precipitation, etc.) to support predictive modeling and assessment of corrective action alternatives. The flow model is well calibrated to observed GRP groundwater conditions between years 2002 and 2024. Geochemical modeling was performed using site-specific data to develop transport parameters describing uranium and molybdenum attenuation for simulation of constituent transport across multiple groundwater-yielding units beneath the GRP. Transport model calibration was then achieved for the same period as the groundwater flow model for both uranium and molybdenum. A surrogate conservative constituent that will be used to model all other constituents for which the model was not specifically calibrated. This topic is discussed further in Section 4.3 of this ACL Application.

Predictions of long-term constituent transport using this calibrated model, presented in Section 4.3, are herein referred to as base-case model predictions. As discussed further in Section 5.1, a bounding-case model is used to calculate the proposed ACLs. The bounding-case model incorporates additional conservatism, by simultaneously applying input parameters at the high end of their reasonable ranges for multiple key parameters above those established for the calibrated model, into the model parameters and, thereby, to the predicted results at the POEs. This conservative approach to the bounding-case predictive simulations is intended to provide additional certainty that the proposed ACLs are amply protective over the long-term.

3.4 Human Exposure Potential

3.4.1 Conceptual Site Model

As shown in the resident gardener conceptual model (Figure 3.4-1), water from an impacted well is considered to be the only mechanism for a resident to incur a potential adverse health effect from the GRP. The most realistic scenario for long-term exposure is the resident gardener who uses only the well water as the household's primary water supply and irrigates a garden using the well water. Under this scenario, the primary complete pathway for human exposure is direct ingestion of groundwater at the point of exposure (POE). Indirect exposure pathways include consumption of vegetables irrigated with well water. Dermal exposure and inhalation exposure during bathing in well water also constitute complete pathways for intake of the COCs but are likely to be of minor importance compared to direct ingestion of groundwater or ingestion of locally raised vegetables.

3.4.2 Pathway and Receptor Characterization

3.4.2.1 Receptor Identification

Given the ultimate fate of the GRP (i.e., closure and transfer to long-term custodian, the primary receptors of interest are homeowners living adjacent to the GRP who have access to wells that may contact the underlying groundwater contaminant plume. The homes in question all have public water supplied by the Village of Milan, located approximately five and one-half miles south of the GRP. Although there is municipal water supplied to all properties with permitted groundwater use within the control boundary (see Section 1.2.2.9.3), thereby removing the necessity to use groundwater for the identified pathways, this analysis assumes potential human exposures are reasonably likely during the contamination period.

3.4.2.2 Exposure Pathways

Each pathway depicted in the conceptual model will be subject to certain element-independent and element-dependent parameters that will influence the rate at which the constituent is transported via that pathway. The element-independent parameters are listed in Table 3.4-1 and apply to each constituent. Table 3.4-2 lists dose coefficients and risk factors for the radionuclides under consideration. Table 3.4-3 lists element specific transfer coefficients for each constituent under consideration.

Calculations are performed for unit (nominal) quantities of each constituent, either in Bq/L or mg/L. Estimates of risk, via cancer or non-cancerous outcome is calculated by multiplying that unit outcome value times the appropriate constituent concentration in the well water. Results may be scaled upward or downward depending on the groundwater modeling output.

3.4.2.2.1 *Resident Ingestion of Well Water*

The well will serve as the primary source of drinking water for the resident gardener. The adult resident is assumed to drink 1.3 liters of water daily as recommended in Table ES-1, Chapter 3, of EPA (2019), all of which is assumed to originate in the well.

3.4.2.2.2 *Resident Ingestion of Well-Irrigated Vegetables*

Well water will be used to irrigate a home garden. Due to the arid climate, it is assumed that the irrigation is direct to the soil, not sprayed. Vegetables contaminated by the water will be consumed by the resident at the rate of about 54 kg/yr (EPA, 2019). Element- or radionuclide-specific transfer coefficients will be used to calculate the potential content of constituents in the ingested vegetables.

3.4.2.2.3 Resident Bathing and Showering with Well Water

Well water will be used for showering and bathing by the resident. Exposure factors specified by EPA (2019) will be used to estimate any potential dermatitis or skin rashes.

3.4.2.2.4 Radon Exposure Due to Domestic Water Use

Showering, and other domestic water uses would lead to the potential inhalation of radon emitted from groundwater. The contribution to radon air concentrations by domestic water use will be calculated, and radon progeny levels (Working Levels) will be used to calculated potential dose and risk.

3.5 Human Exposure Potential from Constituents at Modeled Concentration

Potential radiation dose, cancer risk and systemic effects to a resident gardener are calculated for a nominal constituent concentration using the following assumptions:

- All drinking, irrigation and bathing water comes from same potentially impacted well
- The resident gardener consumes vegetables from a garden irrigated with impacted well water
- The resident bathes in water from the well
- The nominal constituent concentration for radioactive materials is 1.0 Bq/L
- The nominal concentration for non-radioactive constituents is 1.0E-3 mg/L

Radiation doses are calculated on an annual basis. Radiation risk factors are tabulated based on a potential residence duration of 30 years. The effects are directly proportional to the concentration and may be scaled

upward or downward from the effects of the nominal concentration depending on the predicted groundwater concentration at the point of exposure (POE). Exposure parameter values are taken from NCRP Report No. 123 (NCRP, 1996), Screening Models for Releases of Radionuclides to the Atmosphere, Surface water and Ground, and the EPA Exposure Factors Handbook (EPA, 2019), unless otherwise noted.

Equations used to calculate concentrations of constituents in assorted media at unit concentration in well water are shown in Appendix 3.5-A.

It is important to note that the Health Physics Society "*advises against estimating health risks to people from exposures to ionizing radiation that are near or less than natural background levels because statistical uncertainties at these low levels are great*" (HPS, 2019).

3.5.1 Dose and Risk from Radionuclides Groundwater at the Point of Exposure

Ingestion of impacted groundwater or plants irrigated with impacted groundwater result in a potential dose and risk to a resident gardener. That dose and risk is directly proportional to dose and risk calculated for the nominal concentration of 1 Bq/L for radioactive materials and 1.0E-3 mg/L for non-radioactive constituents. Equations to estimate dose and risk from exposure to the unit concentrations are shown in Appendix 3.5-A. Estimated dose and risk from unit POE concentrations are shown in Table 3.5-1. Table 3.5-2 provides calculated daily exposures based on maximum POE concentrations from bounding-case predictive transport modeling presented in Section 5.1. The acceptable risk range is considered to be 1E-4 to 1E-6.

It is important to note that the assumption for this analysis that a resident drinks only the well water and eats no vegetables from other sources is highly conservative. A more realistic scenario might be that only one-half of the resident's drinking water is from the well which would reduce the effective dose nearly 50 percent.

There are limited data on the dermal absorption of either uranium, radium or thorium in water. ATSDR (2013) indicates that dermal exposure to uranium compounds has not been shown to cause systemic effects regardless of the duration of the exposure. While dermal exposure to impacted water was considered a pathway for exposure, no dose or risk is calculated for dermal exposures to the constituents in the following subsections due to limited data.

3.5.1.1 Uranium

Using the equations shown in Appendix 3.5-A, the annual effective dose equivalent due to daily ingestion of uranium from intake of water and irrigated vegetables is calculated to be 3.4 mrem/year for a 70 kg adult at the maximum modeled uranium concentration at the POE of 0.0266 mg/L or 0.67 Bq/L. The 30-year mortality risk is calculated to be 3.1.12E-5 and the 30-year morbidity risk is calculated to be 1.72E-5.

3.5.1.2 Combined Radium-226 and Radium-228

Using the equations shown in Appendix 3.5-A, the annual effective dose equivalent due to daily ingestion of radium from intake of water or irrigated vegetables is calculated to be 0.0134 mrem/year for a 70 kg adult at the maximum modeled uranium concentration at the POE of 0.1088 pCi/L or 4.025E-3 Bq/L.

The use of groundwater for domestic purposes results in an increase of indoor air radon concentrations that results in an additional annual effective dose equivalent of 6.24E-4 mrem/year. The annual effective dose equivalent due to combined radium-226 and radium-228 in groundwater from all exposure pathways at the POE is 8.1E-2 mrem/year. The 30-year mortality risk is calculated to be 5.4E-7 and the 30-year morbidity risk is calculated to be 7.7E-7.

3.5.1.3 Thorium-230

Using the equations shown in Appendix 3.5-A, the annual effective dose equivalent due to daily ingestion of thorium-230 from intake of water or irrigated vegetables is calculated to be 2.55E-5 mrem/year for a 70 kg adult at the maximum modeled thorium-230 concentration at the POE of 1.07E-1 pCi/L. The 30-year mortality risk is calculated to be 9.27E-9 and the 30-year morbidity risk is calculated to be 1.45E-8.

3.5.2 Derived Concentration Guideline Levels

The derived concentration guideline level (DCGL) is a radionuclide-specific surface or volume residual radioactivity level related to a concentration, dose, or risk criterion. A reasonable target dose criterion to use to establish a derived concentration guideline levels for uranium in groundwater attributable to the GRP is 25 mrem/year, which is the unrestricted use dose limit for individual members of the public.

The derived concentration guideline level for each radioactive constituent is shown in the subsections below.

3.5.2.1 Uranium

Based on the annual radiation dose calculated for a resident gardener using a nominal uranium concentration in groundwater of 1 Bq/L and 3.41 mrem/year, the derived concentration guideline level (DCGL) would be as follows:

C_{gw} is the concentration in groundwater

DCGL = C_{gw} * Dose criterion/Calculated dose or

DCGL = 1 Bq/L * 25 mrem/year /3.41 mrem/year = 2.9E-1 mg/L or 7.3 Bq/L

A comparable non-cancer derived concentration guideline level can be derived for uranium in groundwater based on the calculated hazard quotient (HQ) of 6.62E-2, shown in Section 3.5.3.13.

DCGL = 1 Bq/L * 1.0/3.7 = 1.2 E-2 mg/L or 3.0 Bq/L.

It should be noted that this derived concentration guideline level is a factor of 2.5 lower than the drinking water standard of 0.03 mg/L. A derived concentration guideline level applies only to the point of exposure; thus a derived concentration guideline level of 0.03 mg/L is appropriate for wells in the vicinity of GRP.

3.5.2.2 Radium-226 + Radium-228

Based on the annual radiation dose calculated for a resident gardener using a nominal radium-226 concentration in groundwater of 1 Bq/L and 20.2 mrem/year, the derived concentration guideline level would be as follows:

DCGL = C_{gw} * Dose criterion/Calculated dose or

DCGL = 1 Bq/L * 25 mrem/year /20.2 mrem/year = 1.24 Bq/L

3.5.2.3 Thorium-230

Based on the annual radiation dose calculated for a resident gardener using a nominal thorium-230 concentration in groundwater of 1 Bq/Land 6.93 mrem/year, the derived concentration guideline level would be as follows:

DCGL = C_{gw} * Dose criterion/Calculated dose or

DCGL = 1 Bq/L* 25 mrem/year/6.93 mrem/year = 3.61 Bq/L

A derived concentration guideline level applies only to the point of exposure.

3.5.2.4 Summary of Potential Carcinogenic Risks

The exposure to uranium, combined radium 226 and radium 228, and thorium-230 in groundwater results in a calculated effective dose equivalence to a resident gardener of 8.68 mrem/year, and a 30-year mortality risk of 4.31E-5. The calculated dose to a resident gardener is less than the NRC limit for unrestricted use (25 mrem/year), and less than the EPA protective limit for CERCLA sites of 12 mrem/year (EPA, 2014).

The modeled maximum POE concentrations of residual radionuclides originating from the site pose risks that fall below limits deemed protective of the public. Similarly, the maximum modeled POE groundwater constituent concentrations are less than derived concentration guideline levels calculated above.

3.5.3 Risk of Systemic Effects

Systemic effects for intakes of each constituent are shown in the following subsections. The basic equations using a unit concentration of 1E-3 mg/L in well water is shown in Appendix 3.5-A. Equations are shown for direct ingestion of groundwater (Appendix 3.5-A Section 1.1), buildup of a constituent in soil (Appendix 3.5-A Section 1.2), and calculation of the HQ for the constituent intake (Appendix 3.5-A Section 4). The systemic effects for constituents with adequate health information from maximum modeled concentration in well water at the POE using the equations in Appendix 3.5-A are shown in Table 3.5-2.

Since dermal exposure to impacted water is considered a complete pathway for exposure, information regarding potential effects from dermal exposure to impacted well water is also noted for each constituent.

Of the non-radioactive constituents in groundwater, only arsenic poses a carcinogenic risk. Using the equations shown in Appendix 3.5-A Section 4.4, the 30-year mortality risk (excess cancer risk) due to daily ingestion of arsenic from the intake of water or irrigated vegetables for a 70 kg adult at the maximum modeled arsenic concentration at the POE of 6.61E-4 mg/L is calculated to be 3.07E-5. It is noted that risks from arsenic at the promulgated arsenic maximum contaminant level for drinking water of 0.01 mg/L are higher than those from the maximum predicted concentrations at the POE.

3.5.3.1 Arsenic

The maximum modeled well water concentration for arsenic leads to an average adult intake of arsenic from impacted water and irrigated vegetables of 1.7E-5 mg/kg/day (Table 3.5-2). The hazard quotient (HQ) is the daily dose divided by the reference dose, so the hazard quotient is 5.6E-2 (1.7E-4 mg/kg/day / 3E-4 mg/kg/day). A hazard quotient that exceeds 1.0 does not necessarily indicate a toxic level; however, a hazard quotient less than 1 generally indicates a safe daily intake.

According to ATSDR (2007), there is little information available on effects due to direct dermal contact with inorganic arsenic compounds, but several studies indicate local irritation and dermatitis is the main effect, with little risk of other adverse effects.

3.5.3.2 Boron

The average daily intake of boron from drinking well water and eating irrigated vegetables is calculated to be 8.1E-3 mg/kg/day for a 70 kg adult (Table 3.5-2). Using the reference dose (RfD) of 2.0E-1 mg/kg/day this leads to a hazard quotient of 4.1E-2, which is well below the level that might be considered unsafe daily intake.

ATSDR (2010a) reports a few cases of hair loss (focal alopecia) from application to boric acid or borax onto the scalp. However, no studies were reported regarding fatalities, hematological and dermal effects in humans or regarding respiratory, cardiovascular, gastrointestinal, musculoskeletal, hepatic, or renal effects in humans after dermal exposure to boron.

3.5.3.3 Cadmium

Cadmium in well water at the maximum modeled concentration resulted in daily average intake from drinking and eating of irrigated vegetables of 4.1E-6 mg/kg/day (Table 3.5-2). That intake results in a hazard quotient of 8.2E-3 which generally indicates a safe daily intake.

Data from ATSDR (2012) indicates that there is no evidence of human fatalities from dermal exposure to cadmium. Further, that report found no studies regarding respiratory, cardiovascular, gastrointestinal, hematological, musculoskeletal, hepatic, or renal effects in humans after dermal exposure to cadmium. A few patients tested with two percent cadmium chloride showed some skin reaction but "*the effect was likely direct irritation of the skin*."

3.5.3.4 Chlorine/Chloride

Chlorine in groundwater likely exists as chloride. ATSDR (2010b) reports no studies regarding respiratory, cardiovascular, gastrointestinal, hematological, musculoskeletal, hepatic, renal, endocrine, or body weight effects in humans following dermal exposure to hypochlorite solutions. No chronic-duration human study of exposure to hypochlorous acid or sodium hypochlorite was located; thus, a target for long-term exposure to chlorine in humans has not been identified.

ATSDR (2010b) reported an oral reference dose (RfD) for chlorine of 0.1 mg/kg/day based on a No Observed Adverse Effect Level (NOAEL) of 14.4 mg/kg/day for systemic effects in F344/N rats exposed to chlorine in the chlorinate drinking water for two years. The uncertainty factor used in this assessment

was 100 (10 for interspecies extrapolation and 10 for the protection of sensitive human subpopulations). Based on the comments in the previous paragraph, the quoted RfD does not seem to be legitimate for unprocessed groundwater.

3.5.3.5 Fluorine/Fluoride

The maximum modeled concentration of fluoride resulted in an average daily intake by an adult from water and irrigated vegetables of 9.4E-3 mg fluoride/kg/day (Table 3.5-2). This intake results in a hazard quotient of 2.4E-1, which would generally indicate a safe daily intake.

ATSDR (2003) states that "*No studies were located regarding gastrointestinal, hematological, musculoskeletal, endocrine, or body weight effects in humans or animals after dermal exposure to fluoride, hydrofluoric acid, or fluorine*." Fatalities from exposure to fluoride compounds have only occurred due to hydrofluoric acid burns, which would not be possible in this scenario.

3.5.3.6 Molybdenum

The maximum modeled concentration of molybdenum in well water leads to a daily intake of molybdenum of 1.0E-3 mg/kg/day for a 70 kg adult (Table 3.5-2). The hazard quotient is 2.1E-1. A hazard quotient less than 1 generally indicates a safe daily intake.

According to ATSDR (2020) there is limited information on the dermal toxicity of molybdenum. What exists results from a small number of oral exposure studies reporting skin and hair effects and acute-exposure dermal studies. The report cited no effects on humans from dermal exposure.

3.5.3.7 Nitrate

The maximum modeled concentration of nitrate-N at the POE is 5.77 mg/L, which leads to an average daily intake of nitrate from ingestion of water and well water-irrigated vegetables of 4.1 mg/kg/day (Table 3.5-2). The hazard quotient is 1.0E0, which would indicate a safe daily intake. It is important to note that the published RfD of 1.6 mg/kg/day is for intake of nitrogen, not nitrate, and is based on ingestion of drinking water used to prepare baby formula for a 4 kg child, not exposure to an adult. When converted from nitrogen to nitrate, a more appropriate value is 7 mg/kg/day. The health endpoint used to establish the RfD is "*early clinical signs of methemoglobinemia in excess of 10% "* (IRIS, 2022).

According to ATSDR (2017), relevant information regarding outcomes from dermal exposure to nitrates was not available for systemic effects, immunological effects, neurological effects, reproductive effects, developmental effects, or cancer.

3.5.3.8 Selenium

The maximum modeled concentration of selenium in well water leads to a daily intake of selenium of 6.6E-4 mg/kg/day for a 70 kg adult from direct ingestion of well water and eating vegetables contaminated with impacted well water (Table 3.5-2). The hazard quotient is 1.3E-1. A hazard quotient less than 1 generally indicates a safe daily intake.

ATSDR (2003) reports locating no studies concerning respiratory, cardiovascular, gastrointestinal, hematological, musculoskeletal, hepatic, renal, endocrine, or body weight effects in humans or other animals following dermal exposure to selenium or selenium compounds.

3.5.3.9 Vanadium

The maximum modeled concentration of vanadium in well water of 6.4E-04 mg/L leads to a daily intake of vanadium of 1.2E-5 mg/kg/day for a 70 kg adult from ingestion of well water and eating vegetables irrigated with well water (Table 3.5-2). The hazard quotient is 1.7E-3 which would generally indicate a safe daily intake.

According to ATSDR (2012) there are no studies located that observed health effects including death, systemic effects, immunological and lymphoreticular effects, neurological effects, reproductive effects, developmental effects of cancer.

3.5.3.10 Radium

Due to lack of supporting data, no estimates of systemic effects for radium were made. See information in Appendix 3.5-A Section 4.2.

3.5.3.11 Thorium

Due to lack of supporting data, no estimates of systemic effects for thorium were made. See description in Appendix 3.5-A Section 4.3.

3.5.3.12 Uranium

As shown in Table 3.5-2, average daily ingestion of uranium from intake of water and irrigated vegetables is calculated to be 3.4E-4 mg/ d for a 70 kg adult. The hazard quotient is 1.6E-1. A hazard quotient that exceeds 1.0 does not necessarily indicate a toxic level, but a hazard quotient below 1 generally indicates a safe daily intake.

It is worth noting that ATSDR (2013) mentions that the EPA-derived reference dose of 3E-3 mg/kg/day for uranium soluble salts was based on a lowest-observed-adverse-effect level (LOAEL) of 2.8 mg/kg/day for initial weight loss and moderate nephrotoxicity in rabbits exposed to uranium in the diet for 30 days and an uncertainty factor of 1,000 and that the RfD "*is currently under review by EPA*." However, a recent check of IRIS shows the same RfD value.

The majority of toxicity data for natural uranium comes from animal studies of natural uranium conducted over the last 20 years. Current evidence from animal studies suggests that the toxicity of uranium is mainly due to its chemical damage to kidney tubular cells following exposure to soluble uranium compounds. In fact, as a radioactive material, uranium is regulated mainly because of its effect on renal function.

According to ATSDR (2013) some epidemiology studies have found associations between various parameters of renal dysfunction and elevated uranium levels in drinking water. These studies did not find overt signs of toxicity and in many cases, the biomarkers of renal dysfunction were within the normal range. A study by Kurttio et al. (2006) found that uranium exposure was associated with increase blood pressure, both diastolic and systolic. Further, cumulative uranium intake was associated with increased glucose

excretion in urine. The authors concluded, however, that continuous uranium intake from drinking water, even at relatively high exposures, was not found to have cytotoxic effects on kidneys in humans.

ATSDR (2013) also indicates that dermal exposure to uranium compounds has not been shown to cause systemic effects regardless of the duration of the exposure.

It is important to note that the assumption for this analysis that a resident drinks only the well water and eats no vegetables from other sources is highly conservative. A more realistic scenario might be that only one-half of the resident's drinking water is from the well which would reduce the hazard quotient nearly 50 percent. Regardless, it appears that the predicted maximum concentration of uranium in the well water would not represent a serious human health hazard.

3.5.3.13 Summary of Systemic Effects

As shown in Table 3.5-2, none of the constituents investigated had significant hazard quotients and as such should not be a concern for a resident gardener using the predicted maximum groundwater well for drinking or irrigation. No dermal effects are expected from bathing in water containing any of the constituents examined.

3.5.4 Summary of Potential Carcinogenic Risks

The exposure to uranium, combined radium-226 and radium-228, and thorium-230 in groundwater results in a calculated effective dose equivalence to a resident gardener of 7.6 mrem/yr, and a 30-year mortality risk of 1.2E-5. The calculated effective dose equivalent dose is less than the 10 CFR 20.1402 limit for unrestricted use (25 mrem/yr), and less than the EPA protective limit for CERCLA sites of 12 mrem/yr (EPA, 2014). The modeled maximum POE concentrations of residual radionuclides originating from the site pose no human risk based on limits deemed protective of the public. Similarly, the maximum modeled POE concentrations in groundwater are less than derived concentration guideline levels calculated above.

The exposure to arsenic in groundwater at the modeled maximum POE concentration results in a calculated 30-year mortality risk (estimated lifetime cancer risk) of 3.07E-5. The concentration of arsenic at the maximum modeled POE concentration of 6.61E-4 is less than the NRC standard in Criterion 5C of 0.05 mg/L and below the State of New Mexico human health drinking water standard of 0.01 mg/L (NMAC 20.6.2.3103.A). As mentioned above the calculated risks are based on the assumption that a resident in the future utilizes groundwater entirely as their source for drinking water and domestic water, an assumption that is likely conservative. Because the exposure concentration is less than the NRC and State of New Mexico human health drinking water standards, the maximum modeled arsenic concentrations in groundwater are protective of human health.

3.6 Environmental Exposure Potential

The GRP is located within the Semiarid Tablelands ecoregion (22j) of the Arizona and New Mexico plateau that includes mesas, plateaus, cliffs, and valleys with mostly ephemeral streams (EPA, 2010a). Vegetation is typically scattered juniper and piñon-juniper woodland with mixed gamma and western wheatgrass. Beyond the GRP non-residential land use is shrubland with some livestock grazing (EPA, 2010b).

The ecological risk assessment conducted for the Final Remedial Investigation Report (HDR, 2020) was based on wildlife exposure to surface water in the evaporation ponds, surface soil, and sediments. None of these are complete pathways for the current analysis, which is limited to well water used by a resident gardener. However, the data presented in the Final Remedial Investigation Report (HDR, 2020) is used, where applicable. The pathways presented the Final Remedial Investigation Report (HDR, 2020) will not exist if ACLs are approved.

Characteristic animal species in the vicinity of the GRP include 13 species of mammals, 36 species of birds and 3 species of reptiles (HDR, 2020). Wildlife to be considered for this ACL Application include Ord's Kangaroo Rat (*Dipodomys ordii*), the Deer Mouse (*Peromyscus maniculatus)* and Kit Fox (*Vulpes macrotis*).

For the purposes of this analysis, the most reasonable scenario for environmental exposure is represented as groundwater pumped from the same well assumed to supply water to the resident gardener and used for garden irrigation. In that scenario, selected native animals from the area would be subject primarily to ingesting water that pooled on the garden soil and secondarily from eating garden plants irrigated with that water. A simple ecological conceptual model is shown in Figure 3.6-1. Vegetation outside of individually watered gardens would not have access to groundwater due to its substantial depth (typically greater than 35 feet) and, therefore, would not be damaged by contaminants or pose a pathway risk to wildlife through consumption of vegetation.

As a practical matter it is difficult to assess potential harm to wildlife from either pathway, due to uncertainties in both pathways. With the human pathways, it is possible, but highly conservative, to assume that all exposure to a given constituent occurs with what is 100 percent occupancy. Doing the same for wildlife adds additional uncertainty due to the transitory nature of wildlife and frequency that a given specimen might reside near the garden. The fact that the resident controls the water flow adds another level of complexity with very little supporting data. It is also important to note that the constituent concentrations being modeled are for groundwater, which have no specific ecological health standards. Regardless, there are ecological screening values for some constituents for surface water that are used to categorize ecological risk.

Screening assessments are used to identify those contaminants whose concentrations are sufficiently high such that they may be hazardous to wildlife. A screening assessment should be sufficient to include all potential hazards while eliminating clearly insignificant hazards. Assumptions made in a screening assessment are conservative to prevent any potential hazards from being overlooked.

Due to the lack of ecological screening information for ingestion of irrigated vegetables by wildlife, it seems impractical to attempt to make any estimates of potential ecological damage with such limited data and large uncertainties. The sections below refer to screening level assessments of radioactive and inorganic constituents that may be present in the modeled well water.

3.6.1 Radioactive Constituents

Two approaches are used to assess potential radiological impacts to wildlife from exposure to impacted well water at the POE. The first is the RESRAD-BIOTA model and the second is comparison to radioecological screening levels. Results from each are shown below.

3.6.1.1 RESRAD-BIOTA Results

The RESRAD-BIOTA (R-B) code, version 1.8 (ISCORS, 2004) was used to estimate radiation dose to potential species at the modeled POE water concentrations. RESRAD-BIOTA implements DOE's Graded Approach methodology described in DOE Technical Standard DOE-STD-1153-2002. RESRAD-BIOTA analyzes radiation exposures to biota in either a terrestrial or aquatic system. Radiation exposures are considered to result from contaminated soil, water and sediment, which subsequently result in contamination in air and in different food sources. The model was developed to coincide with the content in proposed 10 CFR 834, Subpart F (1995 – 1996) that was not enacted but which represents DOE's thinking regarding limiting exposures to 0.1 rad per day for terrestrial animals and plants. This is in keeping with ICRP thinking that if humans are protected, then biota are protected (ICRP, 2008).

RESRAD-BIOTA has three potential scenarios for exposure of wildlife: soil, water, and sediment. The possibility of pooled irrigation water on the resident's garden is the most likely pathway of well water to a terrestrial mammal. Given that, the most likely organisms to ingest irrigation water are the kangaroo rat, the deer mouse, and the kit fox. This analysis assumes that the animal drinks the well water chronically, when, in reality, such ingestion would be a periodic event.

RESRAD-BIOTA allows three levels of complexity. Level 1 is a screening mode with default parameters and organism descriptions. Level 2 allows editing of certain organism-specific parameters. Level 3 allows further editing of organism-specific parameters and adding new organisms. For this analysis, the deer mouse and the kit fox were added, partly because various geometry settings were available that mimicked those species. For example, RESRAD-BIOTA geometry setting 3, includes cotton rats, voles, shrews, and the white-footed mouse. RESRAD-BIOTA geometry setting 5 includes beavers, coyote, fox, and raccoon. Modeled concentrations of well water were used as a surrogate for surface water and dose was calculated using equations shown in Appendix 3.5-A.

RESRAD-BIOTA was run in Level 3 mode for this exposure scenario to water. The uranium concentration in the well water was set equal to the maximum modeled uranium concentration in the POE well of 0.0266 mg/L, converted into pCi/L for input into RESRAD-BIOTA. Maximum water concentrations of 0.0107 pCi/L and 0.1088 pCi/L were used for thorium-230 and combined radium-226 and radium-228, respectively. It was assumed that the three isotopes of natural uranium, uranium-234, uranium-235, and uranium-238 were in equilibrium.

The Biota Concentration Guide (BCG) represents the concentration in an environmental media, in this case water, that result in the 0.1 rad/day limit. For water, the ratio of impact to the animal and the Biota Concentration Guide summed for all radionuclides were 4.18E-2 and 4.17E-2 for the deer mouse and the fox, respectively (Table 3.6-1). This ratio is far below any level that might cause concern and indicates that drinking of well water containing the modeled concentrations of the modeled radionuclides would result in no detriment to wildlife.

3.6.1.2 Radioecological Screening Levels

Another method of testing for radioecological impact is the use of radioecological screening levels (RESLs). Radioecological screening levels have been developed for various environmental media, such as surface water, sediment, and soil. Most of the values shown in Table 3.6-2 were developed by the Texas Commission on Environmental Quality (TCEQ, 2021). To the best of our knowledge, there are no

radioecological screening levels for groundwater as such, but the values listed in Table 3.6-2 are for water, presumably drinking water, in a terrestrial system. Texas Commission on Environmental Quality radioecological screening level values for aquatic systems are a factor of hundreds or thousands lower, most likely because fish inhabit the water.

Table 3.6-3 shows hazard quotients for each radioactive constituent for the maximum well water concentration and the computed equilibrium value of the constituent in soil as defined in the equations Appendix 3.5-A. In all cases the individual hazard quotients are far below a value of 1. The maximum hazard quotients calculated for soil come from uranium isotopes, but when summed are still well below a value of concern.

3.6.2 Nonradioactive Constituents

Screening assessments serve to identify those contaminants whose concentrations are sufficiently high such that they may be hazardous to wildlife. The primary emphasis of a screening assessment is to include all potential hazards while eliminating clearly insignificant hazards. To prevent any potential hazards from being overlooked, assumptions made in a screening assessment are conservative.

Data to estimate ecological effects of constituents from exposure to well water is limited or non-existent. To screen for potential effects, the ecological screening value (ESV) approach applied by the Savannah River Site (SRS, 1999, Friday, 1999) for surface water has been adopted for use in this study as a surrogate for impacted well water, whenever a constituent is represented in the Savannah River Site data. Savannah River Site surface water ecological screening values were developed using data from EPA Region IV Ambient Water Quality (AWQ) standards (EPA, 1995), EPA Ecotox threshold values (EPA, 1996) as well as calculations by Suter and Mabrey (1994) and Suter and Tsao (1996) or Canadian benchmark values (Environment Canada, 1998). According to the Savannah River Site approach, constituent concentrations lower than the ecological screening value would indicate that the constituent can be excluded from further consideration. It is important to note that the surface water ecological screening value is sometimes intended for use with aquatic life rather terrestrial species as a drinking water source. Those values have not been used in this analysis if other defensible values are available.

Surface water ecological screening values from Savannah River Site (1999) for constituents are compared to the maximum modeled well water concentration for each constituent as shown in Table 3.6-4. The hazard quotient is the predicted maximum concentration in the well water divided by the ecological screening value or benchmark. A hazard quotient less than or equal to 1 indicates that the constituent is unlikely to cause adverse ecological effects.

The ecological screening value for selenium of 5E-3 mg/L suggested by Friday (1999) is taken from the AWQC which was primarily for protection of aquatic life in fresh or saltwater. That being the case it may not be appropriate for a terrestrial animal drinking well water. A better approach is the lowest chronic value for all organisms from Suter and Tsao (1996) of 8.83E-2 mg/L. As shown in Table 3.6-4, use of that benchmark results in a hazard quotient of 2.7E-1, which is well below the level of concern.

Another approach is to use a benchmark from Sample and others (1996) for the meadow vole which would be analogous to a deer mouse that would be found at GRP. In their example, Sample and others (1996) calculated no-observed-adverse-effect level-based benchmarks for use in a screening assessment. They

compared contaminant concentration in water, soil and plants to the benchmark and calculated a hazard quotient. In their example, shown in their Table 13 (Sample et al., 1996), a selenium water concentration of 2E-2 mg/L was compared to a benchmark of 2.46 mg/L, which resulted in a hazard quotient of 8E-3. Using the predicted well water maximum for selenium of 0.024 mg/L leads to a hazard quotient of 2.7E-01, as shown in Table 3.6-4, which would be well below the level of concern for damage to wildlife. Regardless of which option is used, it appears that selenium would not be of major concern at the maximum modeled concentrations.

The ecological screening value suggested for uranium of 2.6E-3 in the Savannah River Site approach is a Tier II Secondary Chronic Value as described by Suter and Tsao (1996) intended to use as a screening value for protection of aquatic organisms in lieu of other benchmarks. According to ATSDR (2013), in a summary of the oral toxicity in both rats and dogs, several uranium compounds were ordered by relative toxicity. Practically nontoxic compounds were uranium tetrafluoride, triuranium octoxide, and uranium dioxide (ATSDR, 2013). It is likely that uranium in the modeled well water is an oxidized form of natural uranium. Therefore, it seems more appropriate to use the ecological screening value derived from the lowest chronic value and applicable to "all organisms" (Suter and Tsao, 1996), as opposed to one intended for only aquatic organisms. In that situation, the predicted maximum concentration of uranium in well water represents a hazard quotient of 1.9E-01, which would not be grounds for concern.

Arsenic, boron, cadmium, chloride, molybdenum, selenium, uranium, and vanadium would be presumed to not represent an ecological hazard. Additional comments for nitrate follow in the subsection below. The hazard quotient value greater than 1 for nitrate does not necessarily represent an unacceptable risk, but indicate further investigation is necessary. The hazard quotient is conservative due to the assumption that wildlife will consume well water as their only water source, which is extremely unlikely as most species that contact the irrigated water would do so only periodically. Most of the species resident in the area would be transitory visitors to the garden area and to ingest water, would need to be present only during irrigation periods, assumed to be 150 days annually, itself a highly conservative assumption. Further, infiltration and evaporation of ponded water would reduce the time ponded water would be available for ecological exposure.

3.6.2.1 Nitrate

The ecological screening values shown in Table 3.6-4 are for surface water as opposed to well water and are for nitrite rather than nitrate. Nitrate and nitrite ions occur naturally in the terrestrial and aquatic environment. Nitrate is formed naturally and results from vegetable and animal decomposition.

To the best of our knowledge, there are no ecological screening values for nitrate as such, but we are assuming similar behavior for nitrate and nitrite. However, the nitrate ecological screening value is relatively low compared to national drinking water goal (maximum contaminant level goal) for nitrate of 10 mg/L. Further, the maximum contaminant level goal for nitrite is a factor of 10 lower, 1 mg/L than that for nitrate.

If we apply the maximum contaminant level goal of 10 mg/L for nitrate as a benchmark or screening value to the predicted maximum well water concentrations, the hazard quotient drops to 0.32, providing a reasonable margin of safety. It's worth noting that the maximum contaminant level goal is considerably higher than the predicted maximum concentration of nitrate in the well water.

3.6.2.2 Uncertainties in Hazard Quotients

There are numerous uncertainties and conservatisms associated with the calculation of potential ecological hazard. One of the major uncertainties is the use of the maximum modeled concentration of each constituent. In every instance, the constituent is an overprediction of what will ultimately be the concentration within the well.

The fact that there are no approved ecologic screening values for groundwater and that surface water ecological screening values were used when available, it is difficult to assess how well the hazard quotient calculations mimic reality. Further, the assumption that wildlife in the area is dependent on pooled well water following irrigation introduces another conservatism as does the frequency of irrigation annually. Given the timeframe of the modeling scenario it is impossible to predict what ecological conditions might exist in the future, but it would appear that ingestion of water would not be a debilitating condition.

3.6.3 Summary of Ecological Effects

Ecological effects estimated using maximum modeled water concentrations at the POE and comparing those to available ecological screening values for surface water and radioecological screening levels for drinking water in terrestrial systems were conclusive that no hazard is indicated. Estimates from RESRAD-BIOTA lead to the same result and applying those to modeled maximum groundwater consumption result in the conclusion that there is likely to be no adverse ecological effect. Therefore, issues related to contaminant interactions and their cumulative effects on exposed populations, projected responses of environmental populations that result from exposure to constituents, and anticipated changes in populations are not addressed.

4 CORRECTIVE ACTION ASSESSMENT

Groundwater investigation and restoration efforts have been ongoing since the late 1970s. The Groundwater Corrective Action Program at the GRP was approved by the NRC on January 16, 1991, after the NRC resumed regulatory authority in 1986. The objective of the Groundwater Corrective Action Program, in accordance with 10 CFR Appendix A, Criterion 5D, is *"…to return hazardous constituent concentration levels in groundwater to the concentration levels set as standards."*

In addition, Criteria 5D states:

"The licensee's proposed program must address removing hazardous constituents that have entered groundwater at the point of compliance (POC) or treating them in place. The program must also address removing or treating any hazardous constituents that exceed concentration limits in groundwater between the POC and the downgradient facility property boundary. The licensee shall continue corrective action measures to the extent necessary to achieve and maintain compliance with the groundwater standards. The NRC will determine when the licensee may terminate corrective action measures based on data from the groundwater monitoring program and other information that provide reasonable assurance that the groundwater protection standard will not be exceeded."

Section 4.1 below presents past contaminant source control activities and groundwater restoration corrective actions at the GRP. Section 4.2 identifies a range of potential corrective action alternatives. Section 4.3 analyzes and compares the performance of each alternative. Section 4.4 presents an analysis of costs and benefits of these alternatives and identifies a proposed alternative for long-term groundwater protection. Finally, Section 4.5 provides a demonstration that the past corrective actions and the proposed alternative has reduced groundwater concentrations to as low as reasonably achievable (ALARA).

4.1 Previous and Current Correction Action Programs

HMC in coordination with NRC, EPA, and NMED has progressively implemented a comprehensive range of appropriate remedial technologies for this type of site over the past four decades. HMC has ensured protectiveness and has continuously improved the remedial actions over the decades by providing alternate water supplies and by implementation of source control, containment, collection, evaporation, groundwater access controls, and *ex situ* treatment that continues to this day. Groundwater corrective actions performed to date at the GRP include source control actions in the Large Tailings Pile and groundwater plume remediation through groundwater containment and removal by groundwater collection, water treatment, water injection, and disposal of wastewater. Water management components of these corrective actions have included water storage in the Large Tailings Pile, reuse of collected water in ore milling, storage and evaporation in lined evaporation ponds, land application, and treatment with reverse osmosis (RO), evaporation, and zeolites (Figure 4.1-1). Starting in the late 1950s, the AEC required monitoring for groundwater protection. Sampling was done on a quarterly basis and reviewed by AEC. Monitoring did not show any increase in radionuclides in groundwater through the mid-1970s. New Mexico assumed authority over the License in 1974 but relinquished that authority back to NRC, the successor agency to the AEC, on June 1, 1986.

A State of New Mexico and EPA study of the New Mexico uranium industry in the late 1970s indicated elevated selenium levels in domestic water at one of the neighboring residential subdivisions downgradient

of the GRP. Consequently, HMC and the State of New Mexico entered into an agreement on August 18, 1976, which specified that HMC would design and construct a system to contain the seepage from the tailings pile. Groundwater corrective action resulting from that agreement was later incorporated into State discharge permits (DP-200 and DP-725, later consolidated into DP-200), which have been renewed several times, most recently in 2014.

Groundwater corrective action requirements were incorporated into the License shortly after NRC resumed regulatory jurisdiction for the GRP. Table 4.1-1 summarizes the NRC licensing history of the groundwater Corrective Action Program. The 1989 groundwater Corrective Action Program amendment request (Hydro-Engineering, 1989) was approved by NRC in License Amendment 5 in 1990 and authorized the continued groundwater collection and freshwater injection that had been ongoing since the late 1970s per an agreement with NMED. The NRC-approved Corrective Action Program is designed to afford the operator substantial flexibility in operation of groundwater injection and collection locations to adapt to the dynamic nature of the groundwater conditions. The Corrective Action Program does not specify wells or areas from which groundwater must be withdrawn, treated, or injected and does not specify minimum quantities of groundwater addressed for corrective action, which treatment technologies must be used, or in what amounts. This groundwater Corrective Action Program has been continuously expanded over the past 49 years (Table 4.1-1).

During the period of Homestake mill operation, collected groundwater was returned to the Large Tailings Pile and/or the Homestake mill for use in the milling process. With the Homestake mill operating at a reduced capacity from 1981 and 1988, the corrective action groundwater collection waters were held in the Large Tailings Pile ponds. Consequently, a single-lined evaporation pond (EP1) was designed, permitted by License Amendment 7, and constructed on the Small Tailings Pile in 1990. By 1995, an additional double-lined evaporation pond (EP2) was permitted and installed between the Small Tailings Pile and the lined brine collection ponds (East and West Collection Ponds, Figure 1.2-1) as approved by License Amendment 19.

As the scope of the groundwater collection activities increased, additional water treatment capacity was needed, leading to approval of License Amendment 30 in 1998. This amendment authorized installation of a water treatment plant using lime softening (pH adjustment), filtration, and a reverse osmosis (RO) membrane unit to treat extracted groundwater, supporting increased water treatment of collected groundwater and increased treated water re-injection. The groundwater Corrective Action Program was further modified by Amendment 41 in 2008, which authorized the construction and operation of double-lined evaporation pond (EP3), which further increased the evaporation and wastewater holding capacity of the water management system. The three evaporation ponds afford over 3.2 million square feet of evaporation surface area and almost 350 million gallons of storage capacity (Table 4.1-2). Spray evaporation systems, authorized in the original 1989 Corrective Action Program, have been added to the evaporation ponds and modified periodically. These systems currently include APEX brand mechanical spray evaporators that are used seasonally to maximize the available evaporative capacity of the three evaporation ponds. HMC has made substantial efforts to maximize evaporative capacity of these ponds by determining optimal evaporative technology and configuration, increasing mechanical spray evaporative capacity (24 new and efficient APEX units installed in 2018) and operational availability (system operated by an automated platform to maximize operation during allowable windspeed, humidity, and temperature conditions). A study was completed in 2018 by Resource West to maximize evaporative capacity by selecting the optimal technology, number of units, and placement configuration on evaporation ponds

(Resource West, 2018). Increases in seasonal or annual average evaporative capacity from the addition of spray evaporation are difficult to quantify and no estimate of those increases is included here. In 2024, EP1 was taken out of service due to the condition of the liner. An interim soil cover was placed over the salts and sediments in the bottom of the pond to mitigate any potential windblown transport.

The RO Plant, originally designed in 1998 to treat water at a theoretical design capacity of 300 gpm, has been expanded twice through a modified Safety and Environmental Review Panel (SERP) process undertaken according to License Condition 16 (as it existed at the time that NRC approved License Amendments 33 and 47, respectively; the License Condition 16 Safety and Environmental Review Panel process was most recently modified in 2021 by Amendment 57). The RO Plant was expanded to a theoretical design capacity of 600 gpm in 2002, although the expanded system could not consistently sustain treatment rates greater than approximately 300 gpm. The RO Plant was again expanded in 2014-2015 by adding an additional clarifier, microfiltration system, and an additional RO unit with a theoretical design capacity of 600 gpm. While these system improvements increased the theoretical design capacity flowrates up to 1200 gpm, these theoretical design capacity rates were never expected to be achievable as long-term treatment rates. The theoretical design capacity is the maximum output of a system operated continuously during a given period under optimal conditions without accounting for site-specific conditions, maintenance, component underperformance, component failure and other site-specific factors (e.g., weather-related downtime). HMC estimates that the actual operational capacity of the RO system is approximately 600 gpm. From 2016 through 2024, the RO input averaged 495 gpm.

The groundwater Corrective Action Program was further modified by License Amendment 55, which NRC approved in February of 2020, authorizing the innovative and previously bench-scale use of zeolites as a means of treating groundwater impacted with low levels of uranium. Zeolite is a natural mineral with ion exchange properties that allow for removal of some constituents from groundwater. The field testing of the zeolite treatment system expanded progressively from 2009 through 2019 to a stated maximum theoretical design capacity of 1,500 gpm; however, the stated theoretical design capacity of this innovative technology was not based on field-tested actual production rates and did not account for necessary routine media regeneration and maintenance, and consequently, substantially overstated the average annual treatment rates. The approval for use of zeolites allowed flexibility in the locations for groundwater collection and injection and does not specify or mandate minimum treatment rates. Due to challenges with managing algae growth in this novel system and the impending placement of final over on the LTP, the zeolite treatment systems were decommissioned in 2022. Off-site water that was previously sent to the zeolite is now routed to the RO Plant for treatment.

Continuous groundwater Corrective Action Program expansion has occurred over the past 49 years (Figure 4.1-1). Appendix 4.1-A presents more detailed summaries of the groundwater corrective action history and performance at the GRP. The following sections summarize the source control, groundwater remediation corrective actions, and associated water management systems implemented over that timeframe. Corrective action operation data, such as pumping rates and treatment rates, volumes, etc. are presented in Section 4.1.4.

4.1.1 Source Control: Tailings Dewatering, Tailings Flushing

Source control of contaminants entering groundwater from the Large Tailing Pile seepage initially included efforts to dewater the tailings using wells and toe drains. Later, an effort to actively rinse the tailings of

high dissolved concentrations by flushing with relatively clean water was added to the source control dewatering efforts.

4.1.1.1 Tailings Dewatering

The first phase of the tailings dewatering program began in 1992 and included the installation of a series of toe drains and a French drain around the perimeter of the Large Tailings Pile to intercept perched zone water (water in an alluvial sand generally 10 feet below the base of the tailings) seeping from the tailings into the alluvium. The perched zone is not naturally saturated but contained seepage from the tailings in the immediate area of the Large Tailings Pile. Locations of the toe drains and two French drains (also referred to as toe drains) around the perimeter of the Large Tailings Pile and their seven associated sumps are shown on Figure 4.1-2. These drains are connected to common sumps (named E-1, E-2, N-2, N-3, S-1, W-1, W-2). Two additional sumps (East and West Reclaim sumps) are connected to the old tailings decant towers (Figure 4.1-2). The cumulative volume of water removed by the toe drains and vertical tailings dewatering wells are shown in Figure 4.1-3. Peak toe drain collection rate of slightly greater than 50 gpm, occurred in 2003, 2004, 2008 and 2009, during the operation of the tailings flushing program. The cumulative volume of water removed by the toe drains through 2024 is approximately 423 million gallons, which is an average collection rate of 25 gallons per minute (gpm) for the past 32 years, although the average rate produced from the toe drains has declined with time and was approximately 2 gpm in 2024 (Table 4.1-3).

Tailings dewatering wells were installed in the Large Tailings Pile beginning in 1994 and the vertical well dewatering program started in 1995 as an additional means to enhance tailings dewatering. Numerous wells were added each year to expand the tailings dewatering program. Tailings dewatering wells were completed in the tailings sand and slime areas as well as in the perched zone, discussed above. A vacuum was applied to dewatering well heads in the early years of the program to enhance the small well yields. The cumulative volume of tailings water pumped since 1995 is approximately 493 million gallons, which is an average rate of 41 gpm over a 23- year period from 1995 through 2017 when dewatering was terminated due to low well yields. Water levels in the Large Tailings Pile have dropped dramatically since 2015 (Figures 4.1-4 and 4.1-5), data from well locations presented in Figure 4.1-2 indicate additional vertical well dewatering is impractical due to very small potential well yields. The peak dewatering rates of between 104 gpm and 107 gpm occurred in 2011 and 2012 (Table 4.1-3). The dewatering rates were restricted during a few years due to the limited available evaporation pond storage during those years.

4.1.1.2 Tailings Flushing

Testing of tailings flushing was deemed necessary to diminish the high constituent concentrations in the tailings water and the lack of decline in constituent concentrations from dewatering alone. Testing of tailings flushing in both the sand tailings area and slime tailings area was conducted in 1999 and the flushing program was started in 2000 and ceased in mid-2015. Figure 4.1-2 shows the location of the injection wells used in the flushing program along with the dewatering wells. The average tailings injection rate varied from 61 gpm in 2000 to a peak of 308 gpm in 2014 and averaged 233 gpm over the 16-year period of operation of this program (Table 4.1-3 and Figure 4.1-6). The performance effects of tailing flushing are discussed in Section 4.1.4, below. The tailings dewatering and flushing programs dramatically reduced uranium and molybdenum concentrations in Large Tailings Pile water from pre-flushing levels of approximately 40 and 100 mg/L, respectively, to average concentrations in 2024 of 5.06 and 12.9 mg/L, respectively, as discussed further in Section 4.1.4.1. Tailings flushing was discontinued in mid-2015. Large

Tailings Pile flushing ceased following investigations of the Large Tailings Pile that identified that the flushing water was primarily moving through the tailings sand material, which had been substantially rinsed of dissolve constituents by that point. By contrast, the porewater within the tailings slimes was bound by capillary forces and was thus inaccessible to flushing. It was therefore concluded that additional tailings flushing would have diminishing benefits in concentration reductions.

4.1.2 Plume Remediation: Groundwater Collection and Injection

After the EPA sampled several Broadview and Murray Acres subdivision wells in early 1975 and found elevated concentrations of selenium, HMC conducted a hydrologic assessment (Hoffman, 1976), which included installation of more than 40 monitoring wells. Based on the results of this assessment, the State of New Mexico and HMC entered into an agreement on August 18, 1976, which specified that HMC would design and construct a system to contain the seepage from the tailings piles.

For the following discussions, uranium is presented as the primary constituent and is used as the key indicator constituent for evaluating groundwater impacts as well as restoration progress. It is recognized that other constituents are present in the groundwater, although generally over lesser spatial extents and generally at concentrations closer to their respective License groundwater protection standards than uranium. A more detailed description of the groundwater collection and injection program with associated data are included in the 2024 Annual Performance Report (HMC and Hydro-Engineering, 2025).

4.1.2.1 Alluvial Aquifer Collection and Injection

HMC designed a collection and injection system using a numerical groundwater flow model (Hoffman, 1977). Injection of fresh water just north of Broadview Acres started in June 1977 and operation of groundwater collection wells adjacent to the tailings piles started in July 1978. Figures 4.1-7 through 4.1-19 illustrate the configuration of the alluvial aquifer collection and injection systems from 1977 to the present. Historically, fresh water, supplied by deep wells screened in the San Andres-Glorieta aquifer (Deepwell 1 and Deepwell 2R), was injected in strategic areas to contain plume migration as a component of the groundwater containment system. This practice was discontinued in 2024. A more detailed description of the groundwater collection and injection program with associated data are included in the 2024 Annual Performance Report (HMC and Hydro-Engineering, 2025).

This program of groundwater collection, injection, and water management continually expanded after beginning in the late 1970s. From 1982 through 1992, the expansions included additional freshwater injection upgradient of the Murray Acres area (added in 1983), additional injection wells to the east of the original injection wells (which were north of Broadview Acres), additional alluvial aquifer collection wells on the west side of the Large Tailings Pile, and additional groundwater collection wells east of Murray Acres that were added in 1990 (Figure 4.1-8). Further additions to the alluvial aquifer collection and injection wells in 1993 and 1994 included an additional line of injection wells southwest and southeast of the Small Tailings Pile, and collection from the K area wells southwest of the Small Tailings Pile (Figure 4.1-9). Expansions in collection and injection operations from 1995 through 1999 included additional collection wells (K area, B area, D area, L area) with these extracted waters reinjected into the alluvial aquifer near the Large Tailings Pile, where constituent concentrations were higher. The 1995 through 1999 expansions also included additional collection wells in the S area and the B and D areas, as well as addition

of injection and reinjection wells on the south and east sides of the Small Tailings Pile, and on the northeast side of the Large Tailings Pile (Figure 4.1-10).

The main addition to the alluvial aquifer collection system during 2000-2004 and 2005-2009 was the collection of alluvial aquifer groundwater to feed the RO Plant and the collection of groundwater for land application, discussed in following sections. Irrigation started in 2002 with the supply wells located in the alluvium west and southwest of the North Irrigation System. The North Irrigation center pivot was expanded to 100 acres in 2005, which resulted in the use of additional irrigation supply wells in the alluvium to the east of the North Irrigation System area and expansion of freshwater injection to the north of the irrigation supply wells.

The South Irrigation System started in 2000 and included a 150-acre center pivot spray system as well as a 120-acre area for flood irrigation (Figure 4.1-11). The common water supply to the South Irrigation system connected the alluvial aquifer collection wells in Township 12 North, Range 10 West, Sections 32 and 33 to the Township 11 North, Range 10 West, Section 3 and Felice Acres collection wells (Figure 4.1-12 and Figure 4.1-13). In 2012, NMED imposed additional restrictions on the quality of water applied to the fields. To address this more restrictive water quality requirement, water from San Andres wells 943 and 915R were added to the South and North Irrigation System supply wells, respectively, to produce water for land application with an average uranium concentration less than 0.16 mg/L. Land application of collected groundwater, which effectively treated over 3.1 billion gallons of impacted water, ceased later in 2012 (HMC and Hydro-Engineering, 2025). These areas have been assessed and released for unrestricted use by NRC in 2021. Cessation of land irrigation for low concentration groundwater treatment decreased the overall treatment rate by between 125 gpm and 653 gpm, or roughly 50 percent for the period 2000 through 2012.

The locations of the On-Site collection and injection operations (Figure 1.2-1) were similar for the periods 2010-2012 and 2013-2015, except that the cessation of the land application program reduced the area (and rate) of Off-Site groundwater collection during 2013 through 2015, as shown by comparing Figure 4.1-13 with Figure 4.1-14 and the data in Table 4.1-2. From 2013 through 2015, Off-Site collection was reduced to smaller areas in Sections 28, 34, and 35 and supplied water for tailings flushing and testing of the zeolite treatment system. Upgradient alluvial groundwater collection ended in 2013 and therefore is not shown on the Figure 4.1-14.

From 2016 through 2019, alluvial aquifer collection supply wells for RO Plant feed were added in the southwestern portion of the Large Tailings Pile area and between the Large Tailings Pile and evaporation ponds (Figure 4.1-15). Groundwater collected from the area southeast of the Small Tailings Pile (L Area) that had previously been used for reinjection near the Large Tailings Pile was redirected as an RO Plant feed source. Treated water injection locations are shown on Figure 4.1-15 for both the South and North Off-Site areas (Figure 1.2-1). The South and North Off-Site collection water was treated through the zeolite systems through 2022 to meet the uranium License groundwater protection standard and enable the reuse of this water for injection supply. Since the decommissioning of the zeolite factilies, the off site water has been routed to the RO Plant for treatment.

Groundwater collection for the reinjection program operated for approximately seven months during 2016 but was discontinued after July 2016 due to concerns raised by the NRC. The Confirmatory Order (CO) issued by the NRC in March 2017 (NRC, 2017a) required that HMC provide an analysis of the collection for reinjection program and its impacts on restoration progress. This analysis was completed and reported (Hydro-Engineering, 2017). The conclusions of this analysis were that the collection for reinjection was successful in preventing the expansion of the L Area contaminant plume without detracting from restoration efforts within the hydraulic control area near the Large Tailings Pile, and the transfer of relatively small quantities of constituents into the hydraulic control area by reinjection did not significantly delay restoration progress near the Large Tailings Pile.

The current (2024) groundwater corrective action collection and injection system is illustrated in Figures 4.1-16 through 4.1-19. The colors on the well names and in the legend denote the specific utilization of each well in 2024. Currently, On-Site (Figure 1.2-1) alluvial aquifer collection and injection wells are located on the west and south sides of the Large Tailings Pile. Collection operations are also occurring on the west and south sides of EP1. This collection, in combination with the injection downgradient of the collection wells, results in hydraulic control of alluvial aquifer flow gradients downgradient of the Large Tailings Pile.

Most of the South Off-Site (Figure 1.2-1) alluvial collection and injection wells operate in and near the Middle Chinle subcrop in South Felice Acres, in Township 12 North, Range 10 West, Section 35 and northeast Township 12 North, Range 10 West, Section 3 (Figure 4.1-18). Restoration activities have focused on this area because its proximity to the Middle Chinle subcrop to assist restoration of the Middle Chinle groundwater in the South Off-Site area.

Existing North Off-Site alluvial collection and injection wells are focused on the leading edge of the uranium groundwater plume (0.1 mg/L contour) and the L Area On-Site alluvial restoration area, which is located to the southeast of the Small Tailings Pile along Highway 605 (Figures 4.1-16 and 4.1-19).

4.1.2.2 Chinle Groundwater Collection and Injection

Figure 4.1-20 shows the locations of the West and East Faults with the subcrop for the Upper Chinle shown in dark blue, the subcrop for the Middle Chinle shown in red and the Lower Chinle subcrop, which is located in Township 11 North, Range 10 West, Section 33, shown in light blue. The subcrop for the Upper Chinle is an important contact with the alluvial aquifer because it extends below the alluvium beneath the western portion of the Large Tailings Pile. This creates a direct pathway by which seepage-impacted alluvial groundwater in the immediate area of the Large Tailings Pile can enter Upper Chinle groundwater. In contrast, seepage-impacted alluvial groundwater must flow significant distances from the Large Tailings Pile area before reaching a subcrop of the Middle or Lower Chinle, thereby decreasing the magnitude of impact to Middle or Lower Chinle groundwater relative to the closer Upper Chinle. Each of the Chinle units extends down dip to the east and northeast of their respective subcrops. Groundwater flow in those units is generally down dip to the east and northeast as described in Sections 1.2 and 1.3.

Chinle groundwater restoration efforts have included both freshwater injection and collection of impacted groundwater and have addressed Upper, Middle, and Lower Chinle groundwater. Freshwater injection was used to inhibit downgradient movement of shallower impacted groundwater, and groundwater collection targeted contaminant removal in upgradient (shallower) areas of observed impact. The system and

sequence of injection and collection that began in 1984 has evolved as more monitoring and characterization data have become available and as the groundwater conditions in the alluvium, which provide the conduit to Chinle groundwater, have also evolved.

Figures 4.1-20 through 4.1-23 illustrate the sequence of Upper Chinle groundwater restoration efforts between 1984 and 2019. Early Chinle groundwater restoration efforts were focused on groundwater collection near the Large Tailings Pile and Small Tailings Pile and hydraulic diversion through injection near the Broadview Acres Area (Figure 4.1-20). Collection of groundwater in the Upper Chinle near the Large Tailings Pile and Small Tailings Pile was expanded between 2000 and 2012, while groundwater collection and injection were initiated in both the Upper and Middle Chinle north of the Large Tailings Pile and in the Felice Acres area. Groundwater collection was also initiated south of the Felice Acres area in the Lower Chinle during this period (Figure 4.1-21). Some collected groundwater was used for the tailings flushing program (e.g., CW1, CW2, CW3, 929 and 934; Figure 4.1-19), some for the land irrigation (e.g., CW53, CW44 and 498), while other groundwater collection from unimpacted areas was used as a supply for freshwater injection (e.g., CW18). Additional evaporation and water storage capacity was added by design, permitting, and construction of Evaporation Pond 3 (EP3) during 2006 through 2008. Land application of low constituent concentration Off-Site groundwater ceased in 2012, which reduced water management capacity and spurred development of expanded RO Plant treatment capacity and expanded testing of the zeolite treatment systems in the following years.

The groundwater restoration activities for the period of 2013 through 2015 were similar to that of 2000 through 2012 although groundwater collection and injection in the Middle Chinle increased south of the Felice Acres area (Figure 4.1-22). Pumping and/or injection at specific wells varied from year to year based on monitoring data and operational needs for freshwater injection or water needed for tailings flushing. Tailings flushing was discontinued at the end of this period (2015) while expansion of the RO Plant treatment system was planned and developed and progressively larger field testing of the use of zeolites in treating off-site groundwater was performed over this period.

The locations of collection and injection wells used in 2016 through 2019 in the Upper, Middle and Lower Chinle are presented on Figure 4.1-23. This period is characterized by increased collection of groundwater from the Upper Chinle near the Large Tailings Pile and Small Tailings Pile (C, B, and T wells in Figure 4.1-20) and injection into the Middle Chinle west of the West Fault (Figure 4.1-20). Water management included increased RO Plant treatment capacity with the 2015 expansion, increased off-site water treatment capacity with expansion of the zeolite testing (2015) and the addition of new and more numerous spray evaporators on the evaporation pond (2018).

The Upper, Middle, and Lower Chinle collection and injection wells used in the current remediation system are illustrated in Figure 4.1-24. Upper Chinle collection is focused mainly near its subcrop area adjacent to the Large Tailings Pile. The operation of collection wells located within and directly adjacent to the subcrop benefits both the Upper Chinle and the alluvial aquifer, as it captures and removes seepage-impacted groundwater from both units. Selected wells in the Upper Chinle subcrop area are completed in both the alluvium and Upper Chinle sandstone because the units are hydraulically connected at the subcrop.

The locations of the Middle Chinle collection and injection wells used in the existing remediation system are presented on Figure 4.1-24. Figure 4.1-24 shows the existing Middle Chinle wells west of the West Fault with only one operating collection well, CW62, and two operating injection wells. The collection and

injection wells in the South Off-Site area include five operating collection and injection Middle Chinle wells. Current Lower Chinle groundwater restoration does not include groundwater collection.

4.1.3 Water Management

Management of groundwater during the source control and groundwater restoration efforts has evolved since the commencement of groundwater corrective actions in 1977. Water management methods have included re-use in the milling process, storage and evaporation in the Large Tailings Pile and lined evaporation ponds, treatment with reverse osmosis (RO), treatment with zeolites, and land application of low concentration groundwater. The following sections describe the development and performance of the individual water treatment systems. Figure 4.1-25 illustrates the location of the current and former water management and treatment systems. Figure 4.1-26 presents a conceptual flow diagram for the water management system. Table 4.1-2 summarizes the historical volumetric water management performance of each system.

4.1.3.1 Evaporation

Evaporation was used to manage water at the GRP starting in 1986 with the construction of the West and East Collection Ponds (Figure 4.1-25) which were lined with a single asphalt liner. These two ponds, which comprise approximately 11,400,000 gallons of storage capacity and 217,800 square feet of evaporative surface area at full storage, were used to manage Homestake mill wastewater during the final years of the Homestake mill operation and were used as part of the evaporation system after 1990. Evaporation Pond 1 (EP1) was constructed in 1990 with a single asphalt liner similar to the collection ponds and comprises over 171,000,000 gallons of storage and over 1,000,000 square feet of evaporative surface area at full storage. Evaporation Pond 1 (Figure 4.1-25) occupies the northern two thirds of the Small Tailings Pile and was constructed by excavating tailings to form pond dikes. Evaporation Pond 2 (EP2) was constructed in 1996 between the Small Tailings Pile and the East Collection Pond with two high density polyethylene (HDPE) liners and a leak detection system. This pond possesses almost 100,000,000 gallons of storage capacity and over 744,000 square feet of evaporative surface area at full storage. The third evaporation pond, EP3, is located approximately one-third mile north of the Large Tailings Pile and consists of two cells, double-lined with HDPE, and a leak detection system (Figure 4.1-25). This pond possesses over 78,000,000 gallons of storage capacity and over 1,150,000 square feet of evaporative surface area at full storage. EP2 and EP3 are currently operated by seasonal use of mechanical spray evaporators made by APEX to increase the evaporative capacity of these systems. Spray evaporators are operated with wind speed and direction sensors that shut off the spray systems at set limits to mitigate potential wind transport of spray outside the limits of evaporation pond liners.

Figure 4.1-27 illustrates the past performance of the evaporation ponds. The data presented in Table 4.1-2 show a steady and progressive increase in evaporative capacity at the GRP from an annual average rate of less than 20 gpm during milling to approximately 200 gpm in 2020. Recent Evaporation Pond 1 (EP1) liner maintenance has necessitated decreased storage and associated evaporative capacity since late 2018, which has reduced evaporation rates. In 2023, EP1 was taken out of service entirely, reducing both the storage and evaporative rate of the site.

4.1.3.2 Reverse Osmosis Treatment

The RO Plant (Figure 4.1-25) was constructed in 1999 to treat collected groundwater and supply a water stream that meets License groundwater protection standards for injection into groundwater. Pilot testing of the RO process was conducted in 1995 (HMC, 1998; Hydro-Engineering, 1998) and information submitted to the NRC in support of the RO process also included an evaluation of the injection of RO produced water (Hydro-Engineering, 1998). The approval of the use of RO treatment was subsequently granted in 1998 as License Amendment 30. The original RO Plant consisted of a 300-gpm low pressure RO which could be operated in series with a high pressure RO unit to treat the brine from the low pressure RO unit at maximum design rates of 75 gpm (Figure 4.1-25). The RO Plant utilized a lime/caustic pre-treatment and sand filter clarification unit at that time.

The RO Plant was expanded in 2002 (RO Expansion 1, Figure 4.1-27) with the addition of a second low pressure unit with a maximum design capacity of 300 gpm (total maximum RO Plant design capacity of a maximum of 600 gpm), using the existing pre-treatment processes. The three RO units were designated as Low Pressure No. 1 (LPRO-1), High Pressure No. 1 (HPRO-1) and Low Pressure No. 2 (LPRO-2). A further expansion and upgrade of the RO Plant was undertaken in 2014 and 2015 with the replacement of sand filtration by microfiltration units and the addition of a third low pressure unit (LPRO-3) with a maximum design capacity of 600 gpm (total maximum RO design capacity of 1,200 gpm). Additional upgrades/changes to the RO Plant at that time included addition of a second clarifier, addition of two equalization tanks to the RO pre-treatment system, and addition of a post treatment tank (PTT). The post treatment tank historically received the RO treated water, treated water from the zeolite system, and up to 300 gpm of fresh water from the San Andres-Glorieta aquifer prior to distribution to the injection system. With the decommissioning of the zeolite system in 2022 and the elimination of San Andres-Glorieta water for supplemental injection, only RO treated water reports to the PTT.

A second high-pressure unit (HPRO-2) with a capacity of 250 gpm was added in 2016 (RO expansion 2, Figure 4.1-27). HPRO-2 was configured to treat the brine from the three low pressure units when they were all operating. The high-pressure RO units only treat brine effluent from the low pressure RO and do not increase the total feed rate to the RO Plant but rather increase the quantity of product water from the plant while reducing the total volume of brine waste effluent. The product water from all five RO units is discharged to the post treatment tank while the final brine stream from the combination of operating units is discharged to the evaporation ponds. Other miscellaneous flows and clarifier blowdown sludge from the plant are pumped to the West Collection Pond. Clarifier blowdown sludge deposited in the West Collection Pond is periodically transferred to EP1 while liquids in the West Collection Pond are recycled to the RO Plant. The RO Plant inputs and output of RO product water for injection are listed Table 4.1-2.

Reverse osmosis treatment is used for treatment of all groundwater collected from both On- and Off-Site wells.

4.1.3.3 Land Application

Land application of mildly impacted groundwater was conducted from 2000 through 2012 as a means of water management. A soil investigation (RIMCON and Hydro-Engineering, 1998) was conducted prior to selection of the land application irrigation areas. The sample results from the 1998 investigation and multiple samples collected from outside the land application area each year were used to establish background soil concentrations of a range of metals and radionuclides. An analysis of the potential risk of

the land application program was conducted prior to the start of irrigation in 2000 (ERG and Hydro-Engineering, 1999). The results of the land application irrigation program were analyzed and presented in successive irrigation reports that presented the cumulative land application records, the most recent of which was submitted in 2014 (HMC et al, 2014).

The land application program consisted initially of a South Irrigation System with 120 acres of flood irrigation in Section 34 and a 150-acre center pivot sprinkler system in Section 33 (Figure 4.1-28). These two irrigation areas were supplied by the same pipeline and only one of the areas was irrigated at a time. The North Irrigation System was started in 2002 in Section 28 with a 60-acre center pivot supplied by wells in Section 28 using a separate supply pipeline (Figure 4.1-28). Table 4.1-2 presents the quantity of water applied to the irrigated areas for each year. The addition of 24 acres of flood irrigation in Section 33 increased the amount of irrigated area during 2004, while the North Irrigation System center pivot was further expanded by 40 acres in 2005. The location of the 24-acre flood area in Section 33 south of Valle Verde subdivision is shown on Figure 4.1-27. The data in Table 4.1-2 show that the yearly applied volumes of water to all irrigated areas ranged from 65,491,589 gallons (201 acre-feet) to 343,423,555 gallons (1,054 acre-feet) of water with the total annual average application rates for the combined North and South Irrigation systems ranging from 125 gpm to 653 gpm.

The yearly average concentrations of uranium, selenium, TDS, sulfate, chloride and molybdenum in water applied to the South and North Irrigation System areas are presented in Tables 4.1-4 and 4.1-5, respectively and identify that uranium concentrations were generally in the range of 0.1 mg/L to 0.35 mg/L, molybdenum was generally less than 0.05 mg/L, selenium was generally in the range of 0.05 mg/L to 0.1 mg/L, sulfate ranged from approximately 600 mg/L to 900 mg/L and chloride ranged from 120 mg/L to 190 mg/L. The concentrations of other constituents (nitrate, vanadium, thorium-230, and combined radium 226+228) in the irrigation supply water were below the corresponding License groundwater protection standards and levels of regulatory concern.

Soil constituent concentrations were measured prior to the use of irrigation in an area and each year during the operation of the land application irrigation system. Suction lysimeters were installed in 2009 to obtain soil moisture samples in the irrigation areas for measurement of constituent concentrations in the water. Lysimeters were installed in 3, 5, 3 and 1 locations in the Section 28 center pivot, Section 33 center pivot, Section 34 flood area and Section 33 flood area, respectively (Figure 4.1-28). Water samples from these lysimeters were used to evaluate the constituent concentrations in soil moisture and the movement of these constituents in the soil profile. The soil moisture chemistry data from the lysimeter water samples were used to evaluate constituent migration in the soil profile as a result of irrigation. Soil moisture instruments were installed prior to the 2012 irrigation season to measure soil moisture content in the upper portion of the soil profile. Data in the reports indicated limited vertical migration of constituents through the unsaturated soil column.

Land application ceased in 2012. The irrigation systems have been decommissioned, post-application soil sampling and surveys performed, and NRC has concurred that the areas meet the NRC-approved remedial action levels. HMC is not required to take further corrective actions at the irrigation areas (NRC, 2021a).

4.1.3.4 Zeolite System Treatment

Zeolite, a natural mineral that has ion-exchange characteristics, was evaluated as an additional method for treating high volumes of groundwater with low constituent concentrations from off-site areas (where uranium is the only constituent above License groundwater protection standards) to improve treatment

capacity at a lower cost than RO treatment. Testing of zeolite to remove uranium from groundwater was initially conducted using bench scale tests in 2007. Favorable results from the bench scale testing led to expansion to a five-gpm capacity pilot scale test using two plastic water tanks filled with zeolite (RIMCON, 2009). The pilot testing was further expanded with the construction and operation of a 50-gpm zeolite system (Figure 4.1-25) consisting of two HDPE lined zeolite cells on top of the Large Tailings Pile (RIMCON and Hydro-Engineering, 2012). A field-scale test of a zeolite system consisting of three HDPE lined cells with a maximum design capacity of 300 gpm was constructed adjacent to the two lined cells used in the 50-gpm system (Figure 4.1-25). This system (abbreviated as 300Z; RIMCON and Hydro-Engineering, 2012; RIMCON, 2013), was tested with supply of both On-Site and Off-Site groundwater (Figure 1.2-1) and successfully reduced uranium concentrations in the supply water to levels that met License groundwater protection standards.

Based on long-term testing of the 300Z, a larger zeolite system (abbreviated as 1200Z) was designed (Hydro-Engineering, 2015) and installed in 2015 in the southeast corner of the top of Large Tailings Pile (Figure 4.1-24). The 1200Z system consists of four trains that each have three sequential treatment cells and a maximum design treatment capacity of 300 gpm for each train (Hydro-Engineering, 2017). The results from treating the Off-Site groundwater with the zeolite process have been documented in Section 2 of the 2016, 2017, 2018, 2019 and 2020 Annual Monitoring Report (HMC and Hydro-Engineering, 2017; HMC and Hydro-Engineering, 2018; HMC and Hydro-Engineering, 2019; HMC and Hydro-Engineering 2020; HMC and Hydro-Engineering 2021). Field-scale pilot testing of the 300Z and 1200Z zeolite beds has been used since 2016 to remove uranium from the Off-Site collection water. Uranium is the only constituent that exceeds License groundwater protection standards in all Off-Site areas. NRC approved the use of the zeolite treatment system, with no upper or lower limits of treatment volume, as part of the groundwater Corrective Action Program on February 3, 2020 in License Amendment 55. Algae fouling of the zeolite media was not identified in bench-scale or pilot-scale testing. Algae growth in the zeolite cell trains has emerged over the past few years and has lowered zeolite system operational time and treatment rate efficiencies due to increased maintenance burdens. The zeolite system annual average water treatment rate has varied from 42 to 267 gpm (Table 4.1-2). In 2022, due to the challenges presented by the algae growth, and with the upcoming placement of the final cover over the top of the LTP, the zeolite systems were decommissioned.

4.1.4 Remediation Performance

Since 1978, remediation of the groundwater system has managed over 11 billion gallons of recovered groundwater (Table 4.1-1). In that time, the On-Site corrective action program has removed and managed an estimated 7.2 billion gallons of water and removed an estimated 204,286,507 pounds of sulfate, 1,130,064 pounds of uranium, and 1,406,383 pounds of molybdenum from the groundwater system (HMC and Hydro-Engineering, 2025). Groundwater collection and treatment from Off-Site areas since 2021 has totaled over 254 million gallons and has removed an estimated 646 pounds of uranium from the groundwater system (HMC and Hydro-Engineering, 2025).

However, substantial constituent mass remains in the tailings and the groundwater system. A first-order decay analysis of the changes in groundwater uranium concentrations from historical groundwater corrective actions was conducted to project times to restore groundwater, which indicated that restoration of uranium concentrations would require between 165 and 283 years and restoration of molybdenum concentrations would require between 263 and 529 years (HMC, 2020f). However, since this first-order

decay analysis evaluates the period of time when the primary source experienced significant depletion, it likely underestimates the timeline it would take for restoration to be achieved.

The assessment of groundwater remediation performance, considered with modeling of the long-term sources of groundwater contamination presented in Section 3, and analysis of the benefits of continued corrective action for the ALARA analysis presented in Section 4.5, establish that restoration of the groundwater is not reasonably achievable and maximum future groundwater concentrations at the POE have already been reduced to levels that are as low as reasonably achievable. The following sections discuss the overall performance of the source control and groundwater plume remediation efforts.

4.1.4.1 Source Control

Dewatering of the Large Tailing Pile started in 1995 and was discontinued in 2017 due to very low well yields (approximately 1.3 gpm for all wells combined), although collection of drainage in the toe drains continues through the present (HMC and Hydro-Engineering, 2025). The toe drain and tailings well dewatering volumes shown in Figure 4.1-3, and the associated data presented in Tables 4.1-6 and Table 4.1-7 indicate the declining rates of tailings fluid recovery since 2012. Tailings toe drain annual average recovery rates for 2024 are approximately 2.0 gpm for the entire tailings (Table 4.1-7).

The effects of tailings dewatering and subsequent tailings drainage are evident in the water level or head changes in the tailings as illustrated in Figures 4.1-4 and 4.1-5, which illustrate a declining rate at which heads are dropping in most tailings wells and the near asymptotic flattening of heads in many wells (e.g., wells CN2, SE2, EN1, ES1, SW1, SW2, SE3, WO32, WC15, etc.). Currently, there is a maximum head of up to 40 feet of water in the center of the slimes (the maximum head in the slimes is approximately 6,615 feet amsl in well WME-6) but lower heads exist in sand tailings due to higher sand hydraulic conductivities and faster draining than slimes. Tailings dewatering has resulted in removal of over 200,000 pounds of uranium, 479,000 pounds of molybdenum and 5,600 pounds of selenium from the tailings (Table 4.1-7).

Current Large Tailings Pile seepage rates have been estimated as approximately 4.5 gpm (HMC and Hydro-Engineering, 2025) and long-term seepage rates after final cover placement have been estimated to be approximately 0.04 gpm. The key factors in limiting long-term infiltration into the Large Tailings Pile are the semi-arid climate, the establishment of an evapotranspiration cover over the top of the LTP that creates positive drainage over the entire Large Tailings Pile.

Tailings flushing, tested in 1999, initiated in 2000 and terminated in mid-2015, substantially reduced measured concentrations of uranium, molybdenum, and selenium concentrations in tailings. Measured concentrations in individual tailings wells tend to be slightly lower than those measured in tailings sumps, which collect seepage from the margins of the tailings. Pre-flushing and post-flushing tailings well concentrations are illustrated in Figure 4.1-29 with data in this figure summarized in Table 4.1-6. Data for tailings wells and sumps are provided in the Annual Monitoring Report (HMC and Hydro-Engineering, 2025). It is noted that the tailings sump concentrations (Figure 4.1-30) fit well with data for wells along the perimeter of the tailings (e.g., wells CS1, EN1, ES1, WW1). Wells in the interior of the tailings generally have lower constituent concentrations than the tailings margins and the sumps. This suggests that a substantial portion of the tailings footprint has seepage with constituent concentrations that are lower than those represented by the sump data, when evaluated on an area and volumetrically weighted basis.

Average tailings concentrations for uranium decreased between threefold and sevenfold from pre-flushing levels, molybdenum decreased between threefold and fivefold, and selenium showed nominal change in tailings well samples but approximately fivefold decrease in tailings sump samples (Figures 4.1-30 through 4.1-32 and Table 4.1-8). In addition, it is noted that 10 years of post-flushing monitoring does not indicate tailings concentration rebound to pre-flushing levels. This absence of a tailings concentration rebound is consistent with the rebound studies performed to date (Arcadis, 2012; WME, 2020a), which do not predict substantial long-term changes to tailings constituent concentrations from current concentrations.

These data demonstrate source control efforts have intercepted and removed substantial volumes of tailings fluids and have decreased current tailings seepage concentrations. However, tailings flushing was stopped in 2015, as concentration changes in many tailings wells and sumps were showing progressively decreasing benefits of continued flushing (smaller levels of concentrations decrease with each year of flushing) and continued flushing prolonged Large Tailings Pile drain down and final cover placement on the Large Tailings Pile. Over the long-term, seepage constituent concentrations are anticipated to remain relatively constant at these lower concentrations.

4.1.4.2 Groundwater Remediation

Groundwater remediation efforts began over 49 years ago and have continually grown both in spatial extent of collection and injection and in treatment and water management capacity. The objective of groundwater remediation has been to return groundwater constituent concentrations to or below License groundwater protection standards. The License groundwater protection standards were established by License Amendment 39 and are shown in Table 1.1-1. These standards are based on NRC approved background concentrations and maximum concentration limits, as allowed for in 10 CFR 40, Appendix A, Criterion 5B(5).

Section 4.1.3 presents performance data on the water management systems (i.e., evaporation, land application, reverse osmosis, zeolites). The historical groundwater concentrations of uranium in the alluvial aquifer and the three Chinle units are illustrated in Figures 4.1-33 through 4.1-36. Mapping of groundwater uranium concentrations over time is taken as representative and bounding of all constituent transport, generally as uranium remains the most extensively distributed of the identified constituents in groundwater at the GRP after nearly 50 years of corrective action.

The maps in Figures 4.1-33 through 4.1-36 indicate that the high groundwater uranium concentrations (1 mg/L to 10 mg/L) in the immediate area of the Large Tailings Pile and Small Tailings Pile, that expanded in extent between 1976 and 1999, have been consistently contained, meaning the plumes have not expanded, since 1999. The isoconcentration contours in the range of 0.16 mg/L and 0.5 mg/L uranium in the North Off-Site plume have been pulled back (i.e., have been reduced in total area) from the Rio San Jose drainage in the alluvial aquifer system since 1999, while the extent of the South Off-Site plume in alluvial groundwater has been held constant and concentrations within that plume substantially reduced since 1999 (Figure 4.1-33).

The C and K wells, near the Small Tailings Pile, have shown order of magnitude to two orders of magnitude decreases in uranium concentrations as a result of corrective action activities as shown in Figures 4.1-38 and 4.1-39. Locations of these well groupings are provided in Figure 4.1-37. In spite of the progress that

has been made in these areas, decreases in groundwater uranium concentrations in some of these wells has stagnated since the early 2000s and groundwater uranium concentrations remain above background, in most cases by at least an order of magnitude. The D, S, and B wells which are located on the downgradient edge of the Large Tailings Pile exhibit similar trends to the wells discussed previously (See Figures 4.1-40 through 4.1-42) with the caveat that a smaller percentage of the wells have observed an order of magnitude concentration decrease. in While some wells in recent years have shown increases at different points in the last decade, the maximum values observed are significantly lower than historic concentrations observed in these areas pre-2000. The concentrations in the T wells underneath the pile show less significant decreases in concentrations, however the period of record for these wells (with the exception of T1 and T2) is much shorter (Figure 4.1-43). Given the high concentrations observed on the downgradient edge of the LTP in the D, S, and B wells, it is likely that historic concentrations observed were significantly higher than in the mid-2000s when the majority of these wells were installed.

The Upper Chinle, which receives recharge from overlying alluvial groundwater directly under the Large Tailings Pile, has shown substantial groundwater restoration in the area south of the Large Tailings Pile in the Broadview Acres and Felice Acres areas (Figure 4.1-34), although elevated uranium concentrations in the immediate areas directly under the Large Tailings Pile persist. The Middle Chinle, which receives recharge from the overlying alluvial groundwater has shown some groundwater restoration in the area southwest of the Large Tailings Pile between the East and West Fault splays north of the Broadview Acres area and diminished extent and groundwater uranium concentrations west of the West Fault splay since 1999. Groundwater uranium concentrations in the Broadview Acres and Felice Acres areas have diminished slightly in extent and magnitude over the past decade as shown in Figure 4.1-35. The very limited impacts to the Lower Chinle groundwater have been contained and reduced in size from their peak in approximately 1999 (Figure 4.1-36).

Table 4.1-2 presents a summary of the annual water collection and treatment rates. These data indicate that nearly 11.8 billion gallons of water have been collected and treated since 1986, with roughly 3 billion gallons (25 percent) permanently removed from the groundwater system as untreatable wastewater. From this collected water, approximately 1,332,833 pounds of uranium, 1,886,747 pounds of molybdenum and approximately 77,506 pounds of selenium have been removed from the tailings and the groundwater system. The source control efforts using tailings vertical dewatering wells and toe drains successfully removed approximately 202,769 pounds of uranium, 480,364 pounds of molybdenum, and 5,621 pounds of selenium, as presented in Table 4.1-7.

4.1.5 Corrective Action Performance Conclusions

The past 49 years of investigation and corrective action have successfully mitigated substantial contaminant mass in the tailings and groundwater systems and, as discussed in Sections 4.4 and 4.5, reduced concentrations to as low as reasonably achievable, while at the same time, enhanced understanding of the hydrologic conditions and efficacy of groundwater corrective action systems. From 2000 through 2024, source control efforts in the Large Tailings Pile recovered over 422.9 million gallons of tailings pore water through collection at the Large Tailings Pile toe drains, which removed over 30.0 million pounds of sulfate, 126.3 thousand pounds of uranium, and 268.5 thousand pounds of molybdenum. Similarly, Large Tailings Pile dewatering wells removed over 493.3 million gallons of tailings pore water, which removed over 20 million pounds of sulfate, 76 thousand pounds of uranium, and 211.8 thousand pounds of molybdenum

(Tables 4.1-6 and 4.1-7). Tailings flushing, a source control measure not performed at any other uranium mill in the United States, decreased tailings pore water uranium concentrations between 18 percent and 38 percent and molybdenum between 20 to 34 percent (Table 4.1-8). The overall corrective action program has treated over 4.2 billion gallons of impacted groundwater with reverse osmosis, over 3.1 billion gallons with land application, over 658 million gallons through evaporation, and over 663 million gallons with zeolite treatment (Table 4.1-2). The corrective action program resulted in over 3 billion gallons permanently removed from the groundwater system via evaporation.

Across all GRP groundwater monitoring wells, significant progress has been demonstrated by the decrease in groundwater constituent concentrations in all areas, primarily over the first 30 years of corrective action. The greatest progress has been made in areas furthest away from the primary source of the Large Tailings Pile, but as noted earlier, License groundwater protection standards have not been achieved at all locations, nor is there any indication from the observed data that it is an achievable objective. Despite the progress in groundwater restoration made over the past several decades of corrective action, continued groundwater corrective action is diminishing in efficacy. Figure 4.1-44 illustrates this point by showing that in spite of the increasing rate of water treatment year over year, the removal efficiency has remained relatively constant over the last decade. Put another way, while the average treatment has doubled since the 1990s, the mass removal efficiency has reduced by a factor of four.

This overall behavior is consistent with the conceptual understanding of the site. The effects of heterogeneous advection, sorption, and diffusion help explain the stagnation in restoration progress. Figure 4.1-45 shows three plots of samples taken as part of the dual domain investigation showing concentrations in both the high K (sands) and low K (silts and clays), and their locations either directly underneath the pile or directly downgradient. The samples taken in the high K zone (shown in blue) show a high degree of variability showing that even if concentrations observed in a given well are low in the most permeable zones, less permeable material directly adjacent can exhibit higher concentrations and thus can act as a secondary source. In the case of DT1B2, concentrations in adjacent lenses can vary by an order of magnitude.

Sorption also plays a significant role in the transport behavior of uranium at the site. Based upon the work done as part of the geochemical characterization of the site as well as the groundwater model, the ratio between sorbed mass and soluble mass can range anywhere from 4.8 to 14.9 using the calibrated Freundlich isotherm from the groundwater model and the range of bulk densities. Figure 4.1-46 shows both the calibrated Freundlich isotherm plot as well as how the described sorption behavior varies by concentration and bulk density.

Predictive modeling of the site demonstrate that long-term restoration of the groundwater to current License groundwater protection standards is not reasonably achievable. Therefore, this ACL Application requests approval for ACLs as the sole reasonable means to satisfy the requirements of Criteria 5B(1) and 5B(5) of Appendix A to 10 CFR Part 40.

4.2 Potential Corrective Action Alternatives

This section discusses the assessment of remedial technologies and process options used to develop corrective action alternatives, and the design of the alternatives. The assessment of technologies and process options from groundwater restoration is based on a more detailed technical memorandum included

in Appendix 4.2-A. Assessment of the alternatives, including predictive modeling, is presented in Section 4.3.

4.2.1 Technical Approach

Groundwater clean-up and human health protection objectives are identified and corrective action alternatives designed to address those objectives. General categories of remedial technologies can be further divided into a number of process options. Remedial technologies are general categories of technologies, such as chemical treatment, thermal destruction, immobilization, capping, dewatering, etc. For remediation of groundwater and source control at the tailings, several broad remedial technologies have been identified for each general response action. Numerous process options may exist within each remedial technology type. For example, chemical treatment is a remedial technology and process options for this technology include precipitation, ion exchange, and adsorption. Site specific treatability studies are addressed, as well as technologies and process options identified from other engineering and restoration applications.

Technologies and process options are assessed for technical implementability. Non-implementability may be based on site constraints, a technology being unproven, or other factors that demonstrate the inability to effectively control or reduce a contaminant to License groundwater protection standards. Initial assessment of technologies and process options is based on published information, site specific treatability studies, and empirical demonstration as well as knowledge of the site characteristics, and engineering judgment. Assessed remedial technologies are identified either as not applicable or potentially applicable for further assessment.

The potentially applicable remedial technologies and process options are further assessed for effectiveness and implementability. In addition, relative qualitative costs are identified (low, moderate, high) but are only used to compare technologies with comparable levels of effectiveness; cost considerations do not result in the elimination of any technology or process option.

Based on the assessment of technologies and process options summarized above and presented in Appendix 4.2-A, a range of corrective action alternatives is developed that includes the majority of the potentially applicable remedial technologies and process options. The approach to identifying technologies for groundwater corrective action alternatives presented in Appendix 4.2-A was borrowed from the EPA regulatory program and guidance is not incompatible with NRC regulation or guidance for assessing groundwater corrective action alternatives and is, therefore, retained for this assessment. Section 4.3 of this ACL Application evaluates the range of alternatives developed for this ACL Application, based in part on predictive modeling using the calibrated base-case model configurations of each alternative.

4.2.2 Groundwater Corrective Action Objectives

To the extent practicable and reasonably achievable, within the meaning of 10 CFR 40, Appendix A, the groundwater corrective action objectives identified for this ACL Application are listed below. They are also summarized in Table 4.2-1.

- Prevent human ingestion of contaminated groundwater.
- Restore groundwater quality in the alluvial aquifer and the Upper Chinle, Middle Chinle, and Lower Chinle.
- Reduce seepage and migration of constituents from the tailings piles to groundwater.

These objectives are used to support design and evaluation of groundwater corrective action alternative performance.

4.2.3 Identification of Practicable Corrective Actions.

This section summarizes the assessment of potential corrective action technologies and process options addressed in Appendix 4.2-A. This assessment addressed a range of practicable, realistic, and reasonable corrective action alternatives. This analysis of groundwater corrective action technologies and process options was based on the following considerations:

- Effectiveness:
    - Achieving groundwater corrective action objectives as appropriate to the site-specific conditions and contamination
    - Technically Implementable
        - availability and capacity of treatment, storage, and disposal facilities
        - availability of equipment and skilled workers needed to implement the process option
        - worker health and safety
- Cost-effective: providing the same level of protection to human health and the environment.

The relative qualitative costs (low, mid, high) for each technology or process option are identified in Appendix 4.2-A consistent with NRC Guidance NUREG 1620 and are used to compare technologies with comparable levels of effectiveness. Cost does not result in the elimination of any technology or process option from consideration in developing or assessing corrective action alternatives.

The retained potentially effective, feasible, and implementable remedial technologies and process options are identified in Table 4.2-1. For purposes of assessing the remedial process option of removing the tailings piles and relocating the tailings to a new, lined, on-site disposal cell, this analysis relies upon the analysis conducted by the United States Army Corps of Engineers which determined that this option was not practicable (USACE, 2010). Therefore, that process option is not retained as part of the corrective action alternatives developed below.

4.2.4 Development of Corrective Action Alternatives

This section describes the corrective action alternatives developed using the retained technologies and process options assessed. The design of the corrective action alternatives described below provides the basis for groundwater modeling of each alternative, as presented in Section 3 and Appendix 4.2-B, and assessment of the alternative's performance.

The range of groundwater corrective action alternatives developed here include source control measures, groundwater restoration measures, *in situ* and *ex situ* treatment methods, and active and passive technologies. Three corrective action alternatives have been identified for detailed analysis and comparison and include combinations of all engineering-feasible, practicable technologies and processes options:

- Alternative 1 – Groundwater Containment and Removal (No Action)
- Alternative 2 – Groundwater Containment and Removal and In Situ Treatment
- Alternative 3 – Alternate Concentration Limits

For all alternatives, the long-term sources of contaminants to the groundwater system are seepage from the Large Tailings Pile and Small Tailings Pile. All alternatives address source control from seepage impacts to groundwater by placement of a final cover over the Large Tailings Pile. Alternatives with ongoing active measures also address seepage impacts to groundwater with removal and management of tailings pore water through toe drains. Groundwater remedial action alternatives with ongoing active measures address groundwater plume clean up using some combination of a) removal, treatment, and disposal of groundwater contaminants; b) containment of groundwater; and/or c) passive *in situ* treatment.

All alternatives rely on controls over access to and use of groundwater, over different areas for each alternative, through property ownership to prevent exposure and use of groundwater until groundwater constituent concentrations are less than License groundwater protection standards. It should be noted that the No Action Alternative under this analysis assumes the ACL Application is denied and groundwater corrective action continues, which differs from a No Action alternative under CERCLA.

The primary components and processes of each corrective action alternative are summarized in the following subsections and establish the conceptual design for predictive modeling of their long-term performance using the calibrated groundwater model. A summary of the alternatives is also presented in Table 4.2-2. For all alternatives, hydrologic inputs include recharge from precipitation, Large and Small Tailings Pile seepage rates, and groundwater corrective action injection. Hydrologic sinks (water removal from the system) include groundwater corrective action water collection (withdrawal) and pumping from municipal wells screened in the San Andres-Glorieta aquifer within the model domain.

4.2.4.1 Alternative 1 – Groundwater Containment and Removal

This alternative constitutes the No Action condition under which this ACL Application is denied and the existing groundwater Corrective Action Program continues. This No Action Alternative differs from that considered under EPA guidance in that NRC considers No Action to be disapproval of the requested License amendment and continuation of the approved corrective action program while EPA considers a No Action alternative to be a walk away scenario where no additional remedial action is undertaken.

Control over access to and use of impacted groundwater are required for this alternative. This control and currently in-place municipal water supplies prevent current and potential future exposures while active measures remove and treat impacted groundwater. Under this alternative, final closure, License termination and transfer to the long-term custodian does not occur, per the restrictions in Criterion 1 and Criterion 6(7) to Appendix A of 10 CFR 40, which require permanent isolation of tailings and associated contaminants without ongoing maintenance.

Under this No Action Alternative, long-term contaminant sources to groundwater persist. Tailings drain down and long-term seepage continues for the entire 1,000-year compliance period (see Section 2.1). Current tailings seepage rate is calculated to be approximately 4 gpm and the base-case long-term steady state seepage rate, which equilibrates with the calculated infiltration rate through the approved reclamation cover (Stantec, 2025) is estimated to be 0.04 gpm for the entire Large Tailings Pile footprint (see Figure 3.1-4). The long-term average uranium concentration for tailings seepage is calculated to be 5.16 mg/L and 13 mg/L for molybdenum (Hydro-Engineering, 2025).

In Alternative 1, the final tailings cover is placed on the Large Tailings Pile within the first three years of predictive modeling (by model year 2027). The Small Tailings Pile is not reclaimed and remains available for disposal of 11(e)2 byproduct materials that cannot be released from the site for the duration of the alternative. Seepage from the Small Tailings Pile is based upon the groundwater model areal recharge rate of approximately 2% of precipitation.

The current groundwater corrective action program continues with the use of extraction wells, injection wells, and injection trenches to hydraulically contain and remove the dissolved constituents in groundwater. The wells utilized for extraction and injection are based upon the operation of the program in 2024, but scaled proportionally to the sustainable rate predicted by the model. Due to the decline in water levels in the system, the treatment rate in this alternative declines asymptotically to approximately 100 gpm as shown in Figure 4.2-1 and Table 4.2-3. Table 4.2-4 presents total volumes collected, injected, and produced as wastewater.

Recovered groundwater is treated *ex situ* in the existing RO treatment system, evaporation in the lined ponds (EP2 and EP3). The initial groundwater collection rates and associated commensurate treatment rates are based upon the upper limits of evaporative capacity of the existing evaporation ponds to manage wastewater production rates including the spray evaporation systems, and to handle the untreatable waste streams from the treatment systems. The treatment efficiency of the RO Plant (approximately 81 percent; 19 percent of process stream is waste) is consistent with historic operational performance (see Section 4.1 and Table 4.1-2). This alternative assumes no use from the San Andres-Glorieta aquifer as supplemental injection water

Wastewater would be disposed by evaporation in the lined ponds. Waste solids from water treatment are disposed in the lined evaporation pond EP1 located on the Small Tailings Pile or directly in the Small Tailings Pile.

The membrane filtration (RO) system and evaporation ponds remain operational for the duration of the alternative. The characteristics of the extracted water, treated water, and wastewater are presented in the Annual Performance Report (HMC and Hydro-Engineering, 2025).

4.2.4.2 Alternative 2 – Groundwater Containment and Removal and *In Situ* Treatment

Like Alternative 1, Alternative 2 includes operation of extraction wells, injection wells, and injection trenches to hydraulically contain and remove the dissolved plumes. Alternative 2 differs from Alternative 1 only in that it replaces long-term collection, injection and *ex situ* treatment with an *in situ* hydroxyapatite permeable reactive barrier in year 36 of corrective action. Control over access to and use of impacted groundwater within the control boundary are also required for this alternative. This control of groundwater and current alternative water supplies prevent current and potential future exposures while active measures remove and treat impacted groundwater. The permeable reactive barrier would require replacement approximately every 50 years for the duration of the 1,000-year period, thus final closure, License termination and transfer to the long-term custodian for this alternative does not occur, per the restrictions in Criterion 1 and Criterion 6(7) to Appendix A of 10 CFR 40, which require permanent isolation of tailings and associated contaminants without ongoing maintenance.

Active remediation in the On-Site area occurs for 36 years through collection and injection wells, after which a passive *in situ* permeable reactive barrier is placed in the On-Site area downgradient of the Large Tailings Pile in the alluvium to mitigate long-term groundwater source constituent concentrations (Figure 4.2-2).

As with Alternative 1, long-term contaminant sources to groundwater persist. Tailings drain down and seepage rates and concentrations are the same as those for Alternative 1, described above. Also like Alternative 1, the final tailings cover would be placed on the Large Tailings Pile in by year 2027 of the predictive model runs. The Small Tailings Pile is not reclaimed and remains available for disposal of 11(e)2 byproduct materials that cannot be released from the site for the duration of the alternative.

The current On-Site and Off-Site groundwater corrective action programs continue with the use of extraction wells, injection wells, and injection trenches to hydraulically contain and remove the dissolved constituents in groundwater for 36 years. The 36 years of collection and injection is the predicted time from a previous model iteration to retract the On-Site area plume upgradient of the proposed permeable reactive barrier location. After 36 years of active On-Site groundwater remediation, the active On-Site collection and injection ceases, and an *in situ* hydroxyapatite permeable reactive barrier would be installed in the alluvium downgradient of the Large Tailings Pile to provide long-term treatment of the dissolved On-Site plume (Figure 4.2-2).

The permeable reactive barrier is installed to intercept groundwater constituent plume migration away from the Large Tailings Pile following the cessation of the On-Site active remediation. The proposed permeable reactive barrier is 2,750 feet in length and has an average depth of 41 feet, based upon fully penetrating the entire alluvial aquifer saturated thickness in this area. The hydroxyapatite injection components are calcium-citrate and sodium phosphate (Na_3PO_4) or similar reactants, which are installed in 138 injection wells spaced 20 feet apart. The injection components, when interacting post-injection in the alluvial aquifer, would create a reactive treatment zone of hydroxyapatite with a width of 40 feet. The permeable reactive barrier treatment efficiency was estimated to be 75.7 percent (the permeable reactive barrier removes 75.7 percent of the influent mass) and an effective capital life of 50 years based on an assessment of hydroxyapatite treatment of uranium in groundwater (See Appendix D to Appendix 4.2-B of this ACL Application).

The permeable reactive barrier would be installed in year 35 and would be replaced every 50 years for the duration of the 1,000-year period. At the end capital and effective treatment life of each permeable reactive barrier, the wells would be plugged and abandoned, and an entirely new permeable reactive barrier system would be installed immediately downgradient of the previous permeable reactive barrier, as continual renewal of the hydroxyapatite in a single location would lead to blocking the pore space and groundwater flow.

Collection and injection in the Off-Site areas are operated in the same manner as described for Alternative 1. Table 4.2-3 presents a summary of groundwater collection, injection, and wastewater production rates for this alternative. Table 4.2-4 presents total volumes collected, injected, and produced as wastewater. Similarly, wastewater and waste solids would be managed in the same manner as described for Alternative

1. All waste materials associated with operation and maintenance of the permeable reactive barrier would be placed in the Small Tailings Pile.

The RO Plant and On-Site corrective action collection and injection wells would be decommissioned after 36 years.

4.2.4.3 Alternative 3 – Alternate Concentrations Limits (ACLs)

Alternative 3 assumes the approval of ACLs, control of access to, and use of groundwater over the long-term area of plume migration by property ownership within the proposed control boundary, and monitoring of the dissolved plumes. The control boundary (Figure 1.5-1) circumscribes the area over which long-term control of access to and use of groundwater would be required under this alternative. The control boundary represents the groundwater point of exposure (POE) for this ACL Application and is a pragmatic construct, not a current physical boundary, used to identify and conservatively estimate potential future exposure concentrations. Control over access to and use of impacted groundwater within the control boundary are assumed present for this alternative. The control and current municipal water supply system prevents current and potential future exposures. Under this alternative, HMC would transfer property ownership within an NRC approved long-term care boundary to DOE as the long-term custodian upon license termination, although that future action is not part of this ACL Application. License termination and transfer to the long-term custodian could occur as no long-term active program maintenance is required to ensure protection.

Under Alternative 3, corrective action extraction and treatment of groundwater would cease upon approval of the proposed ACLs and final decommissioning and reclamation of the GRP groundwater corrective action infrastructure would be performed in accordance with the approved reclamation plan (AK Geoconsult and Jenkins, 1993). The primary activity in Alternative 3 is groundwater monitoring to confirm groundwater concentration remain below the approved ACLs. This alternative is modeled using natural attenuation of the current groundwater plumes.

4.3 Analysis And Comparison Of Corrective Action Alternatives

This section summarizes the detailed analysis of the corrective action alternatives included in Appendix 4.3-A, which is based on results from the calibrated base-case groundwater flow and transport model, described in Section 3.1, configured to represent each of the alternatives. A report detailing the development of the predictive groundwater flow and transport simulations for each alternative is presented in Appendix 4.2-B. The corrective action alternative predictive simulations use the calibrated base-case model runs to generate best-estimate predictions of long-term flow and transport of constituents in groundwater. As discussed in more detail in Section 5.1, bounding-case model simulations, which result in more conservative predictions of POE concentrations than those produced from the base-case models, are performed to support calculation of proposed ACLs for the Proposed Action selected from the following analysis. The following sections summarize the results of that modeling and analysis of the alternatives using eight evaluation criteria and compare the relative performance of each alternative for each evaluation criterion.

As will be demonstrated in the following sections of this chapter, the past 49 years of corrective action, final surface reclamation, and the control of groundwater access afforded by the Proposed Action have reduced the groundwater POE concentrations to ALARA.

4.3.1 Evaluation Criteria

The evaluation of practicable corrective action alternatives, as identified in Section 4 of NUREG-1620 (NRC, 2003a) assesses "*…the technical feasibility, costs, and benefits of each alternative.*" The evaluation criteria evaluate the technical feasibility of the corrective action alternatives to assure protection of public health, safety, and the environment using the following criteria:

1. Protection of Human Health - Occupational Health and Safety
2. Protection of Human Health - Public Health and Safety
3. Protection of the Environment - Risks to Wildlife
4. Protection of the Environment - Preservation of Groundwater Resource
5. Implementation - Ability to Construct and Operate
6. Implementation – Administrative Feasibility
7. Implementation – Restoration of Resource
8. Implementation - Source Reduction and Control

These evaluation criteria are addressed qualitatively, as discussed below. In the following sections, each alternative is assessed as fully meeting, partially meeting, or not meeting each evaluation criterion. The corrective action objectives, summarized below, are addressed in these evaluation criteria:

- Prevent human ingestion of contaminated groundwater.
- Restore groundwater quality in the alluvial aquifer and the Upper Chinle, Middle Chinle, and Lower Chinle.
- Reduce seepage and migration of constituents from the tailing piles to groundwater.

The nominal costs (total undiscounted cost) and the present value (discounted costs) of each alternative's potential future cost has been identified to support demonstration that the Proposed Action has reduced exposure concentrations to ALARA (Section 4.5). Costs are not used as a criterion to select the Proposed Action. Cost bases for each alternative are presented in Appendix 4.3-B. Analysis of the costs and benefits for the Proposed Action is presented in Section 4.4.

4.3.1.1 Protection of Human Health – Public Health

Protection of human health is assessed considering both public health and worker occupational health associated with constructing and operating an alternative. Public health is assessed considering the human access pathway to groundwater and considering maximum predicted POE concentrations in relation to the License groundwater protection standards. Fully meeting the criteria for protection of human and environmental health means that all maximum POE concentrations are below License groundwater protection standards at and beyond the POE; not meeting the criteria means one or more constituent maximum concentration(s) are above the License groundwater protection standards at and beyond the POE.

4.3.1.2 Protection of Human Health – Occupational Health and Safety

Occupational health is assessed considering the overall exposure potential for implementing and operating each alternative. This considers the potential exposure workers can have throughout the duration of a given alternative action. The lowest criteria rating is assigned to the alternative with the highest opportunity for

exposure to workers, while the highest criteria rating is assigned to the alternative with the lowest opportunity for exposure to workers. The exposure opportunity is generally related to the amount of intrusive work in contaminated media, the duration of the action during which workers operating, maintaining or replacing treatment systems are needed, and the relative quantity of contaminated wastes generated and handled.

4.3.1.3 Environmental Protection - Risks to Wildlife

Protection of environmental receptors is assessed considering the type and duration of ecological exposure pathways to impacted groundwater and/or treatment wastes, as well as the overall consumption of groundwater related to implementing the alternative. The highest criteria rating is assigned to the alternative with no pathway for ecological exposure and no consumption of groundwater during the corrective action alternative; the lowest criteria rating is assigned to the alternative with the longest exposure duration to impacted groundwater and/or treatment wastes, and the highest consumption of groundwater during the corrective action alternative.

4.3.1.4 Environmental Protection - Preservation of Resource

Preservation of groundwater resource considers the amount of groundwater irrevocably removed from the local groundwater basin in the water treatment process as wastewater that cannot be re-injected or returned to the groundwater system. The highest criteria rating is assigned to the alternative with no pathway for ecological exposure and no consumption of groundwater during the corrective action alternative; the lowest criteria rating is assigned to the alternative with the longest exposure duration to impacted groundwater and/or treatment wastes, and the highest consumption of groundwater during the corrective action alternative.

4.3.1.5 Implementability – Ability to Construct and Operate

Implementability of each corrective action alternative is assessed with respect to four criteria; 1) the ability to construct and operate the designed alternative; 2) the administrative feasibility of implementing the alternative; 3) the ability to restore groundwater to License groundwater protection standards; and 4) the ability to reduce seepage and migration from the tailings. The highest criteria rating is assigned to each of the four implementability criteria for 1) easiest ability to construct and operate; 2) easiest ability to license; 3) that restores the most groundwater; and 4) that have the greatest ability to reduce sources of contamination and control its migration.

The ability to construct and operate the designed alternative is assessed qualitatively by considering such factors as the relative technical complexity of the alternative; the relative amount of demonstrated successful construction and operation of the technology in other applications; and the availability of materials and services needed to design construct and operate the alternative. The highest criteria rating is assigned to the alternative with the overall least technical complexity, largest amount of demonstrated successful construction and operation, and the fewest expected limitations on the availability of materials and services. The lowest criteria rating is assigned to the alternative with the overall highest technical complexity, least amount of demonstrated successful construction and operation, and the most expected limitations on the availability of materials and services.

4.3.1.6 Implementability – Administrative Feasibility

The administrative feasibility of implementing the alternative is assessed qualitatively by considering the permitting and/or licensing burdens associated with each alternative. The highest criteria rating is assigned to the alternative(s) with the overall least administrative burden and most precedents for permitting and/or licensing comparable actions; the lowest criteria rating is assigned to the alternative with the overall highest administrative burden and fewest precedents for permitting and/or licensing.

4.3.1.7 Implementability – Restoration of Resource

The ability to restore the groundwater to License groundwater protection standards is assessed by comparison of predictive modeling results for uranium transport. Specifically, the areas of the extent of uranium concentrations above the License Groundwater protection standards for all water-yielding units for the current period (2024 predicted groundwater conditions at end of model calibration), at 200 years and at 1,000-years of model simulation are identified for each alternative. These areas are the projection to the ground surface of the isocontours of groundwater concentrations above the License groundwater protection standards for each water-yielding unit and represent the area over which control of access to groundwater would be needed for each alternative at each time frame. This approach is based, in part, on the idea that a potential water user could penetrate more than one water-yielding unit and, even if groundwater in a single water-yielding unit is restored to its protective standard concentration at a specific location, an underlying or overlying water-yielding unit that has groundwater that is not restored at that location would preclude use of groundwater from that area. In other words, for an area to be available for unrestricted access to groundwater, all groundwater constituent concentrations in all hydrostratigraphic units at a given location must be below their protective standards. The differences in areas between the present period and the predicted uranium distributions at 200 years and 1,000 years are used as a means for assessing the degree of groundwater restoration for assessment of the alternatives. The highest criteria rating is assigned to the alternative(s) with the overall greatest area of groundwater restoration (or least amount of overall plume expansion), the lowest criteria rating is assigned to the alternative(s) with the overall least area of groundwater restoration (or greatest amount of overall plume expansion).

4.3.1.8 Implementability – Source Reduction and Control

The ability to reduce seepage and migration from the tailings is assessed by predictive modeling of tailings seepage and related groundwater uranium concentrations. All alternatives assume the same final tailings reclamation covers are promptly placed and limit long-term seepage from infiltration of precipitation through the final cover. The impacts to groundwater from tailings seepage alone are evaluated independently from existing groundwater impacts by performing a model sensitivity run in which it is assumed there is no current groundwater impact and the tailings seepage is the only input to groundwater concentrations and mass. The sensitivity model is run for 1,000 years and the maximum extent of uranium in groundwater from tailings seepage alone is isolated and assessed. Since all alternatives share the same cover design and, therefore, the same control of this long-term source, this factor is not a discriminator consideration between alternatives. However, the engineered cover providing long-term source control of tailings seepage is a relevant factor addressing a remedial action objective and, therefore, is addressed as a criterion

4.3.1.9 Cost

The design of the corrective action alternatives is conceptual per NRC guidance in Chapter 4 of NUREG-1620 (NRC, 2003a), and the cost estimates are considered to be order-of-magnitude. The following costs are estimated for each alternative:

- Capital (construction) costs, including both contingency and professional/technical services
- Annual operation and maintenance costs
- Periodic costs, including decommissioning

The calculated present value of all future costs is developed to produce a common basis for comparison of costs that occur over different time periods. Cost information for each alternative includes a detailed cost estimate for each of the major cost elements. Appendices 4.3-A and 4.3-B provide details regarding calculation of the present value (discounted costs) of nominal (undiscounted) costs. The calculated present value of the future costs for each alternative are calculated using generally accepted accounting practices as described in detail in Appendix 4.3-A. The discount rates applied for these calculations are consistent with NRC guidance in NUREG-1757, Vol. 2 Rev. 2.

Contingency costs and project management costs are estimated and used to cover unknowns, unforeseeable circumstances, or unanticipated conditions that are not possible to evaluate from the data available at the time the estimate is prepared. Project management costs were estimated by applying percentages to the total cost of activities. The expected level of accuracy of the cost estimates ranges from minus 30 percent to plus 50 percent. Typical unit rates derived from work at the GRP and other sites were also used to estimate costs. A summary of assumptions and a description of the alternative components and timing used to estimate the capital cost for each alternative are presented in the detailed costs bases provided in Appendix 4.3-B.

4.3.2 Analysis of Alternatives

The following subsections provide a summary of the detailed assessment of the alternatives, presented in Appendix 4.3-A using the criteria described above. The predictive groundwater modeling results used to support this analysis in the following subsections are summarized from the detailed report on the predictive modeling presented in Appendix 4.2-B. The groundwater simulation timeframe of 1,000 years reasonably captures long-term effects of seepage from the Large Tailings Pile, existing groundwater contaminants, and physical and geochemical properties that affect contaminant transport, and is consistent with the requirements of Criterion 6(1)(i) of Appendix A to 10 CFR 40 to provide reasonable assurance of control of radiological hazards to be "….*effective for 1,000 years, to the extent reasonably achievable, and, in any case, for at least 200 years."*

4.3.2.1 Predictive Modeling of Alternatives

Calibrated (base-case) groundwater flow and transport models for each alternative (Appendix 4.2-B) were used to simulate changes in groundwater uranium concentrations for a 1,000-year period to support evaluation of the relative feasibility and efficacy of the three groundwater corrective action alternatives. The calibrated model was used to simulate the groundwater impacts of long-term sources of constituents to groundwater (Large Tailings Pile seepage and diffusion from the immobile domain) in isolation from current groundwater impacts. These model simulations were performed by assuming the current

groundwater has ambient uranium concentrations. The predicted groundwater concentrations that result from these two individual base-case model sources, in isolation from current groundwater impacts (existing groundwater impacts removed from models, so only impacts from current and future sources are modeled), allows assessment of the relative significance and impacts of each source.

The primary base-case predictive model inputs are summarized in Table 4.3-1. Large Tailings Pile seepage rates are illustrated in Figure 3.1-4 and are supported by tailings drainage modeling described in Appendix 4.2-B. Bounding-case modeling inputs for the Proposed Action used to conservatively calculate ACLs, discussed in Section 5.1 of this ACL Application, are also shown on Table 4.3-1.

4.3.2.1.1 Points of Exposure

The groundwater POEs are, herein, defined as the control boundary. This control boundary circumscribes the area over which control of access to and use of groundwater is proposed through property ownership within the proposed control boundary for the compliance period of up to 1,000 years, to the extent reasonably achievable, per 10 CFR Part 40, Appendix A, Criterion 6(1)(i). It is at this boundary where maximum potential future exposures that hypothetically could occur are assessed.

To assess representative maximum predicted groundwater concentrations along the control boundary, the boundary was broken into seven segments in order to avoid any bias in selecting a specific point along the boundary (Figure 1.5-1). These segments allow for identifying the maximum concentration along each segment across each water-yielding unit at any point in time in the 1000-year predictive model run. While These segments allow for the quantification of where the maximum concentrations occur, these locations are not physical monitoring wells currently in place.

4.3.2.1.2 Predicted Exposure Point Concentrations

Potential future groundwater exposure point concentrations for each alternative are developed by assessing base-case predicted maximum uranium concentrations in each water yielding unit at the seven POE segments along the identified control boundary, described above (Figure 1.5-1).

4.3.2.2 Analysis and Comparison of Alternatives

The following provides a summary of the detailed assessment of the alternatives, presented in Appendix 4.3-A. Figures 4.3-1 through 4.3-3 illustrate the predicted maximum extent of uranium in groundwater above the License uranium groundwater protection standards for each water-yielding unit or mixing zone for the periods 2024, year 200, year 500 and year 1,000 of the simulation period for each alternative. In other words, these areas are the projection to the ground surface of the isocontours of groundwater concentrations above the License groundwater protection standards for each water-yielding unit and represent the minimum areas over which control of access to groundwater would be needed for each alternative at each timeframe. The differences in areas between (i) the present period, represented by 2024 groundwater uranium concentration distributions at the end of the model calibration, and (ii) the predicted uranium distributions at 200 years and 1,000 years, are used to assess the degree of groundwater restoration. This approach is based, in part, on the idea that a potential groundwater user could penetrate more than one water-yielding unit. Thus, even if groundwater within a single water-yielding unit were less than License groundwater protection standards at a particular surface location, groundwater in an underlying or overlying water-yielding unit beneath that same surface location would not necessarily comply with License

groundwater protection standards, precluding groundwater use there. In other words, for an area to be available for unrestricted access to groundwater, all groundwater constituent concentrations at a given location in all water-yielding units must be below the License groundwater protection standards.

None of the alternatives are able to fully restore the groundwater to the License groundwater protection standards in the 1,000-year time frame. Table 4.3-3 summarizes the calculated areas above the License groundwater protection standard for each water-yielding unit or mixing zone for the periods 2024, year 200 and year 1,000 of the simulation period for each alternative. These are the areas over which groundwater access must be controlled at different time periods, reflecting the areas over which groundwater access is restored. Alternative 1 restores the largest amount of area after 200 years (1.17 square miles) and over the 1,000-year period (1.48 square miles). Alternative 2 restores in the second largest total area after 200 years (0.38) and at 1,000 years (0.65 square miles). Alternative 3 results in the smallest area restored after 200 years (-0.13) and after 1,000 years (0.02 square miles) compared to the other alternatives. Alternative 3 results in control over access to groundwater of approximately 1.46 square miles more than Alternative 1 at 1,000 years.

Table 4.3-4 summarizes the maximum predicted uranium concentrations at any POE for all water-yielding units over the 1,000-year prediction for each alternative. All predicted maximum POE groundwater uranium concentrations are below the respective License groundwater protection standards for each water-yielding unit. The alternatives show few distinctions between concentrations observed as the POE boundary was drawn to encompass all site related impacts above the 0.03 mg/L MCL for uranium for the bounding case model run for uranium (see Appendix 4.2-B)

Table 4.3-5 summarizes the results of this analysis for the evaluation criteria. Overall, all the alternatives analyzed below provide reasonable assurance of protection of public health, safety, and the environment and are technically feasible. None of the alternatives are able to fully restore the groundwater to the License groundwater protection standards in the 1,000-year time frame. All alternatives rely on control over access to and use of affected groundwater, although the area over which these controls are required and the duration over which they are required vary between alternatives.

Although Alternatives 1 and 2 would remove contaminant mass from groundwater through active and/or passive treatment and reduce groundwater constituent concentrations to License groundwater protection standards in some but not all areas, these alternatives cannot fully restore all affected groundwater in all water-yielding units for the full compliance period of at least 200 years and, to the extent practicable, 1,000 years. Portions of the Chinle sandstone units are not remediated to License groundwater protection standards for the full compliance period with either Alternative 1 or Alternative 2. These long-term ongoing treatment operations would cause the permanent loss of billions of gallons of groundwater from the local hydrologic basin, as that water would be evaporated during the treatment of waste for disposal (Table 4.2-4). These alternatives would also require long-term use of evaporation ponds, with high concentrations of constituents, creating an exposure risk to wildlife that would not otherwise exist, because local groundwater is not accessible to wildlife.

Alternative 3 does not actively remove mass through treatment but rather relies on natural attenuation and property ownership, within the proposed control boundary, control on access to groundwater to ensure long-term public health protection. It thus does not require the permanent loss of billions of gallons of groundwater and does not create evaporation pond exposure pathways to wildlife or generate waste over

the long-term that requires handling and management. It is noted that the maximum POE groundwater uranium concentrations for this alternative are below the maximum contaminant level for drinking water of 0.03 mg/L for all units (Table 4.3-2 and Table 4.3-4).

4.3.2.3 Analysis of Long-Term Sources

Three additional sensitivity simulations were performed in order to assess the relative impacts on a range of input values for sources of uranium mass in the predictive model. The three evaluations are discussed in the following sections and are based on the simulations discussed in Section 4.5 of Appendix 4.2-B.

4.3.2.3.1 Large Tailings Pile Seepage Source Sensitivity

In order to address uncertainty behind future predictions of seepage rate and concentrations of seepage, a bounding case prediction was developed to accompany the base-case draindown model. The bounding case seepage prediction assumes a long term seepage rate of 2.4 gpm, a value 60 times higher than the base case prediction. In addition, it assumes the concentrations to reflect pre-flushing concentrations of 45 mg/L, a value 9 times higher than volume-weighted average concentration in the base case scenario. The evaluation showed the additional mass contribution from the conservative assumptions on seepage have little impact on the overall footprint exceeding site standards.

4.3.2.3.2 Increased Initial Mobile Domain Mass Beneath LTP and STP

The objective of this simulation was to assess the potential impact of the initial concentration condition in the alluvial aquifer at the GRP. This simulation amounts to a "what-if" scenario to assess the possibility that sampling has not adequately captured the upper end of concentrations beneath the LTP and STP. In this simulation, the initial uranium concentration in each alluvial aquifer cell within the footprint of the LTP and STP was increased by 25%. The evaluation showed that the increased mass has little influence on the spatial extent of concentrations above site standards, but does change the footprint of higher concentrations to a small degree within that footprint.

4.3.2.3.3 Back-Diffusion Source Sensitivity

The objective of this simulation was to assess the uranium concentrations that would result solely form the back diffusion from the immobile domain to the mobile domain. In order to isolate this influence, immobile domain mass was assumed to reflect the concentrations at the end of 2024, the LTP seepage and the mobile domain concentrations were assigned concentrations of 0.01 mg/L, the Chinle water-yielding units were assigned initial concentration values of 0.02 mg/L, and the SAG was assigned initial concentrations of 0.005 mg/L. The results of the evaluation showed that the effects from back diffusion are not significant as a source to the mobile domain, but they do present the potential to generate enough mass to exceed site standards in the vicinity of the LTP.

4.3.3 Summary and Selection of Proposed Action

All of the corrective action alternatives are technically feasible and provide long-term protection of public health, safety, and the environment. All alternatives rely on long-term control of access to and restricted use of groundwater to ensure no unprotective groundwater exposures occur, although the areas over which those controls are needed and the time over which those controls are needed vary by alternative. Table 4.3-5 summarizes the ranking of the eight assessment criteria identified in Section 4.3.1. Appendix 4.3-A presents the details analysis of these alternatives on which this summary is based.

Overall, Alternatives 1 and 2 rank similarly with respect to protection of human health, although Alternative 1 ranks the lowest of the alternatives for this criterion due to the potential for occupational exposures due to waste generation and handling associated with 1,000 years of operation, while Alternative 3 ranks the highest for this criterion as there are no additional wastes generated or managed and occupational health and safety risks are minimal in comparison to other alternatives.

Alternative 3 ranks higher than the other alternatives for environmental protection, as it does not develop any exposure pathways for ecological receptors, while Alternatives 1 and 2 both continue to have evaporation ponds and waste generation for extended periods, although best management practices are expected reduce potential wildlife impacts to acceptable levels. In addition, Alternative 3 ranks higher than Alternatives 1 and 2 for preservation of groundwater resource, as Alternative 3 does not require the loss of billions of gallons of groundwater as treatment waste.

Alternatives 1 and 3 have similar implementability rankings, while Alternative 2 has the lowest implementability ranking, primarily due to the unproven efficacy in the permeable reactive barrier technology under these groundwater constituent concentrations and hydrogeologic conditions. Alternative 3 has the highest relative implementability ranking of the three alternatives as there is (i) precedent for ACL approval with groundwater access controls (ii) there is no NRC precedent for Alternative 1 groundwater corrective action for many hundreds of years and (iii) no precedent for approval of Alternative 2 *in situ* passive treatment for centuries at uranium mill sites regulated under Tile II of the Uranium Mill Tailings Radiation Control Act. There are NRC-approved demonstration studies of passive *in situ* groundwater treatment systems at uranium mill sites regulated under Tile I of the Uranium Mill Tailings Radiation Control Act (managed by DOE), but none using a permeable reactive barrier with hydroxyapatite technology proposed by Alternative 2 have been applied for such an extended duration and at these groundwater constituent concentration levels.

The analysis and comparison of corrective action alternatives presented above identifies Alternative 3 as the Proposed Action. The costs and benefits of each corrective action alternative are further evaluated in Section 4.4.

4.4 Costs and Benefits of Corrective Action Alternatives

The following sections address the costs and benefits of groundwater corrective action alternatives considering the guidance in the NRC ACL Guidance (NRC, 1996), NUREG-1620 (NRC, 2003a), and NUREG-1757, Volume 2, Revision 2 (NRC, 2022a). Types of decommissioning costs and benefits that may be considered in ALARA analyses identified in NUREG-1757, Appendix N, Table N.1 (NRC, 2022a) include those outlined below. The current and projected resource value of the pre-contaminated groundwater and timeliness of remedy completion identified by NRC in NUREG-1620 are added to the list of benefits. The value of the groundwater lost to evaporation as untreatable wastewater is added to the list of costs.

- Benefits
    - Current and Projected Resource Value of the Pre-Contaminated Groundwater
    - Collective Dose Averted

    - Regulatory Costs Avoided
    - Changes in Land Values
    - Timeliness of Remedy Completion
    - Esthetics
- Costs
    - Remediation Costs (capital costs, operation and maintenance costs, decommissioning costs)
    - Additional Occupational/Public Dose
    - Occupational Non-radiological Risks
    - Transportation Direct Costs and Implied Risks
    - Environmental Impacts
    - Present Value of Groundwater Lost as a Treatment Waste Stream
    - Loss of Economic Use of Site/Facility

Further, NUREG-1757 indicates it is necessary to use a comparable unit of measure to compare benefits and costs of a remedial action, most commonly the unit of measure is the dollar with benefits and costs given a monetary value. However, NUREG-1757 makes the following acknowledgement:

Sometimes it is very difficult or impossible to place a monetary value on an impact. A best effort should be made to assign a monetary value to the impact, because there may be no other way to compare benefits to costs. However, there may be situations for which a credible monetary value cannot be developed. In these situations, a qualitative treatment may be the most appropriate. Qualitative analyses should be evaluated on their merits on a case-by-case basis.

Therefore, this analysis of the costs and benefits for the corrective action alternatives addresses the acceptance criteria for corrective actions identified in Section 4.3.3.3 of NUREG-1620 through quantitative and, where appropriate, semi-quantitative and/or qualitative analysis of the costs and benefits of the corrective action alternatives.

4.4.1 Benefits of Corrective Action

Pursuant to Section 3.3.3.2 of the NRC ACL Guidance (NRC, 1996), the benefits of implementing the identified corrective actions are weighed against the costs of performing (or not performing) such measures. Benefits of implementing the identified corrective action alternatives are evaluated considering:

"…the avoidance of adverse health effects, value of pre-contaminated ground-water resources, prevention of land-value depreciation, and benefits accrued from performing the corrective action."

Similarly, Section 4.3.3.3 of NUREG-1620 (NRC, 2003a), states the following.

"*The **direct benefits** of implementing the corrective actions have been determined by **estimating the current and projected resource value of the pre-contaminated ground water**. Estimates of pre- contaminated ground-water value should be based on water rights, availability of alternate water supplies, and forecasted water use demands. The value of a contaminated water resource **is generally equal to the cost of a domestic or municipal drinking water supply or the cost of water supplied from an alternate source to replace the contaminated resource**. The absence of available alternate water supplies increases the relative value of a potentially contaminated water resource. The **indirect benefits** are determined by assessing the **avoidance of adverse health effects** from exposure to contaminated water, the **prevention of land value depreciation**,*

*and any **benefits accrued from performing the corrective action**, including timeliness of remediation. The reviewer should verify the water yields; costs for developing alternate water supply sources; and legal, statutory, or other administrative constraints on the use and development of the water resources.*" [emphases added].

The following sections address quantifying the cost of domestic or municipal water supply for projected future groundwater demand as a measure of the direct benefit of groundwater restoration. Valuation of the pre-contaminated groundwater resources in this ACL Application considers:

- projected future water use demands
- the availability of alternate water supplies
- the estimated costs for providing domestic or municipal water supplies to meet the projected water use demands

As a conservative measure for this analysis, the projected groundwater demand and value of the pre-contaminated groundwater assumes that no alternate water supply is present and all permitted groundwater wells are used to meet estimated current and projected groundwater demand for the next 1,000 years.

4.4.1.1 Current and Projected Future Water Demand

Although projection of hypothetical future groundwater use demands is speculative because the future use of any of the property is uncertain, this ACL Application identifies reasonable and conservative estimates of current and projected future water use demand to value the groundwater resource. As discussed in Section 1.2.3, current groundwater uses in the proposed control boundary outside the HMC-owned land currently include:

- Irrigation for crops (forage; e.g., alfalfa)
- Domestic uses

Future groundwater use demand for the area within the proposed control boundary is projected based on estimated current groundwater use demand and assumes that demand change would be proportional to projected population change over the next 1,000 years. Section 1.2.2.2 of this ACL Application and the Environmental Report identify the historical population trends and current population of McKinley County, Valencia County, and Cibola County since 1900. Overall, the Valencia County area from which Cibola County was formed in 1981 has experienced an annual average population growth rate of 3.75 percent. Cibola County area has experienced a net annual population decrease of 0.23 percent since the county was formed in 1981. Therefore, projected future groundwater demand is assumed to escalate the current groundwater use demand for each water use type (e.g., domestic, irrigation, stock watering, etc.) by the range of changes in annual population rates. Appendix 4.4-A provides a detailed basis for estimating future groundwater use demand and the net present value of that projected future demand. The following text summarizes the information in that appendix.

No current groundwater use or demand exists on HMC-owned land associated with the GRP. All use of the groundwater on HMC-owned land associated with the GRP is related solely to groundwater corrective action and monitoring. HMC will not have future water use demands on the lands associated with the GRP after closure.

Current groundwater use demands are estimated herein based on active groundwater well permits and estimated use rates for each permitted well use type. The proposed control boundary area for this estimate of water use demand encompasses the following areas, illustrated in Figure 1.2-57.

Review of the New Mexico Office of the State Engineer database and recent aerial photography using Google Earth and ArcGIS for the areas identified in Figure 1.2-57 identified 20 active well permit files that are located on land not controlled by HMC and that have specified water diversion allocations, visible evidence of use, and evidence of infrastructure allowing beneficial use of groundwater from the associated wells. The number of wells for each well use type are summarized in Table 4.4-1 (See Appendix 4.4-A for specific New Mexico Office of the State Engineer database data set). The records considered include only active well permit files. Inactive permit files, which are those files with canceled or expired permits that have been otherwise closed, have been removed from the data set.

Active well permit file types identified within the area described above include the number of well permits and following uses.

- 19 Domestic water supply wells (DOM, MUL, SUB)
- 1 Irrigation water supply well (IRR)

There are no permitted stock water wells with water diversion allocations or with confirmed infrastructure for beneficial use within the control boundary. All properties with active well permits have access to and have been connected to the existing municipal water supply lines from the Village of Milan, New Mexico as part of an earlier corrective action implemented by HMC. The State of New Mexico has established a legally enforceable prohibition against the drilling of new, replacement, or supplemental wells within the proposed control boundary, precluding installation of new wells and replacement of existing wells after their functional life ends (estimated to be approximately 50 years) for most of this area. While HMC has demonstrated serious and good faith efforts to procure all the land within the proposed boundary, this analysis assumes that the existing permitted wells remain functional and projected water demand growth from these wells can be met over the next 1,000 years. This is a highly conservative assumption that will over-estimate projected groundwater demand and, consequently, the value of the pre-contaminated groundwater based on projected future demand.

No reported groundwater use rates for the active well permits were identified from State records. Therefore, estimates of current and projected future groundwater use rates for each use type are based on the following observations and assumptions and approach (also see Table 4.4-2):

HMC-Owned Land

- No current or projected future groundwater use demand

Private Parcels

- Active well permits for irrigation wells (IRR):
  - Access to and use of the SAG aquifer for irrigation is unaffected by the proposed action and the alluvial aquifer and the Chinle Aquifers are incapable of sustaining the pumping rates required crop for crop irrigation. Therefore, this analysis does not consider irrigation water use for valuation of the water resource.

- Active well permits for domestic water supply:
  - *Domestic wells (DOM):*
    - Assume each well supports one household of three persons
    - Assume water use (cooking, bathing, lawns and gardens, etc.) are supplied by groundwater
  - *Multifamily wells (MUL):*
    - Water resource allocation is 3-acre feet per year or 2,678 gallons per day. This will support 9 households of 3 persons with a 100 gallon per day per person demand per EPA: https://www.epa.gov/watersense/how-we-use-water
  - *Subdivision wells (SUB):*
    - One of the two subdivision well permits conveyed water rights, but no well was ever installed, and the application was withdrawn in 1988.
    - The other subdivision well permit authorized a well in the SAG aquifer, which is not impacted by the Site. Therefore, this analysis does not consider subdivision water use for valuation of the water resource.

Table 4.4-3 summarizes the projected groundwater use volumes and values for domestic water well use based on the assumptions and approach described above. The basis of estimate for these volumes and values are provided in Appendix 4.4-A.

4.4.1.2 Availability of Alternate Water Supplies

Municipal water is currently available and is supplied by the Village of Milan for all of the properties with permitted wells within the control boundary shown on Figure 1.2-57. The water supply wells for the Village of Milan are located several miles to the south and outside the area of the proposed control boundary. A 2018 New Mexico Office of the State Engineer Order restricts the permitting and drilling of wells for new appropriations, or replacement or supplemental wells, and restricts the permitting of any change to the point of diversion of any existing wells within the boundaries defined (Figure 1.2-56). The order is stated to be in effect in perpetuity or until groundwater concentrations decrease to levels less than Water Quality Control Commission standards.

4.4.1.3 Alternate Domestic/Municipal Water Supply Costs

The cost for an alternate water supply is estimated based on the cost to provide municipal water supplied by the Village of Milan, New Mexico for the current and projected future groundwater demand. Table 4.4-4 presents the 2026 water rates for the Village of Milan, New Mexico. The estimated range of potential future demand is based on the long-term annual population growth rate of 3.76 percent, no population growth, and short-term annual decrease of -0.23 percent.

Municipal water rates are assumed to increase annually over the next 1,000 years, based on an estimated annual inflation rate of 3.16 percent (approximate annual average inflation from 1913 through 2026). Water use costs are assumed to be incurred monthly for each household. The present value of the monthly

payments from all households for each water use type is calculated using a discounted cash flow analysis, based on the following equations.

Percent Cash Flow Discount = $\frac{1}{1+(r/n)^{(n \times y_f)}}$ [Equation 4-1]

Where:

r = Annual discount rate

n = Number compounding periods per year (12)

y_f = Year fraction of total period (the fraction of the year represented by the number of whole days between the start date and the date of the monthly payment)

[Equation 4-2]

Present value of monthly payments = sum of (Percent Cash Flow Discount x Monthly Payment Amount)

Table 4.4-3 summarizes the nominal water use cost (total dollar amount) and presents the value of the monthly water use payments over the next 1,000 years, based on the estimated range in potential population growth rates. Appendix 4.4-A includes an electronic copy of the Microsoft Excel spreadsheet that sets forth the calculations underlying this cost determination. Water resource values are presented as nominal values (no annual discounting) and as present worth values calculated using both 3 percent and 7 percent annual discount rates.

These calculations indicate that the conservative upper bound on present value for the cost of supplying municipal water supply for all the projected future water use demands over the next 1,000 years for the high growth rate and 3 percent discount rate assumptions is approximately $1.6 million. The present value of the cost to supply an alternate water supply for the low growth rate assumption is approximately $0.148 million. If the low end of the estimated population change rate is assumed (-0.23 percent population change per year), groundwater demand for domestic uses will cease within 480 years, (Appendix 4.4-A).

These estimates are considered to conservatively bound the pre-contaminated value of this groundwater resource for the following reasons. First, this analysis is based on the conservative assumption that all existing permitted wells and groundwater diversions remain in operation for 1,000 years despite a State of New Mexico prohibition on installing new wells or replacing the existing wells after their functional life ends. Second, this analysis assumes that the current permitted domestic groundwater wells are the sole source of water supply, even though all properties within the proposed control boundary are connected to the municipal water supply and there is no evidence of groundwater well use.

4.4.1.4 Indirect Benefits of Groundwater Corrective Action (All Alternatives)

Indirect benefits of groundwater restoration are assessed by considering the averted radiological dose from exposure to contaminated water, the prevention of land value depreciation, and any other benefits accrued from performing the corrective action, including improvement to local aesthetics and timeliness of remediation. These indirect benefits are addressed below. A technical memorandum that calculates benefit of averted radiological dose for each of the three corrective action alternatives is included as Appendix 4.4-

B. Comparison of these benefits support assessment of the differences in indirect benefits between alternatives.

4.4.1.4.1 Avoided Adverse Health Effects: Radiological

Benefit of averted radiological dose from exposure to the constituents in groundwater is primarily related to avoidance of dose from the direct ingestion pathway through drinking water. Although other groundwater exposure pathways do contribute to total dose and are included herein, drinking water provides by far the greatest dose of all pathways. NRC guidance provided in NUREG-1757 identifies the following equation for calculation of the benefit derived from averted radiological doses (NRC, 2022a). The benefit is calculated as present worth dollars from the averted dose to the entire affected population over 1,000 years. The pathways considered for calculation of averted dose are for the resident gardener scenario and include the drinking water pathway, and consumption of vegetables irrigated with contaminated water.

$B_{AD} = V_{AD} \times PW(AD_{Collective})$ [Equation 4-3]

Where B_{AD} = benefit from an averted dose for a remediation action, in current U.S. dollars

V_{AD} = value in dollars of a person-rem averted (see NUREG/BR–0058; NRC, 2017b and NUREG-1757; NRC, 2022a)

$PW(AD_{Collective})$ = present worth of a future collective averted dose

The most recent version of NUREG-1530 (NRC, 2022) identifies a value in dollars of a person-rem averted (V_{AD}) of $5,200 per person rem averted in 2014 dollars. This equates to approximately $7,230 per person rem in 2026 dollars using the Bureau of Labor Statistics consumer price index inflation calculator (Bureau of Labor, 2022). The present worth of a future collective averted dose [$PW(AD_{Collective})$] is calculated using a more complex equation, as described in detail in Appendix 4.4-B, but generally calculates the discounted total population dose in person-rem from cumulative groundwater exposure over 1,000 years. NUREG-1530, Rev.1 (NRC, 2022b) also recommends varying the dollar per person rem conversion factor by plus or minus 50 percent. This sensitivity analysis is presented in Appendix 4.4-B but only the base case results are presented here.

The radiological constituents considered in this ACL Application that are above the License groundwater protection standards are combined radium-226 and 228, thorium-230, and uranium. Combined radium-226 and 228 is present at concentrations above License groundwater protection standards only directly under the tailings piles and is below the MCL of 5 pCi/L beyond the POC. Similarly, thorium-230 is present in concentrations greater than License groundwater protection standards only directly under the tailings piles and is present in concentrations near the License groundwater protection standard only a few additional isolated wells. Future transport of these constituents to the existing potential domestic well locations within the proposed control boundary, during the functional life of those wells, and at concentrations above the protective standards, is not reasonably expected, given average groundwater flow rates and geochemical mobility in this environment (see Section 1.3.2.6.4). Therefore, uranium is the only radioisotope for which corrective action is assumed to contribute to averted dose value. No methods for calculating the benefit for avoided dose to non-radiological and non-carcinogenic hazardous constituents are known, therefore no value is attributed to their avoided toxicological dose.

A review of the New Mexico Office of State Engineer records identifies 16 active domestic well permits (DOM) and one multifamily domestic use well permit (MUL) within the proposed control boundary, the residences associated with these well permits all have access to the existing municipal water supply lines (Figure 1.2-57). Each domestic well (DOM) is assumed to support a household of three persons, the average household population for New Mexico (see Section 1.2.2.2). The multifamily domestic well permit (MUL) has an annual water resource allocation of 3 acre-feet (1.89 gallons per minute or 2,678 gallons per day), which is sufficient to support 9 households of 3 persons at a demand rate of 100 gallons per person per day. Therefore, the estimated population with a current or potential future exposure potential within the control boundary is estimated to be 27 households or 75 persons. This is the population for whom doses could be averted if the groundwater were remediated under each of the alternatives. However, after HMC completes anticipated land acquisitions, there will be no exposed population within the proposed control boundary. In addition, the wells currently present cannot be replaced given of the 2018 State of New Mexico Order prohibiting new or replacement wells in this area (NMOSE, 2018). Therefore, although HMC considers potential future exposures at these locations for 1,000 years, this scenario is highly conservative to the point of being unreasonable. However, it represents the maximum potential benefit to be derived if full groundwater restoration were to be permanently achieved.

The dose and related risks from a unit concentration of exposure to uranium in groundwater is calculated as presented in Appendix 3.5-A. The unit dose and risks are then used to calculate the doses and risks from exposure to the predicted average concentrations over the next 1,000 years at the 16 domestic wells and a single multifamily domestic use well identified from the records search. Table 4.4-5 summarizes the calculated total effective dose from exposures for each alternative, as developed in Appendix 4.4-B. Table 4.4-5 also presents the calculated $PW(AD_{Collective})$ in person-rem as well as the calculated values of B_{AD} in dollars for each alternative.

The calculation of the benefit of averted dose for implementing each alternative identifies that the benefits range from $34,958 (Alternative 1, 7 percent discount rate) to $1.57 million (Alternative 3, 3 percent discount rate). The calculations developed in Appendix 4.4-B identify the present worth of averted dose for Alternative 1 to be $4.84 per person rem (7% discount rate) and $217.27 per person rem for Alternative 3 (3% discount rate).

4.4.1.4.2 Prevention of Land Depreciation

Assessment of the amount or likelihood of land value depreciation for various remedial action alternatives is subjective and qualitative. The following assessment discusses factors potentially affecting land value, the likelihood that they will do so, and the estimated extent of any adverse effects.

Factors affecting potential land depreciation considered herein include proximity to the reclaimed tailings impoundments and the potential for adverse perception based on historical land use, although remediated, and the perception that groundwater remains affected under some alternatives. The presence of, and proximity to, reclaimed tailings impoundments and groundwater impacts are considered the most significant factors potentially affecting land value depreciation. Because the presence of reclaimed tailings piles applies to all alternatives, this is eliminated as a factor for discriminating between alternatives. However, it is acknowledged that it is difficult to quantify and discriminate between land value impacts from proximity to the tailings piles and any such impacts attributable instead to the potential presence of groundwater impacts, even though groundwater is not accessible by surface users.

The potential for adverse perception of land value based on historical land use (milling) also applies to all alternatives even though the surface will be remediated to standards for unrestricted surface use. As a result, this factor is also eliminated for discriminating between alternatives.

Therefore, the principal remaining factor potentially affecting land value depreciation is based on an adverse perception from the presence of groundwater contamination and the inability to use local groundwater. Spatial limits of existing groundwater impacts and potential future restrictions on groundwater use are all within the control boundary.

Under Alternatives 2 and 3, groundwater constituent concentrations will remain above License groundwater protection standards over the long-term in all groundwater bearing units within the proposed control boundary. Alternative 1 requires approximately 200 years to reduce concentrations of constituents in the alluvial groundwater to within License groundwater protection standards in areas beyond the footprints of the Large Tailings Pile and Small Tailings Pile. Alternative 1 will not reduce constituents in groundwater to below License groundwater protection standards in portions of the Chinle sandstone units. Although access to and use of groundwater is not permitted under any of these scenarios, the presence of groundwater use restrictions and the proximity to the reclaimed tailings makes the likelihood of adverse perception and associated adverse impacts on land values high. Table 4.3-5 identifies the areas of affected groundwater for each alternative at different times. The differences in areas requiring groundwater access controls between the alternatives are not considered sufficiently different to indicate a difference in adverse perception and their impact on land value between the alternatives. Therefore, the relative adverse impact of adjacent property values is, though not specifically quantified, considered moderate for all alternatives.

4.4.1.5 Other Potential Benefits of Corrective Action

Two additional potential benefits are the timeliness of decommissioning and closure and the avoidance of aesthetic impacts from an alternative. Alternatives 1 and 2 would be operated for 1,000 years. Under these two alternatives, final closure and License termination and transfer would likely not occur, due to NRC historical practice of only transferring sites without active remedial action programs, and the restrictions in Criterion 1 and Criterion 6(7) of Appendix A to 10 CFR 40, which require that disposal areas are closed without needing ongoing maintenance. Alternative 3 supports final closure and License termination and transfer, which is estimated to be completed in approximately five years after ACLs are approved. The comparison of the relative timeliness of remedy completion between alternatives is presented in Table 4.4-6.

Differences in aesthetic impacts (e.g., noise, visual impacts) between the different alternatives are addressed qualitatively. Alternatives 1 and 2 would both operate for 1,000 years with comparable levels of labor effort and site activities for the first 36 years. Alternative 1 requires full time staff and treatment facilities operation for the full 1,000 years while Alternative 2 implements passive *in situ* treatment after year 36, which would allow substantially decreased surface activities and staff but would still require replacement of the permeable reactive barrier every 50 years and annual monitoring and inspections, resulting in lower relative aesthetic impacts compared to Alternative 1. Implementation of Alternative 3 would allow for the least relative aesthetic impacts due to the timeliest completion of decommissioning and surface reclamation. The comparison of the relative aesthetic impacts between alternatives is presented in Table 4.4-6.

4.4.2 Costs of Corrective Actions

Pursuant to NUREG-1757 Appendix N (NRC, 2022a), the benefits of implementing the corrective actions are weighed against the costs of performing such measures, such as the direct costs of implementing the corrective action alternatives include remedial action costs (capital costs, operation and maintenance costs, and decommissioning costs), as well as the indirect costs of additional occupational and or public dose, costs of occupational and transportation risks associated with each alternative, potential environmental impacts, and potential loss of economic use of the GRP. In addition, groundwater permanently removed from the hydrologic system has value and its irretrievable loss has an associated cost. An example of groundwater that will be lost are the waste brines produced from reverse osmosis. For the different alternatives, this represents permanent consumption of the groundwater resource for which a monetary value can be calculated.

Potential benefit in averted public radiological dose between alternatives has been addressed in Section 4.4.1. Therefore, the potential costs associated with incremental public doses as discriminators between alternatives and monetization of those incremental costs is not developed herein.

Conceptually, the potential occupational exposures and associated doses from installation of the groundwater recovery systems would be extremely minor, for the following reasons:

- The proposed alternatives are located outside the area of active surface remediation; therefore, contaminant concentrations in surface and subsurface soils would be expected to be below the established soil cleanup derived concentration guideline levels (DCGLs).
- Uranium concentrations in groundwater and limited pathways for exposure (principally dermal contact) would be largely mitigated by implementation of a radiation work permit with appropriate personal protective equipment, personnel radiation safety training, and exposure monitoring.

Therefore, the total and differential monetary cost of potential occupational exposure between the remedial action alternatives are expected to be extremely small and not a material discriminator between alternatives. However, qualitative discussion of the relative costs associated with radiological, non-radiological, and transportation risks for each alternative is presented below.

4.4.2.1 Direct Remedial Action Monetary Costs

Capital costs, operating and maintenance costs, and decommissioning and reclamation costs for each corrective action alternative are presented in Section 4.3.1.6 and are summarized in Table 4.3-6 and Table 4.4-6. Monetized costs also include the present value of groundwater pumped from the local water-yielding units but permanently lost to evaporation as untreatable waste stream, which are calculated in the same manner as the calculated value of the pre-contaminated groundwater resource presented in Appendix 4.4-A. A detailed basis for the capital costs, operating and maintenance costs, and decommissioning and reclamation each alternative is included in Appendix 4.3-B. Calculation of the present value of all future costs associated with each alternative is developed accounting for the time value of money using general accepted accounting practices as discussed in Appendix 4.3-A.

Overall, present value costs for the alternatives range from $20.7 million (Alternative 3, 7 percent discount rate) to $249 million (Alternative 1, 3 percent discount rate). Alternatives 1 and 2 have undiscounted costs more than one hundred times that of Alternative 3. For the range of discount rates evaluated, the net present value for Alternative 1 is 9.3 to 10.5 times higher than Alternative 3, and Alternative 2 is 4.8 to 8.4 times

higher than Alternative 3. Alternatives 1 and 2 have actions that are not consistent with final site closure requirements for no active maintenance, precluding License termination and transfer to the long-term custodian, and do not provide permanent groundwater restoration of all areas. Alternative 3 establishes conditions consistent with the final site closure requirement of no active maintenance and would not preclude License termination and transfer to the long-term custodian. Additionally, Alternative 3 provides the requisite reasonable assurance of long-term protection through modified compliance limits, monitoring, restriction of groundwater use through access controls, and long-term governmental custodial care, but does not restore the groundwater.

4.4.2.2 Occupational Non-radiological Risks and Transportation Risks

Costs associated with non-radiological occupational risks and transportation are addressed qualitatively. These costs are associated with monetizing the occupational risks from worker hours needed to install, operate, and decommission these alternatives. These risks relate to the occupational hazards of transporting equipment and materials to the GRP, as well as installing, operating and decommissioning the equipment. Table 4.4-6 summarizes the capital costs, operation and maintenance costs and periodic costs for each alternative. Although the bases for occupational risk-related monetized costs are not developed in Appendix 4.4-A on a worker-hour basis, their relative direct costs can be used as a first order estimator of relative person-hour efforts and, therefore, person-hour labor risks. Using this approach, Alternative 1 would involve the relatively highest occupational risk, while implementation of Alternative 3 would have the lowest relative occupational risk, as it involves primarily administrative activities with only minor occupational field actions over a substantially shorter period relative to the other alternatives.

Alternatives 1 and 2 involve the installation of groundwater recovery systems, operation of water treatment and waste management systems, and/or installation and replacement of permeable reactive barriers for 1,000 years. These two alternatives have higher potential for non-radiological occupational and transportation risks than Alternative 3, which does not rely on long-term operation and maintenance of active or passive treatment systems but rather on monitoring, inspections, and property ownership within the proposed control boundary.

To facilitate assessment of the relative magnitude of potential occupational non-radiological and transportation risk, each alternative is given a relative rank for occupation and transportation related risk from high to low, as summarized in Table 4.4-6. Although this qualitative assessment of risks does not afford quantification of the monetary benefits between the alternatives, HMC believes it is evident that the likely increments in those monetary benefits, given the scale of actions and associated labor hours for each alternative would not likely be a substantive discriminating factor between the alternatives and this qualitative assessment is sufficient to support decision making.

4.4.2.3 Environmental Impacts

Environmental impacts associated with each alternative vary based on the scope of the alternatives and are addressed qualitatively herein. Overall, the potential environmental impacts associated with the corrective action alternatives include irrevocable consumption of groundwater as a treatment waste, the areas of land disturbance, noise, dust, odor, and visual and aesthetic impacts.

Alternatives 1 and 2 involve active mitigations that include roughly comparable land disturbances in the off-site areas for the duration of both alternatives, while Alternative 3 has no additional land disturbance.

Both Alternatives 1 and 2 permanently consume over a billion of gallons of groundwater (over 12 billion gallons for Alternative 1) as treatment waste, which represent substantial portions of potential future groundwater demand and substantial portions of the calculated groundwater resource value, as described in the following sections, while Alternative 3 requires no further consumption of groundwater. Alternative 1 has greater land disturbance in the on-site areas due to the need for active removal, containment, treatment, and disposal systems for 1,000 years while Alternative 2 has lesser surface disturbance due to the need for active removal, containment, treatment, and disposal systems for only 36 years. Alternative 2 does require periodic surface disturbance every 50 years for replacement of the permeable reactive barrier over the entire 1,000-year compliance period but these impacts are qualitatively considered lesser than those in Alternative 1 due to the absence of active annual operations and maintenance tasks, which would result in relatively lower overall area of land disturbance, noise, dust, odor, and visual and aesthetic impacts.

Implementation of Alternative 3 has the least relative environmental impact as it only involves the decommissioning of unused monitoring wells and routine monitoring. To facilitate assessment of the relative magnitude of potential environmental impacts, each alternative is given a relative rank from highest (1) to lowest (3), as summarized in Table 4.4-6. Alternative 3 is ranked as having the lowest relative environmental impacts (3) due to the smallest scope and duration of surface activities while Alternatives 1 and 2 are ranked as having low to moderate relative environmental impacts (2) due to their large scope and duration of surface activities.

Environmental impacts are addressed in the context of the NRC requirements under 10 CFR Part 51 in the Environmental Report, that accompanies this ACL Application according to the requirements of Criterion 11(c) to Appendix A of 10 CFR Part 40.

4.4.2.4 Consumption of Groundwater Resources

Alternatives 1 and 2 both involve the removal and *ex situ* treatment of groundwater, Alternative 2 also includes the long-term periodic replacement of the passive *in situ* permeable reactive barrier treatment of groundwater. Operational performance data indicate that *ex situ* treatment of Off-Site groundwater with reverse osmosis treatment has an operational efficiency of 81 percent (19 percent is waste). The wastewater volumes of untreatable groundwater are irretrievably lost from the hydrologic system. Table 4.2-3 summarizes the rates and volumes of groundwater collected for treatment and the rates and volumes of wastewater requiring irretrievable disposal by evaporation. Alternative 1 collects over 64 billion gallons of groundwater which results in approximately 12 billion gallons of waste groundwater permanently consumed from the hydrologic system while Alternative 2 collects approximately 6.5 billion gallons and results in approximately 1.2 billion gallons of wastewater. Alternative 3 does not result in any future consumption of groundwater.

Using the same methods applied for estimating the value of the pre-contaminated water resource (based on projected groundwater demand discussed in Section 4.4.1 and Appendix 4.4-A), the present value of groundwater permanently consumed as evaporated wastewater can be quantified as a potential cost. Future groundwater removal rates and wastewater generation rates for each alternative are identified Table 4.2-3. If the wastewater was replaced by municipal water supply at the municipal water rates, the present value of that future supply ranges from $1.78 million dollars for Alternative 2 at 7 percent discount rate and $3.76 million dollars for Alternative 1 at a 3 percent discount rate.

The consumed groundwater from Alternative 1 represents:

- Approximately 23 percent of the 1,000-year high projected groundwater demand (12.19 billion gallons consumed ÷ 54.0 billion gallons of demand; see Tables 4.2-3).
- Approximately 445 percent of the 1,000-year no population growth projected groundwater demand (12.17 billion gallons ÷ 2.74 billion gallons; see Table 4.2-3).
- Approximately 2,017 percent of the 1,000-year low population growth projected groundwater demand (12.17 billion gallons ÷ 604.4 million gallons; see Table 4.2-3).
- 25.5 times greater than the present value of the 1,000-year low population growth rate projected groundwater demand with a 7 percent discount rate ($3,763,376 ÷ $147,524; see Table 4.4-6).
- 2.35 times greater than the present value of the 1,000-year high population growth rate projected groundwater demand at a 3 percent discount rate ($3,763,376 ÷ $1,603,374; see Table 4.4-6).
- These values indicate that under all population growth rate and monetary discount rate scenarios considered, the present value of the water removed from the aquifers and evaporated as wastewater for Alternative 1 exceeds the present value of the projected groundwater resource demand for the Alluvial and Chinle aquifers.
-

The consumed groundwater from Alternative 2 represents (see values in Tables 4.4-3 and 4.4-6):

- 2.3 percent of the 1,000-year high population growth rate projected groundwater demand (1.25 billion gallons consumed ÷ 54.0 billion gallons of demand; see Tables 4.2-4).
- Approximately 46 percent of the 1,000-year no population growth projected groundwater demand (1.25 billion gallons ÷ 2.96 billion gallons; see Table 4.2-3).
- Approximately 1.9 times the 1,000-year low population growth projected groundwater demand (1.25 billion gallons ÷ 604.4 million gallons; see Table 4.2-3).
- 19 times the present value of the 1,000-year low population growth rate projected groundwater demand at a 7 percent discount rate ($2,823,689 ÷ $147,524; see Table 4.4-6).
- 76 percent more than the present value of the 1,000-year high population growth rate projected groundwater demand at a 3 percent discount rate ($2,823,689 ÷ $1,603,374; see Table 4.4-6).
- These values indicate that under all population growth rate and monetary discount rate scenarios considered, the present value of the water removed from the aquifers and evaporated as wastewater for Alternative 2 meet or exceeds the present value of the projected groundwater resource demand for the Alluvial and Chinle aquifers.

Overall, this indicates that, for both Alternative 1 and Alternative 2, the present value of the groundwater resource benefit is offset by the present value cost associated with the permanently consumed groundwater as treatment wastewater for both the high and low estimate of projected groundwater demand and for both discount rates considered. The electronic spreadsheet file that calculates these values is provided in Appendix 4.3-B.

4.4.2.5 Loss of Economic Use of Site/Facility

No structures will remain at the GRP following decommissioning and reclamation. All surface areas outside the Large Tailings Pile and Small Tailings Pile will be remediated to approved standards for unrestricted use except for access to groundwater. No alternative precludes future, post-reclamation

economic use of the GRP and land within the control boundary other than access to and use of groundwater, except for the land utilized for permanent storage of 11e.(2) Byproduct Material. All other potential future uses that do not involve access to groundwater are preserved. Therefore, any potential costs differentials between alternatives for loss of economic use are not considered as material discriminators between the alternatives and are not quantified herein.

4.4.3 Corrective Action Assessment Summary and Conclusions

Table 4.4-6 summarizes the results of the assessment of costs and benefits for the reasonable range of corrective actions identified in Section 4.2 and analyzed in Section 4.3. These costs and benefits include direct monetized costs and benefits as well as indirect cost and benefits (monetized and non-monetized).

The assessments provided in Section 4.2, 4.3, and 4.4 above support selection of Alternative 3 as the proposed action. This alternative is technically feasible, has the highest ranking of the combined evaluation criteria, and provides the requisite reasonable assurance of protection of public health, safety, and the environment the period of compliance (at least 200 years, and to the extent practicable, 1,000 years).

Groundwater corrective actions performed over the past 49 years, including groundwater collection, treatment, reinjection and tailings flushing have continually expanded in scope and volume of treatment capacity, resulting in the most robust groundwater corrective action of any Title II uranium mill tailings program. These actions have recovered over 85 percent of the uranium mass in the alluvial groundwater from tailings seepage (see Appendix G to Appendix 3.1-A) and have limited source mitigation. However, further decreases in groundwater concentrations and further reductions in mobile domain contaminant mass under and around the Large Tailings Pile have stagnated over the past decade, indicating that groundwater corrective action has decreased in efficacy. Further, mass balance calculations, modeling of groundwater constituent concentrations, and assessments of alternatives to the Proposed Action indicate that long-term groundwater restoration is not reasonably achievable. Modeling that supports this conclusion includes first order decay analysis of the groundwater constituent concentration trends during the historical corrective action program, transport sensitivity analysis of long-term sources, and contaminant mass balance calculations for the water-yielding units. These analyses all indicate that restoration of the mobile domain will take many tens of decades and long-term restoration for unrestricted release is not reasonably achievable. Therefore, although further corrective action can continue to remove mass from the groundwater system, the compliance requirement of groundwater restoration is not reasonably achievable, and, as discussed further in Section 4.5, the benefit of increments of restoration are orders of magnitude lower than the cost of restoration.

The monetized benefits of implementing the other corrective action alternatives, including a conservative valuation of the pre-contaminated groundwater resource and the benefit of averted dose, are more than an order of magnitude lower than the monetized costs. Alternatives 1 and 2 have additional monetized costs in the value of the billions of gallons of groundwater removed from the hydrogeologic system as wastewater that, alone, rival the total calculated value of the pre-contaminated groundwater resource.

Further, non-monetized benefits of the other alternatives are not sufficiently large to offset the direct and indirect costs of implementing them. Therefore, selection of Alternative 3 is confirmed considering all costs and benefits of each alternative.

Section 4.5, below, presents the demonstration that the decades of groundwater corrective action and the Proposed Action (Alternative 3) satisfies the ALARA demonstration requirement.

4.5 ALARA Demonstration

NRC regulations in 10 CFR 20.1003 identify ALARA as follows:

"*(acronym for "as low as is reasonably achievable") means making every reasonable effort to maintain exposures to radiation as far* ***below*** *the dose limits in this part as is practical consistent with the purpose for which the licensed activity is undertaken, taking into account the state of technology, the economics of improvements in relation to state of technology, the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to utilization of nuclear energy and licensed materials in the public interest.*" [emphasis added]

Further NRC guidance on decommissioning in NUREG-1757 (NRC, 2022a) states that for decommissioning and license termination under restricted use conditions, "*...licensees must demonstrate that the site is acceptable for license termination under restricted conditions. This information should be sufficient to allow NRC staff to determine that:*

- ***Further*** *reductions in residual radioactivity would:*
    - *result in net environmental harm (a demonstration that the benefits of dose reduction are less than the cost of doses, injuries and fatalities) or*
    - *not be necessary because the proposed levels are ALARA. This analysis should include a complete cost-benefit calculation, ...*

The ALARA requirement identified in 10 CFR 40 Appendix A is based on the necessary minimum condition that concentrations at the POE be protective, meaning exposure point concentrations meet and remain at or below the specified radiological dose limits and other groundwater protection standards identified in the License. Under 10 CFR 40, Appendix A, licensees seeking ACLs must demonstrate that the exposure concentrations have been reduced to levels that are ALARA or that ACLs are ALARA. The ALARA demonstration does not prescribe a specific value for all licensees or conditions. Rather, it is an analytical framework through which alternatives are assessed for their relative costs and benefits to determine whether further reduction of concentrations is reasonably achievable.

For this analysis, the ALARA process is applied solely to radiological exposures, for which further incremental dose reductions below the dose limits are considered to have further incremental health benefits. For non-radiological and non-carcinogenic constituents such as most metals that have only toxicological health effects, there are no incremental health benefits assumed to be derived from further incremental reductions in exposure concentrations below their respective protective limits.

As stated in NUREG-1620, Section 4.3.3.3 (Corrective Action Assessment):

"*The corrective action assessment should demonstrate that the proposed alternate concentration limit is as low as is reasonably achievable, considering practicable corrective actions, as required by 10 CFR Part 40 Appendix A, Criterion 5B(6). A principal way of demonstrating this is by estimating and comparing the benefits imparted by a corrective action measure against the cost of implementing that measure.*"

Further, this section of NUREG-1620 also states:

The "as low as is reasonably achievable" analysis typically considers (a) the direct and indirect benefits of implementing each corrective action to achieve the target concentration levels; (b) the costs of performing the corrective action to achieve the target concentrations; and (c) a determination whether any of the evaluated corrective action alternatives will reduce contaminant levels below the proposed alternate concentration limit, considering the benefits and costs of implementing the alternative."

When evaluating the results of the ALARA process, NURGEG-1757 states: "*If the desired beneficial effects (benefits) from the remediation action are greater than the undesirable effects or "costs" of the action, the remediation action being evaluated is cost-effective and should be performed. Conversely, if the benefits are less than the costs, the levels of residual radioactivity are already ALARA without taking the remediation action.*" Section N.4 of Appendix N to NUREG-1757 provides a basis for demonstrating that further reductions in residual radioactivity would be prohibitively expensive. This basis considers an analysis using ten times the monetized value of averted dose per person rem. Taken more broadly, this basis indicates if costs to further reduce POE concentrations below protective limits are more than ten times the monetized benefits, then the alternative actions may be considered prohibitively expensive.

Section 4.4.1 identifies and develops the direct and indirect benefits of implementing each corrective action to achieve the predicted POE groundwater constituent concentrations. Section 4.4.2 identifies and develops the direct and indirect costs of performing the corrective action to achieve the predicted POE groundwater constituent concentrations. The developed costs and benefits are summarized in Table 4.4-6. The predicted maximum POE groundwater uranium concentrations are all below the License groundwater protection standard for each respective hydrogeologic unit for all alternatives (Table 4.3-6).

The proposed ACLs are based on predicted maximum POC concentrations established from bounding-case model results, that use input parameters at the high end of their reasonable ranges for multiple key parameters, above those established for calibrated model. These conservative modifications to the calibrated model provide additional assurances that the proposed ACLs are amply protective over the long-term.

In order to compare "…*the benefits imparted by a corrective action measure against the cost of implementing that measure,*" monetized costs are divided by the monetized benefits and this ratio is herein termed the cost/benefit ratio. The cost/benefit ratios range from 65 to 103 for Alternative 1, between 55 and 70 for Alternative 2, and between 7.4 and 25.2 for Alternative 3 (Table 4.4-6). This means that the monetized costs to perform either alternative compared to the Proposed Action is between 55 times and 103 times more than the monetized benefit from performing those actions.

Although the ALARA process is typically applied to exposure point concentrations and addresses public dose reductions, NRC indicated in its May 27, 2022, pre-submittal review comments of an earlier version of this ACL Application the need to include discussion that the control boundary itself is ALARA. To address this comment, the costs and benefits of further reducing the area requiring control over access to and use of groundwater on an area basis are presented. The Proposed Action (approval of ACLs and cessation of groundwater corrective action) would result in control over access to and use of groundwater over all 6,830 acres within the control boundary. The Proposed Action provides the reasonable assurance of meeting the radiological dose limit and other groundwater protection standards identified in the License at the POE. The total present value of monetized benefit from corrective action, including benefits from averted dose and pre-contaminated water resource value range from $832,461 to $3,844,944 (Table 4.4-6).

The area hypothetically to be transferred to the long-term custodian if full groundwater restoration could be achieved is assumed to be the current NRC License boundary without the portion north of Anaconda Road for a total hypothetical transfer area of 911 acres. Considered on a per acre basis for the 5,919-acre area within the control boundary (6,830 acres) not occupied by the tailings impoundments and land that would be transferred to the long-term custodian if full restoration could be maintained, the total monetized benefit of groundwater restoration, including benefits from averted dose and pre-contaminated water resource value, ranges from $140.64/acre to $649.59/acre (e.g., $3,844,944 maximum monetized benefit from Table 4.4-6 ÷ 5919 acres = $649.59/acre). Given the annual operating costs for groundwater corrective action are approximately $6,183,000 (Alternative 1, Appendix 4.3-B) and applying the cost threshold of 10 times the benefit from NUREG-1757, Appendix N, Section N.4, each year of additional groundwater corrective action operation would need to permanently restore beneficial use of groundwater over 989 acres ([$6,183,000/year ÷ 10] ÷ $649.59/acre = 951.8 acres/year or 1.49 square miles per year) to justify further restoration beyond the Proposed Action. This analysis indicates that additional groundwater corrective actions to further reduce the area of long-term control are not reasonable to implement if they do not permanently restore access to groundwater over 951.8 acres per year, as the derived benefits are more than an order of magnitude lower than the associated costs to do so. This rate of groundwater restoration has never been realized and is unlikely to be achieved even with significant expansion of the existing groundwater corrective action systems. Therefore, this analysis supports the assertion that further groundwater corrective action is not reasonable and the proposed control boundary for the Proposed Action is consistent with the ALARA concept.

Looking at the results of corrective action over a shorter time frame (200 years rather than 1,000 years), Alternative 1 restores groundwater to current License groundwater protection standards over an area of 747 acres while Alternative 2 restores 240 acres. The present value cost of implementing Alternative 1 (3% discount rate) is calculated to be $248,771,919 (Appendix 4.3-B and Table 4.4-6). This value is roughly 65 times the total maximum monetized benefit of full and permanent groundwater restoration ($3,844,944; Table 4.4-6).

Comparison of the non-monetized costs and benefits is necessarily qualitative due to the qualitative nature of those costs and benefits. Non-monetized benefits (land depreciation, timeliness of remedy completion, and aesthetics) are developed in Section 4.4.1 while non-monetized costs (relative transportation risk, environmental impact, and loss of economic use of the GRP area) are developed in Section 4.4.2, both costs and benefits are summarized in Table 4.4-6.

The non-monetized costs for all alternatives are identified as relatively low. The non-monetized benefit of mitigating land value depreciation is considered moderate for all alternatives, meaning that this metric does not differentiate between alternatives (no one alternative substantially reduces the impact of land value depreciation over another alternative). The assessment in Section 4.4.1.4.2 identifies that it is difficult to quantify and discriminate between land value impacts from proximity to the tailings piles and any such impacts attributable instead to the potential presence of groundwater impacts, even though groundwater is not accessible by surface users.

The non-monetized benefit related to timeliness of remedy completion is relatively low for Alternatives 1 and 2 as they require ongoing corrective action operations and maintenance for 1,000 years while

completion of the Proposed Action could be completed in five to ten years. Similarly, the non-monetized benefit related to aesthetic impacts from implementing the alternatives are also considered low for all alternatives. Therefore, although the non-monetized costs for each alternative are low, the relative benefit of implementing each alternative are also fairly low and are not of a magnitude to substantially alter the order of magnitude cost/benefit ratios calculated from the comparison of monetized costs and benefits.

It is also noted that the calculated present value of groundwater permanently removed from the hydrogeologic system as wastewater for treatment under Alternatives 1 and 2 alone ($3.609 million dollars to $1.778 million dollars) is between 11 and 25 times the low-estimate of the present value of projected future groundwater demand for the next 1,000 years ($147,524; Table 4.4-6) and is between 111 percent and 225 percent of the high-estimate of the present value of projected future groundwater demand ($1,603,374; Table 4.4-6). In other words, the present value of water irretrievably removed from the hydrologic system to restore through treatment is more than the present value of the entire water resource based on projected future water demand. This counterintuitive result occurs because of the different rates of water consumption or demand and how the present value calculation weighs those volumes and costs through time. Water uses incurred later in time have a lower calculated present value than equivalent water uses earlier in time due to the discounting of value with time.

These order of magnitude differences between benefits and costs of Alternatives 1 and 2 with respect to the Proposed Action demonstrate that costs to achieve further reductions in POE groundwater constituent concentrations are far in excess of the value of the resource and the benefits associated with performing the alternative actions. In addition, the cost of restoring access to groundwater over different areas is also substantially more than 10 times the associated monetized benefits. Another perspective on the cost and benefits of continued groundwater corrective action is that the annual operating cost of groundwater corrective action ($6.2 million per year) is larger than the high-end estimate of the combined value of all the averted dose for 1,000 years and the high-end estimated value of the pre-contaminated groundwater resource based on a conservative estimate of projected demand. Further, differences in the non-monetized indirect benefits and costs for a given alternative, summarized in Table 4.4-6, are not sufficiently large or substantial to reasonably change the order of magnitude of the cost/benefit ratios.

Therefore, based on the analyses presented in this ACL Application, over four decades of groundwater corrective actions performed to date have reduced concentrations to ALARA. The Proposed Action affords the requisite reasonable assurance of protection of public health, safety, and the environment and meets the requirements in Appendix A of 10 CFR Part 40 for approval of ACLs, which include the following:

- Criterion 5B(1) - manage 11e.(2) Byproduct Material to confirm to the standard that constituents entering the groundwater must not exceed the specified concentration limits in the uppermost aquifer beyond the point of compliance during the compliance period.
- Criterion 5B(6) - the proposed limits are ALARA, after considering practicable corrective actions, and that the constituents will not pose a substantial present or potential hazard to human health or the environment as long as the alternate concentration limit is not exceeded.
- Criterion 7A - establish detection monitoring program to provide the basis for identifying constituents for which compliance standards are needed.

While there may be a number of configuration variations of the alternatives that could be considered, other practicable alternatives that could achieve comparable or lower POE groundwater constituent

concentrations, at comparable or lower costs have not been identified and are highly unlikely. Therefore, the magnitude of differences between the estimated costs and the benefits between the Proposed Action and the other alternatives are sufficiently large to mitigate debate over the fine points of different alternative configurations and estimation methods.

5 ALTERNATE CONCENTRATION LIMITS

Based on the assessments presented previously in this ACL Application, groundwater restoration to background concentrations or the License groundwater protection standards, whichever is higher, is not reasonably achievable and through decades of corrective action, groundwater constituent concentrations have been reduced to concentrations that will remain protective at the POE and that are ALARA. Approval of ACLs is identified as the Proposed Action to comply with 10 CFR Part 40, Appendix A, Criterion 5. The proposed ACLs developed herein rely on the identified POE and POC, conservative predictive transport model results, and control of access to and restricted use of groundwater within the identified control boundary, discussed further below.

Proposed revisions to the current groundwater monitoring program identified in License Condition 35A provide for robust monitoring of the post-corrective action conditions including six locations within the tailings to monitor source conditions, six POC wells at the margins of the tailings piles, and 93 intermediate monitoring wells in the five hydrologic units through which groundwater is transported (Alluvium, Upper Chinle, Middle Chinle, Lower Chinle and the San Andres-Glorieta aquifer). Comparison of measured values to proposed ACLs and predicted maximum concentrations at intermediate monitoring locations will allow verification that groundwater constituent concentrations will remain protective at the POE.

Current control of access to and use of contaminated groundwater within the control boundary is provided by several means, including property ownership of land owned by HMC, removal of demand for groundwater use by an alternate water supply to all parcels with permitted access to groundwater, annual water well use inventories documenting that no groundwater wells accessing contaminated groundwater are being used, and an order from the New Mexico Office of the State Engineer restricting permitting and drilling of wells for new appropriations, or replacement or supplemental wells. There will be no groundwater use allowed on HMC owned land within the proposed control boundary prior to License termination and site transfer to the long-term custodian. HMC has obtained ownership of the substantial majority of surface and subsurface estates within the anticipated long-term care boundary, continues its good faith and serious efforts to obtain all such estates, and intends to comply with regulatory requirements governing acquisition and transfer of property within the control boundary. Documentation demonstrating HMC's serious and good faith efforts being made to acquire the remaining estates is available for NRC staff review onsite.

5.1 Proposed Alternate Concentrations Limits

The proposed ACLs are set above the current (2021-2025) measured maximum groundwater constituent concentration of each analyte at the POC area wells, which are also above the predicted POC well maxima based on conservative bounding-case groundwater flow and transport model runs. This ACL Application identifies appropriate POC, as well as upgradient and intermediate monitoring points and monitoring of tailings sumps. The POE is defined by a proposed control boundary that circumscribes the area over which control of access to and restricted use of groundwater will be maintained (Figure 1.5-1).

ACLs are proposed for 10 constituents as identified in Section 2.2 and Appendix 2.2-A of this ACL Application. These proposed values are to be applied at the proposed POC wells and have been developed to ensure long-term protection at and beyond the POE are maintained for the compliance period of up to 1,000 years.

As a means to verify the long-term protectiveness of the proposed ACLs, the current groundwater compliance monitoring plan identified in License 35A will be retained with a few modifications until License termination, including monitoring at 103 locations including tailings sumps, wells directly under the LTP, wells upgradient of the LTP, POC wells, and more than 80 well downgradient of the POC wells. Maximum predicted groundwater constituent concentrations for each of the 10 constituents at each intermediate monitoring location are provided. Predicted maximum groundwater constituent concentrations for intermediate monitoring wells beyond the POC wells can be used to verify that measured groundwater constituent concentrations continue to be consistent with conditions predicted to provide long-term protection at the POE.

Verification that predicted maximum POC groundwater constituent concentrations and long-term source conditions, when transported to the POE, result in POE groundwater constituent concentrations below the License groundwater protection standards for 1,000 years, is performed using the conservative bounding-case groundwater models, which were developed from modified forms of the calibrated base-case flow and transport models. Modification of the calibrated base-case flow and transport models used in assessment of the corrective action alternatives in Section 4 was made to represent conservative bounding-case conditions by adjusting major input parameters to endpoint values in their sensitivity ranges (e.g., high end of their reasonable range). These conservative model runs, referred to as bounding-case model runs, are intended to provide additional assurances that the proposed ACLs are amply protective over the long-term. As demonstrated in Section 4.5, above, the proposed ACL concentrations are ALARA.

5.1.1 Points of Compliance

The proposed individual POC alluvial wells C2, D1, M3, SB, SZ, and X, located at the downgradient margins of the Large Tailings Pile and Small Tailings Pile (Figure 5.1-1) and are screened in the alluvium. As presented in Section 1.2.2.7 of this ACL Application, the alluvium is the geologic unit nearest the natural ground surface that is an aquifer. Well construction information for these wells and the complete groundwater monitoring program proposed for this application are included in the Proposed Compliance Monitoring Plan discussed in Section 5.2 of this ACL Application.

Current groundwater quality conditions for the POC area associated with the Large and Small Tailings Pile are characterized by the maximum current (2021-2025) measured groundwater quality concentration data from the 40 POC area wells B3, B4, B5, B6, B7, B8, B9, B15, B16, B19, B20, B31, B32, B35, B40, B42, B44, D1, DR, DT, K9, M3, S1, S3, S4, S5R, S11, S12, S19, SA, SB, SO, SQ, SSR, ST, SUR, SV, SW, SZ, and X. These wells, screened in the uppermost aquifer (alluvium) around but not under the downgradient margins of the Large and Small Tailings Piles (see Figure 5.1-1), are considered to be representative of current groundwater conditions in the POC area. This data set is provided in Appendix 5.1-A. Well construction information for these wells is included in the Proposed Compliance Monitoring Plan discussed in Section 5.2 of this ACL Application. It is noted that these wells cove ra large area upgradient of the line of POC wells and that use of the maximum value from this set of wells overestimates the actual current POC concentrations.

As presented in further detail in Section 5.1.3 below, the maximum measured and predicted groundwater constituent concentrations across the entire modeled domain are all in the alluvium at the Large Tailings Pile. Further, all primary constituent sources are above the alluvium and must pass through the alluvium to enter the underlying water bearing units (i.e., Chinle and San Andres-Glorieta); therefore, establishing

ACLs for alluvial groundwater, in conjunction with long-term monitoring of the other hydrogeologic units, will provide prompt detection of groundwater conditions in the highly unlikely case they exceed the upper limits of predictions that demonstrate long-term protection at the POE.

5.1.2 Points of Exposure

As discussed previously in Section 4.3, the groundwater POE is defined as the proposed long-term control boundary identified in Figure 1.5-1. This control boundary circumscribes the area over which control of access to and use of groundwater is controlled through property ownership for the compliance period of up to 1,000 years, to the extent reasonably achievable, per 10 CFR Part 40, Appendix A, Criterion 6(1)(i). It is at and beyond this control boundary where potential future access to groundwater could occur. ACLs are established at levels that will ensure that groundwater constituent concentrations at the POE will remain protective.

To assess representative maximum predicted groundwater concentrations at the POE, the proposed long-term control boundary was conceptually divided into seven segments (Figure 5.1-1) to facilitate assessment of predicted maximum exposures along different transport pathways. Point of exposure Segment 1 addresses upgradient inputs to the alluvial and SAG aquifers. Point of exposure Segment 2 addresses any transport pathway in the Lower Chinle. Segment 3 was established to address upgradient inputs to the alluvial, Upper Chinle, and Middle Chinle formations. Point of exposure Segments 4, and 5 were established to address the southern groundwater transport pathway. Point of exposure Segment 7 was established to address the northern groundwater transport pathway. Point of exposure Segment 6 was established to address the most southern portion of both the northern and southern groundwater transport pathways.

Identification of the maximum predicted groundwater concentration for each constituent in each water-yielding unit along each segment for the 1,000-year modeling period allows assessment of maximum POE concentrations for all flow and transport paths and avoids bias that may occur by assessing a single specific exposure point along the boundary (Figure 1.5-1). While these segments allow for the quantification of the predicted maximum concentrations from the flow and transport models, there are no physical monitoring wells currently in place at these locations.

5.1.3 Bounding-Case Analysis of Long-Term Contaminant Transport

Model sensitivity runs, presented in further detail in Appendix 4.2-B, were performed to assess the sensitivity of predicted POE groundwater constituent concentrations from the combined effects of simultaneous changes to the sensitivity input parameters. These model sensitivity runs were developed to represent conservative bounding-case conditions by adjusting major input parameters to endpoint values in their sensitivity ranges (e.g., high end of their reasonable range). Use of these endpoint values causes the model to predict greater transport of constituents. A summary of input parameter adjustments made to the calibrated model is presented in Table 4.3-1. The detailed description of the predictive transport modeling and associated electronic modeling files are included in Appendix 4.2-B.

Bounding-case predictive model runs were performed for two constituents, uranium, and a hypothetical conservative (i.e., non-sorptive, non-reactive) constituent, as discussed in Section 3.1 and Appendix 4.2-B. Predicted maximum groundwater uranium concentrations at the POE and proposed intermediate monitoring

points, discussed in Section 5.2 of this ACL Application, are established directly from the bounding-case model output.

The hypothetical conservative constituent model was developed to provide a technical basis for conservatively estimating potential future groundwater concentrations of other constituents for which the model was not calibrated. Applying the conservative constituent model results, which are based on the bounding-case model hydrologic system inputs, to estimate those constituent's transport will overestimate the future transport of those constituents by assuming they are not retarded in transport when, in fact, they have some unquantified amount of potential retardation in transport. In this way, the application of the conservative constituent model results to these other constituents provides a conservative bounding estimate on future POE groundwater concentrations for those constituents, as detailed further below.

The maximum predicted groundwater constituent concentrations for each POE segment assessed for the bounding-case uranium, molybdenum and selenium models and the bounding-case hypothetical conservative constituent models for the proposed action are presented in Tables 5.1-1 and 5.1-3, respectively. The current (2021-2025) maximum measured POC area concentrations are presented in Table 5.1-2 and the underlying data set for those POC area wells are provided in Appendix 5.1-A.

Outputs from these model runs are considered to represent conservative upper bounds on predicted groundwater constituent concentrations at the POE. These conservative predicted POE groundwater constituent concentrations were used to verify the proposed ACLs will remain protective at the POE and provide additional assurances that the proposed ACLs are amply protective by addressing potential model uncertainties associated with those bounding-case input parameters.

5.1.3.1 Conservative Constituent Model

Predictive modeling of all constituents other than uranium, molybdenum, and selenium were performed using a output of the bounding-case hypothetical conservative constituent model to bound potential future transport of other constituents for which the model was not calibrated. Because the conservative constituent is assumed to transport in a non-reactive manner, sorption-based retardation was not simulated. This conservative assumption means that the conservative constituent transport model results bound the potential future transport of other constituents, which have some potential for geochemical interaction in the water-yielding unit and retardation in transport. Individual modeling of these other constituents with constituent-specific retardation would result in lower predicted groundwater constituent concentrations at the POE. Diffusion-based dual-porosity processes in the bounding-case model were assumed to apply to the conservative constituent, and model input values for mass transfer coefficients and ratio of mobile/immobile domain porosities were employed as described in Sections 3.1 and 3.2, above.

A unit concentration approach was undertaken for this analysis to simulate travel times and compare simulated groundwater constituent concentrations relative to input source concentrations at various points in the model domain (e.g., within the groundwater constituent plume and at the POE). The input source concentrations in Large Tailings Pile seepage were set at a value of 1 (generic mass per volume concentration units) so that model output concentrations can be readily interpreted as percentages of the source concentration. This approach assumes that the source concentration of recharge from Large Tailings

Pile seepage does not change through time. Detailed development of this conservative constituent model is described in Appendix 4.2-B.

The transport model cannot be calibrated for a non-specific conservative constituent due to the absence of initial groundwater constituent conditions against which the prediction can be compared to evaluate the quality of calibration. This analysis assumes that other model input parameters developed during calibration of the uranium and molybdenum models (e.g., porosity, hydraulic conductivity, boundary conditions, aerial and channel recharge, hydraulic pumping stresses, etc.) are reasonable to use for the conservative constituent.

In addition, two precursor simulations were performed to provide a reasonable estimate of these initial conditions for the predictive period as historical conditions at the GRP for a generic conservative constituent are not available to inform and provide initial concentration conditions for a predictive transport simulation. For one precursor condition, a 44-year simulation was performed to represent the historical period from the beginning of uranium milling activities to the beginning of the historical period of the model (1958-2001) using the recharge seepage concentration from the LTP set to a value of 1.0 while recharge in other areas of the model was assumed to have zero concentration as input source concentrations. This established an initial upper bound estimate of concentration distribution conditions for constituents with minimal sorption (i.e., fluoride, and nitrate+nitrite). Appendix 4.2-B describes this model initialization simulation in more detail and refers to this condition as Unit Concentrations – Non-Sorbed COCs.

A second initialization simulation was then performed with the historical calibration-period model representing 2002-2024. Initial concentration conditions in each model layer were assigned from the ending simulated concentrations of the preceding 1958-2001 model. LTP seepage recharge rates were unchanged from the historical calibration model, and the LTP seepage recharge concentrations were set to 1.0 to represent the input source of the generic constituent. Appendix 4.2-B describes this model initialization simulation in more detail and refers to this condition as Unit Concentrations –Sorbed COCs.

Initial concentration conditions in each model layer for the predictive simulation were assigned from the ending simulated concentrations for year 2024, except for Unit Concentration – Sorbed COCs simulation, in which the concentrations outside of a 100-foot buffer around the LTP were specified as zero, consistent with measured data for the COCs of interest. For the Unit Concentration – Non-Sorbed COCs, concentrations for the predictive period were based on the simulated 2024 concentrations. Outputs from the conservative constituent model for both initial conditions, which are percentages of the input concentrations, are then related to measured groundwater concentrations for each constituent.

Anywhere a current maximum groundwater constituent concentration is both predicted and measured (i.e., maximum occurs during a period with measured concentrations), the predicted future maximum groundwater constituent concentration downgradient can be calculated. The relationship between the maximum current measured groundwater constituent concentration and a specific maximum predicted downgradient groundwater constituent concentration is described using what is herein called the attenuation factor, as defined below.

$$\text{Attenuation Factor} = \frac{\text{Maximum Predicted Upgradient Concentration}}{\text{Maximum Predicted Downgradient Concentration}} \qquad \text{(Equation 5.1-A)}$$

This factor describes how much the maximum predicted concentration at a point decreases in transport to a downgradient location. To calculate the future maximum groundwater concentration of constituents at downgradient locations (other than uranium, molybdenum and selenium which are produced directly from

the model outputs), Equation 5.1-A is solved for the maximum predicted downgradient groundwater constituent concentration, and the maximum measured upgradient groundwater constituent concentration is used in place of the maximum predicted upgradient groundwater constituent concentration:

(Equation 5.1-B)

$$\text{Maximum Predicted Downgradient Concentration} = \frac{\text{Maximum Measured Upgradient Concentration}}{\text{Attenuation Factor}}$$

This approach is applied to calculate maximum predicted future POE groundwater concentrations for all constituents other than uranium, molybdenum and selenium which are modeled directly, and allows verification that the identified ACLs remain protective at the POE for the 1,000-year period of compliance. Table 5.1-1 identifies the calculated Attenuation Factors for the sorbed and non-sorbed conservative constituent model runs. These Attenuation Factors are used in Table 5.1-3 to calculate bounding-case maximum predicted POE concentrations for arsenic, cadmium, vanadium, fluoride, nitrate+nitrite, thorium-230, and combined radium-226 plus 228.

5.1.3.2 POC Area Concentrations

For calculation of ACL values, it is necessary to know what the maximum POC groundwater constituent concentrations are predicted to be, as these maximums will drive the maximum future POE groundwater constituent concentrations via use of the Attenuation Factor. Tables 5.1-2 and 5.1-4 summarize the maximum current (2021-2025) measured groundwater concentrations for all 11 constituents in the proposed POC area. Table 5.1-4 also identifies the maximum predicted POC concentrations for the bounding-case models. The bounding-case predictive models for uranium, molybdenum and selenium all have maximum predicted POC concentrations that are greater than the current measured concentrations. The predicted maximum POC concentrations for the bounding-case hypothetical conservative constituent model are the same as the current maximum measured POC concentrations, as the predictive conservative constituent model has a unit concentration of 1 in the uppermost aquifer at the start of the predictions.

5.1.4 Calculation of Proposed ACLs

Criterion 5B(6) states that ACLs are groundwater constituent concentrations that "*...will not pose a substantial present or potential hazard to human health or the environment as long as the alternate concentration limit is not exceeded.*" Therefore, ACLs, which apply at the POC, have been calculated based on conservatively predicted conditions from bounding-case predictive model output to assure that groundwater constituent concentrations will remain within protective levels at the POE.

Per the criterion above, the potential maximum ACLs are those threshold values that result in maximum POE concentrations just at the protective standards. Those potential maximum ACLs are ALARA if the cost of further reducing POE concentrations further below the protective limits far exceeds (generally more than 10 times) the derived benefits. Section 4.5 clearly establishes that the costs of further groundwater corrective action far exceed the benefits derived from further action. However, the maximum potential ACLs are higher than the current measured POC concentrations. Therefore, in an abundance of caution and to provide time and opportunity for assessment and potential implementation of additional corrective action in the unlikely case that ACLs may be exceeded, the proposed ACLs are set at values somewhat lower than the maximum potential maximum ACLs.

Table 5.1-4 identifies the current (2021-2025) POC maxima for all 11 hazardous constituents addressed in this application, the maximum predicted hazardous constituent concentration at the POE, as well as the POE segment in which those maxima occur (all POE maxima occur in the alluvial aquifer), the modeled Attenuation Factor, the maximum potential ACL value that area ALARA and would result in a bounding-case POE predicted concentration at the applicable protective standard, and the proposed ACLs, which are lower than the maximum potential ACL values.

The potential maximum ACLs that would result in POE concentrations just at the protective standards is calculated from Equation 5.1-A by solving for the maximum predicted POC concentration and using the applicable standard as the maximum POC concentration:

(Equation 5.1-C)

Maximum potential ACL = Attenuation Factor x Protective Standard

For example, based on the values presented in Table 5.1-4 for selenium;

Maximum potential ACL = Attenuation Factor x Protective Standard = 117.3 x 0.05 mg/L = 5.87 mg/L

The attenuation factor approach to characterize the bounding-case predicted relationship between POC and POE (Equation 5.1-A, above) establishes a directly proportional and linear relationship between POC and POE concentrations. For example, a two-fold increase in POC concentration results in a 2-fold increase in POE concentration.

The proposed ACL values for the 10 identified constituents are set above the current (2022-2025) measured groundwater concentration maxima but below the upper limit of potential protective POC concentrations, based on the bounding-case model results. In general, the proposed POC values are set at factors above the current measured maximum POC concentrations, which are a function of the attenuation factor and the amount by which the maximum potential ACLs are above the current measured POC maxima. Specifically, the proposed ACLs for arsenic, cadmium, vanadium, and combined radium-226 plus 228 are set at a factor of 10 above their respective current measured POC maximums. The thorium-230 ACL is set at a factor of 5 above the current measured POC maximum while the ACLs for fluoride and nitrate+nitrite are set at a factor of 3 above their respective current measured POC maximums. The ACLs for molybdenum, and selenium are set at a factor of 1.5 above their respective current measured POC maximums, while uranium is set at a factor of 1.3. These ACLs are set at concentrations above both the current measured POC maxima and the predicted maximum POC concentrations but below the potential maximum ACLs that would result in POE concentrations just at the protective applicable standards. These proposed ACLs provide time and opportunity for assessment and potential implementation of additional corrective action before POC concentrations reach levels that could result in POC exposures above the applicable standards.

The proposed ACLs are highly conservative for several reasons. First, the bounding-case models from which these ACLs are developed, is a highly conservative model with controlling input parameters set at the upper end of their reasonable range and above those established for the calibrated model. Consequently, the predicted model results reasonably overestimate both source conditions and transport conditions of all constituents, and consequently, predicted future POE conditions. Second, the proposed ACLs for

constituents modeled via the hypothetical conservative constituent approach (arsenic, cadmium, vanadium, fluoride, nitrate+nitrite, thorium-230 and combined radium-226 plus 228) are set at concentrations that result in protective POE levels with no transport retardation.

The proposed ACLs are applicable to all POC wells (C2, D1, SM3, SB. SZ, and X).
As previously discussed in this Application, chloride, sulfate, and total dissolved solids (TDS) are not considered hazardous and are not listed as hazardous constituents in Appendix A to 10 CFR Part 40, and thus do not require an ACL. HMC therefore proposes to remove them from the GRP License Condition 35B. Chloride, sulfate, and TDS are retained as monitoring parameters in the proposed monitoring program. Although boron has been discussed in this document, it too is not hazardous, is not identified as a hazardous substance in Part 40 Appendix A, and thus does not require an ACL. It also will not be retained as a water quality monitoring constituent.

5.1.5 Controls for Long-Term Protection

Current control of access to and use of contaminated groundwater for parcels HMC does not yet control within the proposed control boundary is provided by several means. First, HMC restricts access and does not and will not allow use of impacted groundwater on any land it owns within the control boundary. Second, all properties not currently controlled by HMC with legal access to groundwater by permitted groundwater wells within the control boundary are already connected to an alternate water supply through municipal water system from the Village of Milan installed by HMC (Figure 1.2-57). Third, HMC performs annual water well use inventories documenting that no groundwater wells accessing contaminated groundwater are being used. Fourth, as discussed in Section 1.2.2.9.3, the New Mexico Office of the State Engineer issued an order restricting permitting and drilling of wells for new appropriations, or replacement of supplemental wells, and restricts the permitting of any change to the point of diversion of any existing wells within the boundaries defined (Figure 1.2-56). The boundary of the NMOSE order does not encompass the entirety of the proposed control boundary, however there are two wells currently identified in the areas not encompassed by the NMOSE order boundary. The areas not encompassed by the NMOSE order are on the eastern and southern edges of the proposed control boundary and are not expected to see any site-related impacts for centuries, if ever. While the boundary of the NMOSE order does not currently encompass the entirety of the proposed control boundary, HMC will work with NMOSE to amend the boundary upon approval of the ACL Application.

In accordance with NUREG-1620 and 10 CFR Part 40 Appendix A, HMC has acquired a substantial majority of the surface and subsurface estates within the proposed control boundary and has demonstrated serious and good faith efforts to obtain the remaining surface and subsurface estates by extending good faith and serious offers to willing sellers to acquire the remaining estates.

While “serious” and “good faith” efforts are not clearly defined under NUREG-1620 and or 10 CFR Part 40 Appendix A, HMC evaluated similar precedents on sites where serious and good faith efforts were demonstrated. Factors cited at other sites when determining sufficiency of licensee effort include:

1. Reasonable offers above fair market value;

2. Multiple offers, communications and/or lengthy negotiations;
3. Coverage for improvement removal and relocation;
4. Alternative measures/compensation/assistance: e.g., accommodating special circumstances, relocation/moving assistance, compensating for commercial factors.

Using precedential factors, HMC has demonstrated serious and good faith efforts by making offers to willing sellers that have included, but are not limited to, the following elements:

1. Multiple third-party appraisals;
2. Offers based upon the highest appraisal;
3. Acceptance of counter offers up to 10% over original offer;
4. Minimum 90-day rent free "grace period" for vacating property;
5. Cash payment per well plus covering of costs for plugging & abandonment of private wells.
6. Lease back options for purchased properties below market rental rates;
7. Moving assistance;
8. Home and outbuilding relocation assistance;
9. Tailored household support where moving is physically and or financially unviable;
10. Multiple offers, communications and lengthy multi-year negotiations.

HMC currently owns approximately 5,874 acres (86%) of the 6,830 acres of surface estate within the control boundary. Within the control boundary, HMC currently owns 507 (93%) of the 542 parcels (Figure 1.2-57). Good faith offers have been extended to the remaining 35 parcels within the proposed control boundary. HMC currently owns approximately 5,241 acres (77%) of the 6,830 acres of subsurface estate and has made serious efforts to obtain subsurface rights by extending good faith offers on the remaining third-party subsurface estate. One remaining subsurface parcel is owned by the US government (Bureau of Land Management) and will require a land withdrawal. HMC owns the majority of the water rights within the proposed control boundary and has made serious efforts to obtain water rights by extending good faith offers to purchase the remaining water rights. All wells not required for the approved groundwater monitoring plan within the proposed control boundary on surface/subsurface estates owned by HMC will be plugged and abandoned. No impacted groundwater use will be allowed by HMC on any surface and subsurface estates owned by HMC within the proposed control boundary. In addition, in many cases where HMC has not acquired an estate that contains a well, HMC has provided a cash payment per private well and covered the costs for plugging and abandonment of the private well.

In summary, HMC has obtained ownership of the substantial majority of property within the anticipated long-term care boundary and continues its good faith and serious efforts to obtain all surface and subsurface property, and to plug and abandon wells on property not owned by HMC. Documentation demonstrating HMC's serious and good faith efforts being made to acquire the remaining estates and plug and abandon remaining wells is available for NRC staff review onsite. For any estate not acquired by HMC, and for any existing private well on such estate that is not plugged and abandoned, reasonable assurance exists that the public health and safety and the environment will be protected because of (1) the aforementioned State of New Mexico advisory; (2) the State of New Mexico legally enforceable prohibition against the drilling of new, replacement, or supplemental wells within the proposed control boundary; and the notification requirements provided in 10 CFR Part Appendix A Criterion 11C, which HMC will follow.

Long term custodianship is expected to be undertaken by the Department of Energy Legacy Management (DOE-LM). DOE currently planning for the site to be transferred to Legacy Management in 2035 (https://www.energy.gov/lm/articles/site-management-guide).

5.2 Proposed Implementation and Groundwater Monitoring Measures

The following section identifies a proposed groundwater monitoring system that modifies the current requirements in License Condition 15 for reporting monitoring results and the compliance monitoring program identified in License Condition 35A.

5.2.1 Proposed Groundwater Monitoring

HMC requests approval to modify the current Groundwater Compliance Monitoring Plan identified in License Condition 35A to reflect the approved ACLs. The proposed revision to the current groundwater monitoring plan also includes modification of the list of analytes for which sampling and analysis are performed, the locations at which monitoring is performed and the monitoring frequency. In addition, proposed changes to the reporting frequency are presented. The full proposed Groundwater Compliance Monitoring Plan is provided in Appendix 5.2-A.

The six proposed POC wells (Figure 5.1-1; Table 5.2-1) are distributed along the downgradient edge of the area of the Large and Small Tailings Piles and form a continuous network of wells to provide prompt detection of groundwater constituent concentrations in excess of the proposed ACLs. The proposed POC well network provides reasonable monitoring density immediately downgradient of the areas with the highest historical measured groundwater constituent concentrations beneath the Large Tailings Pile using wells with an established monitoring record.

In addition to the proposed POC wells, the proposed revision to the Groundwater Compliance Monitoring Plan wells for each water-yielding unit retains the majority of wells in the current approved groundwater monitoring program per License Condition 35A. The proposed monitoring program will provide robust monitoring of groundwater conditions as the hydrologic system stabilizes following cessation of corrective action. This proposed monitoring across the entire hydrologic domain will be used to verify groundwater constituent concentrations remain below predicted constituent concentrations that remain protective at the POE for 1,000 years. The proposed wells, as well as the analytes for which monitoring and reporting are proposed, the analytical methods, minimum reporting limits for each analyte, and the proposed monitoring frequency are identified in Table 5.2-1

Overall, the proposed groundwater monitoring network includes six POC wells in the alluvium, two upgradient alluvial wells, six tailings sump sample locations, six monitoring locations directly under the Large Tailings Pile, two wells upgradient of the Large Tailings Pile in the alluvium, and 90 downgradient monitoring wells across the five hydrologic units (alluvium, Upper Chinle, Middle Chinle, Lower Chinle, and San Andres-Glorieta). Table 5.2-2 summarizes the rationale for each set of monitoring wells.

The following identifies the proposed modifications from the current approved Groundwater Monitoring Plan identified in License Condition 35A.

- Add Large Tailings Pile sumps East 1 Sump, East 2 Sump, North 1 Sump, North 3 Sump, South 1 Sump, West 1 Sump to the monitoring program to assess tailings source concentrations.
- Add the following three constituents to the Groundwater Compliance Monitoring Plan list of analytes
    - arsenic, cadmium, and fluoride
- Removal of chloride, sulfate, and TDS as compliance parameters as the constituents are not identified in 10 CFR 40 Appendix A, Criterion 13. Note, these constituents are retained for analysis within the monitoring program but compliance standards (ACLs) are not proposed.
- Add the following two field monitoring parameters to the Groundwater Compliance Monitoring Plan
    - dissolved oxygen and oxidation reduction potential (ORP) to assist in assessing groundwater conditions relevant to constituent transport.
- Groundwater levels in all wells will be recorded quarterly for the first year after corrective action cessation, annually thereafter, to assist in assessing changes to hydraulic gradients.
- Groundwater level measurements for gradient reversal monitoring wells B, BA, KZ, DZ, SM, SN, S2, S5 are not retained because ample water level data are provided through monitoring of the proposed wells.
- Remove Evaporation Pond 3 wells, DD and DD2, which will be plugged and abandoned as Evaporation Pond 3 is to be decommissioned following approval of ACLs.
- Monitoring results will be reported annually.

The locations of the proposed monitoring wells are illustrated in Figure 5.1-1. Construction completion information for each well is included in Appendix 5.2-A.

Measured groundwater constituent concentrations at each POC and intermediate monitoring well location will be compared to the maximum predicted groundwater constituent concentrations from the bounding-case model to verify that groundwater conditions continue to remain within the predicted conditions for each monitoring location. Maximum predicted groundwater constituent concentrations at each downgradient monitoring well are presented in Table 3 of the proposed Groundwater Compliance Monitoring Plan, included as Appendix 5.2-A of this ACL Application. Confirmed and verified exceedance of ACLs in the POC wells may result in reporting and other actions as determined in consultation with NRC as specified in Appendix 5.2-A.

5.2.2 Implementation

HMC's current understanding of ACL and groundwater compliance activity implementation is outlined by the following steps, although a precise timeframe for these steps is not yet known or required:

- HMC documents its good faith and serious efforts to obtain ownership of all property within the control boundary, prior to approval of this ACL Application.
- NRC approves ACLs and the associated monitoring program through amendment of License Conditions 15 and 35.
- HMC implements the approved monitoring program and reporting until License termination and transfer.

- HMC terminates groundwater corrective action, performs decommissioning and reclamation of groundwater corrective action infrastructure per approved Decommissioning and Reclamation Plan.
- HMC submits to NRC a construction completion report documenting how HMC has satisfied all License and reclamation and decommissioning obligations related to groundwater compliance and corrective action.

5.2.3 Proposed License Amendment

Based on the data and analyses presented in this ACL Application, HMC respectfully requests the following amendments to the current License conditions 15, 35, 36, and 42 as follows in redline/strikeout.

15. The results of all effluent and environmental monitoring required by this license and regulation shall be reported ~~semi-~~annually by March 31 ~~and September30~~. All groundwater monitoring data shall be reported per the requirements in License Condition 35.

35. The licensee shall implement a groundwater compliance monitoring, as follows:

A. Implement the groundwater monitoring shown in the Groundwater Compliance Monitoring Plan submitted by the licensee on June 30, 2026 ~~November 20, 2017 (ML18018A102), as updated by the licensee in correspondence dated October 8, 2019 (ML19281C055)~~.

B. The following ground water protection standards are established for the POC wells C2, D1, M3, SB, SZ and X ~~each designated aquifer/zone~~ as described in the table below ~~Ground-Water Hydrology for Support of Background Concentration at the Grants Reclamation Site (Hydro-Engineering, December 2001) and Background Water Quality Evaluation of the Chinle Aquifers (Homestake Mining Company and Hydro-Engineering, October 2003)~~:

Constituents	*Alluvial Aquifer*	*Chinle Mixing Zone*	*Upper Chinle Non-Mixing Zone*	*Middle Chinle Non-Mixing Zone*	*Lower Chinle Non-Mixing Zone*
~~Selenium (mg/L)~~	~~0.32~~	~~0.14~~ *	~~0.06~~ *	~~0.07~~ *	~~0.32~~ *
~~Uranium (mg/L)~~	~~0.16~~	~~0.18~~ *	~~0.09~~ *	~~0.07~~ *	~~0.03~~ *
~~Molybdenum (mg/L)~~	~~0.1~~	~~0.1~~ *	~~0.1~~ *	~~0.1~~ *	~~0.1~~ *
~~Sulfate (mg/L)~~	~~1500~~	~~1750~~ *	~~914~~ *	~~857~~ *	~~2000~~ *
~~Chloride (mg/L)~~	~~250~~	~~250~~ *	~~412~~ *	~~250~~ *	~~634~~ *
~~TDS (mg/L)~~	~~2734~~	~~3140~~ *	~~2010~~ *	~~1560~~ *	~~4140~~ *
~~Nitrate (mg/L)~~	~~12~~	~~15~~	*	*	*
~~Vanadium (mg/L)~~	~~0.02~~	~~0.01~~	~~0.01~~	*	*
~~Thorium-230 (pCi/L)~~	~~0.3~~	*	*	*	*
~~Ra-226+228 (pCi/L)~~	~~5~~	*	*	*	*
~~* - ground-water protection standards not necessary for the constituents in the indicated zones~~					

Constituents	*Alluvial Aquifer*	*Chinle Mixing Zone*	*Upper Chinle Non-Mixing Zone*	*Middle Chinle Non-Mixing Zone*	*Lower Chinle Non-Mixing Zone*
Arsenic (mg/L)	*0.3*	*	*	*	*
Cadmium (mg/L)	*0.03*	*	*	*	*
Fluoride (mg/L)	*9*	*	*	*	*
Molybdenum (mg/L)	*116*	*	*	*	*
Nitrate+Nitrite as N (mg/L)	*41*	*	*	*	*
Selenium (mg/L)	*4.2*	*	*	*	*
Uranium (mg/L)	*50.0*	*	*	*	*
Vanadium (mg/L)	*0.3*	*	*	*	*
Thorium-230 (pCi/L)	*11*	*	*	*	*
Radium-226+228 (pCi/L)	*51*	*	*	*	*
* * groundwater protection standards not necessary for the constituents in the indicated zones*					

~~*C. Implement the corrective action program described in the September 15, 1989 submittal, as modified by the reverse osmosis system described in the January 15, 1998 submittal, excluding all sampling and reporting requirements for Sample Point 1, with the objective of achieving the concentrations of all constituents listed in License Condition 35B. Composite samples from Sample Point 2 (SP2) will be taken monthly and analyzed for the constituents listed in License Condition 35B; the results of these analyses will be reported in the semi-annual and annual reports required by License Conditions 15 and 42.*~~

~~*D. Operate evaporation ponds, EP1, EP2 and EP3, and enhanced evaporation systems located in each pond as described in the June 8 and 28, 1990; July 26, August 16, August 19, September 2 and 15, 1994; October 25, 2006, February 7, 2007, July 18, 2007, and March 17, 2008, submittals. Monitoring and mitigation measures for EP3 contained in the HMC Environmental Report dated January 30, 2007, are incorporated into this LC by reference.*~~

~~*E. Operate the zeolite water treatment systems located on the Large Tailings Pile as described in the December 11, 2017 (ML17361A006), February 22, 2018 (ML18066A583), and May 17, 2019 (ML19149A366), submittals, including all monitoring and mitigation requirements specified therein.*~~

~~*F. Submit by March 31 of each year, a performance review of the corrective action program that details the progress towards attaining groundwater protection standards.*~~

42. An annual report will be submitted to the NRC that includes (1) a description of any changes, tests, or experiments approved by a SERP including a summary of the safety and environmental evaluations, (2) the ALARA audit report, (3) land use survey, (4) monitoring data, ~~(5) corrective action program report, and (6)~~ (5) the effluent and environmental monitoring reports.

6 REFERENCES

AK Geoconsult, Inc., Jenkins Environmental, Inc., and Radiant Energy Management. (AK Geoconsult, et al). 1991. Reclamation Plan Homestake Mining Company Grants Operation, Volume 1. January. (ML080030080)

AK Geoconsult, Inc. and Jenkins Environmental, Inc. (AK Geoconsult and Jenkins). 1993. Reclamation Plan, Revision 10/93, Homestake Mining Company of California Grants Operation, Volume 1. October. (ML091490367 and ML091490469)

AK Geoconsult, Inc. (AK Geoconsult). 1996. Completion Report Mill Decommissioning Homestake Mining Company Grants Uranium Mill. February. (ML092820142)

Agency for Toxic Substances and Disease Registry (ATSDR). 1990. Toxicological Profile for Radium. U.S. Department of Health and Human Services. Atlanta, Ga. December.

Agency for Toxic Substances and Disease Registry (ATSDR). 2003a. Toxicological Profile for Selenium. U.S. Department of Health and Human Services. Atlanta, Ga. September.

Agency for Toxic Substances and Disease Registry (ATSDR). 2003b. Toxicological Profile for Fluorides, Hydrogen Fluoride and Fluorine. U.S. Department of Health and Human Services. Atlanta, Ga. September.

Agency for Toxic Substances and Disease Registry (ATSDR). 2007. Toxicological Profile for Arsenic. U.S. Department of Health and Human Services. Atlanta, Ga. August.

Agency for Toxic Substances and Disease Registry (ATSDR). 2009. Health Consultation, Homestake Mining Company Mill Site. Milan, Cibola County, New Mexico. U.S. Department of Health and Human Services. Atlanta, Ga.

Agency for Toxic Substances and Disease Registry (ATSDR). 2010a. Toxicological Profile for Boron. U.S. Department of Health and Human Services. Atlanta, Ga. November.

Agency for Toxic Substances and Disease Registry (ATSDR). 2010b. Toxicological Profile for Chlorine. U.S. Department of Health and Human Services. Atlanta, Ga. November.

Agency for Toxic Substances and Disease Registry (ATSDR). 2012a. Toxicological Profile for Vanadium. U.S. Department of Health and Human Services. Atlanta, Ga. September.

Agency for Toxic Substances and Disease Registry (ATSDR). 2012b. Toxicological Profile for Cadmium. U.S. Department of Health and Human Services. Atlanta, Ga. September.

Agency for Toxic Substances and Disease Registry (ATSDR). 2013. Toxicological Profile for Uranium. U.S. Department of Health and Human Services. Atlanta, Ga. February.

Agency for Toxic Substances and Disease Registry (ATSDR). 2017a. Toxicological Profile for Molybdenum, Draft for Public Comment. U.S. Department of Health and Human Services. Atlanta, GA. April.

Agency for Toxic Substances and Disease Registry (ATSDR). 2017b. Toxicological Profile for Nitrate and Nitrite. U.S. Department of Health and Human Services. Atlanta, GA. July.

Agency for Toxic Substances and Disease Registry (ATSDR). 2019. Toxicological Profile for Thorium. U.S. Department of Health and Human Services. Atlanta, GA. September.

Agency for Toxic Substances and Disease Registry (ATSDR). 2020. Minimal risk levels. March 2020. https://www.atsdr.cdc.gov/mrls/. Accessed 1 June 2020.

Alexander, M. (Alexander). 1977. Soil Microbiology. 2nd Edition. John Wiley & Sons, New York. 467 pp.

Alloway, B.J. (Alloway). 1990. Heavy Metals in Soils. Blackie, Glasgow and London. 339 pp.

Anderson, M.P., W.W. Woessner, and R.J. Hunt. (Anderson et al.). 2015. Applied Groundwater Modeling Simulation of Flow and Advective Transport. Academic Press. San Diego, California. 564 pp.

Appelo, C.A.J. and D. Postma. (Appelo and Postma). 2013. Geochemistry, Groundwater, and Pollution. Second Edition. A.A. Balkema, The Netherlands. 649 pp.

Arcadis. 2012. Rebound Evaluation Summary Report Grants Reclamation Project Grants, New Mexico. December. (Enclosure 4 of ML13345A256)

Arcadis. 2016. Expanded TPP Pilot Test in the Alluvial Aquifer. October. (ML16351A351)

Arcadis. 2018. Evaluation of Water Quality in Regard to Site Background Standards at the Grants Reclamation Project. Prepared for Homestake Mining Company. September. (ML19025A300)

Arcadis. 2019. Supplemental Background Soil and Groundwater Investigation Report. August.

ASTM. 2006. Standard Guide for Subsurface Flow and Transport Modeling, 8p.

ASTM. 2008. Standard Guide for Calibrating a Groundwater Flow Model Application, 8 p.

Bachmaf, S. and B.J. Merkel. (Bachmaf and Merkel). 2011. Sorption of uranium(VI) at the clay mineral-water interface. Environmental Earth Sciences. 63:925-934.

Baldwin, J.A. and S.K. Anderholm (Baldwin and Anderholm). 1992. Hydrogeology and ground-water chemistry of the San Andres-Glorieta aquifer in the Acoma embayment and eastern Zuni uplift, west-central New Mexico: U.S. Geological Survey Water-Resources Investigation Report WRI 91-4033, 304 pp.

Baldwin, J.A. and D.R. Rankin, 1995. Hydrogeology of Cibola County, New Mexico, U.S. Geological Survey, Water-Resources Investigation Report 94-4178.

Bechtel Jacobs Company (BJC). 1998. Empirical Models for the Uptake of Inorganic Chemicals from Soil by Plants. September.

Bohn, H., B. McNeal, and G. O'Connor. (Bohn et al). 1985. Soil Chemistry. 2nd Edition. John Wiley & Sons, New York. 339 pp.

Bosbach, D., M. Böttle, V. Metz. (Bosbach et al). 2010. Experimental Study on Ra2+ Uptake by Barite (BaSO4). Swedish Nuclear Fuel and Waste management Co. Stockholm. March.

Bridges, L.L. and J. Meyer. (Bridges and Meyer). 2007. Environmental Report for the Construction of Evaporation Pond #3 (EP3) and Associated Operations Boundary Expansion. January 30. (ML070850561)

Brookins, D.G. (Brookins). 1988. Eh-pH Diagrams for Geochemistry. Springer Verlag, New York. 176 pp.

Brooks, R. H. and A. T. Corey. (Brooks and Corey). 1964. Hydraulic Properties of Porous Media. Hydrology Papers 3, Colorado State University, Fort Collins, CO

Brown and Caldwell, 2018, San Mateo Creek Basin and HMC Mill Site Hydrogeologic Site Conceptual Models, Technical Memorandum, January 8. (ML18025B341)

Bullock, L.A. and J. Parnell. (Bullock and Parnell). 2017. Selenium and molybdenum enrichment in uranium roll-front deposits of Wyoming and Colorado, USA. Journal of Geochemical Exploration. 180:101-112.

Butler, A.P. (Butler) 1972. Uranium in Geologic Atlas of the Rocky Mountain Region, Mallory et al. (editors). Rocky Mountain Association of Geologists, Denver, Colorado. pp. 315-317.

Byrd, D., Allen, H., and Montano, M. (Byrd and Montano). 2004. Water Resources Data - New Mexico Water Year 2004. U.S. Geological Survey Water-Data Report NM-04-1. 2005. https://pubs.usgs.gov/wdr/2004/wdr-nm-04-1/nmadr.pdf.

Chao, T.T., M.E. Harward, and S.C. Fang. (Chao et al.). 1962. Adsorption and desorption phenomena of sulfate ions in soils. Technical Paper No. 1418. Oregon Agricultural Experiment Station. Oregon State University, Corvallis.

Chavez, E.A. (Chavez). 1961. Progress Report on Contamination of Potable Ground Water in the Grants-Bluewater Valencia County, New Mexico. New Mexico State Engineer Office, Roswell, New Mexico.

Chenoweth, W. L. (Chenoweth). 1989. The Geology and Production History of Uranium Deposits in the Salt Wash Member of the Morrison Formation, Near Rough Rock, Apache County, Arizona. Arizona Geological Survey Contributed Reports, CR-89-C, 9 p.

Coleman, R.G. and M. Delevaux. (Coleman and Delevaux).1957. Occurrence of selenium in sulfides from some sedimentary rocks of the western united states. Economic Geology. 52:499-527.

Cullen, W.R. and K.J. Reimer. (Cullen and Reimer). 1989. Arsenic speciation in the environment. Chemical Reviews. 89:713-764.

Curtis, G.P., M. Kohler, and J.A. Davis. (Curtis et. al). 2009. Comparing approaches for simulating the reactive transport of U(VI) in Ground Water. Mine Water and the Environment. 28:84-93.

D'Appolonia Consulting Engineers, Inc. (D'Appolonia). 1980. Engineer's Report: Stability Assessment. Uranium Mill Tailings Pond, United Nuclear-Homestake Partners. Grants, New Mexico. (ML20212B474)

Dhillon, K., S. Dhillon. (Dhillon and Dhillon). 2000. Selenium accumulation by sequentially grown wheat and rice as influenced by gypsum application in a seleniferous soil. Plant and Soil 227, 243–248.

Dong, W. and S.C. Brooks. (Dong and Brooks). 2006. Determination of the formation constants of ternary complexes of uranyl and carbonate with alkaline earth metals (Mg^{2+}, Ca^{2+}, Sr^{2+}, and Ba^{2+}) using anion exchange method. Environmental Science and Technology. 40:4689-4695.

Dzombak, D.A. and F.M.M. Morel. (Dzombak and Morel). 1990. Surface Complexation Modeling – Hydrous Ferric Oxides. John Wiley & Sons, New York. 393 pp.

Eisler, R. (Eisler). 1990. Boron hazards to fish, wildlife, and invertebrates: a synoptic review. U. S. Fish Wildlife Service, Biol. Rep. 85(1.20). https://www.pwrc.usgs.gov/eisler/CHR_20_Boron.pdf

Environment Canada. 1998. Summary of Canadian Water Quality Guidelines for the Protection of Aquatic Life. Interim draft guidelines transmitted on 20 April 1998 to G.P . Friday from Robert Kent, Head, Water Quality Guidelines and Assessments Section, Guidelines and Standards Division, Environment Canada.

Environmental Restoration Group, Inc. (ERG) 1995. Completion Report for Reclamation of Off-Pile Area at the Homestake Mining Company of California Uranium Mill, Grants Operation, License SUA- 1471. Prepared for Homestake Mining Company of California. November. (ML092990193)

Environmental Restoration Group, Inc. (ERG) 2003a. Grants Reclamation Project Background Water Quality Evaluation of The Chinle Aquifers. October. (ML033160207, ML033140212, ML033140215, ML033160203, ML033140223, ML033140218, ML033160201, ML033160213)

Environmental Restoration Group, Inc. (ERG) 2003b. Statistical Evaluation of Chinle Aquifer Quality at The Homestake Site Near Grants, NM. Uranium, Selenium, Molybdenum, Sulfate, Nitrate, Chloride, Vanadium, Thorium-230, Total Radium. October. (ML033140226)

Environmental Restoration Group, Inc. (ERG) 2004. Statistical Evaluation of Chinle Aquifer Quality at The Homestake Site Near Grants, NM. Uranium, Selenium, Molybdenum, Sulfate, Nitrate, Chloride, Vanadium, Thorium-230, Total Radium. October. (ML042080337)

Environmental Restoration Group and Hydro-Engineering LLC (ERG and Hydro-Engineering). 1999. Evaluation of the Use of Alluvial Ground Water for Irrigation, Consultant's report for Homestake Mining Company, Grants, New Mexico.

ERM. 2018. Environmental Report - Grants Homestake Site. February.

Evans, H.T. and S. Landergren. 1974. Vanadium. pp. 23-A-1 to 23-O-1. In K.H. Wedepol (ed.) Handbook of Geochemistry. Springer-Verlag, Berlin.

Finch, W. I. 1967. Geology of Epigenetic Uranium Deposits in Sandstone in the United States. Geological Survey Professional Paper 538. U.S. Government Printing Office, Washington, D.C.

Frascoli, F. and K.A. Hudson-Edwards. (Frascoli and Hudson-Edwards). 2018. Geochemistry, mineralogy, and microbiology of molybdenum in mining-affected environments. Minerals. 8(2):42.

Freeze, R.A. and J.A. Cherry, (Freeze and Cherry). 1979. Groundwater, McGraw-Hill, New York.

Frenzel, P.F. and F.P. Lyford. 1982 Estimates of Vertical Hydraulic Conductivity and regional ground-water Flow Rates in rock so Jurassic and Cretaceous Age, San Juan basin, New Mexico and Colorado, U.S. Geological Survey Water-Resources Investigations Report 82-4015.

Frenzel, P.F. (Frenzel). 1992. Simulation of ground-water flow in the San Andres-Glorieta aquifer in the Acoma embayment and eastern Zuni uplift, west-central New Mexico: U.S. Geological Survey Water-Resources Investigations Report 91-4099.

Friday, G P. (Friday) 1999. Ecological Screening Values for Surface Water, Sediment, and Soil. United States: N. . Web. Doi:10.2172/4764.

Frondel, C. (Frondel). 1958. Systematic Mineralogy of Uranium and Thorium. Geological Survey Bulletin 1064. U.S. Government Printing Office, Washington, D.C.

Gardiner, J. (Gardiner). 1974. The chemistry of cadmium in natural water—I. A study of cadmium complex formation using the cadmium specific-ion electrode. Water Research. 8(1): 23–30.

Gerth, J. (Gerth). 1990. Unit-cell dimensions of pure and trace metal-associated goethite. Geochimica Cosmochimica Acta. 54:363-371.

Goldberg, S. (Goldberg). 1993. Chemistry and mineralogy of boron in soils. In Boron and its Role in Crop Production. U.C. Gupta (ed.) pp. 3-34. CRC Press. Boca Raton.

Goldberg, S. (Goldberg). 1997. Reactions of boron with soils. Plant and Soil. 193:35-48.

Goldberg, S. (Goldberg). 2002. Competitive adsorption of arsenate and arsenite on oxides and clay minerals. Soil Science Society of America Journal. 66:413-421.

Goldberg, S. (Goldberg). 2009. Influence of soil solution salinity on molybdenum adsorption by soils. Soil Science. 174:9-13.

Goldberg, S. (Goldberg). 2012. Modeling selenite adsorption envelopes on oxides, clay minerals, and soils using the triple layer model. Soil Science Society of America Journal. 77:64-71.

Goldberg, S. (Goldberg). 2014. Modeling selenate adsorption behavior on oxides, clay minerals, and soils using the triple layer model. Soil Science. 179:568-576.

Goldberg, S., H.S. Forster, and C.L. Godfrey. (Goldberg et al). 1996. Molybdenum adsorption on oxides, clay minerals, and soils. Soil Science Society of America Journal. 60:425-432.

Gordon, E.D. (Gordon). 1961. Geology and Ground-Water Resources of the Grants-Bluewater Area, Valencia County, New Mexico, with a section on aquifer characteristics by H.L. Reeder, and with a section and chemical quality of the ground water by J.J. Kunkler. New Mexico State Engineer Technical Report 20, 109 pp.

Gupta, U.C., Y.W. Jame, C.A. Campbell, A.J. Leyshon, and W. Nicholaichuk. (Gupta et al). 1985. Boron toxicity and deficiency: A review. Canadian Journal of Soil Science. 65(3):381-409.

Harshman, E. N. and S.S. Adams. (Harshman and Adams). 1980. Geology and Recognition Criteria for Roll-Type Uranium Deposits in Continental Sandstones. Prepared for the U.S. Department of Energy. September.

HDR. 2020. Homestake Mining Company Superfund Site. Final Remedial Investigation Report. March.

HDR. 2021. Characterization of the San Andres-Glorieta Aquifer at Homestake Mining Company Superfund Site Near Grants, New Mexico.

HDR. 2024. Phase I Technical Memorandum for the Characterization of the Geochemical and Physical Properties of Mobile and Immobile Groundwater in High Permeability and Low Permeability Zones at Homestake Mining Company Superfund Site, Grants, New Mexico. August.

Health Physics Society. (HPS). 2019. Radiation risk in perspective. Health Physics Society Position Statement [online]. Available at http://hps.org/documents/radiationrisk.pdf. Accessed 4 June 2020.

Hingston, F.J., A.M. Posner, and J.P. Quirk. (Hingston et al). 1972. Anion adsorption by goethite and gibbsite I. The role of the proton in determining adsorption envelopes. Journal of Soil Science. 23:177-191.

Hoffman, G.L., (Hoffman). 1976, Groundwater Hydrology of the Alluvium, Consulting report to Homestake Mining Company. (ML20217M828)

Hoffman, G.L., (Hoffman). 1977. Modeling, Design and Specifications of the Collection and Injection Systems, Consulting Report to Homestake Mining Company.

Homestake Mining Company of California (HMC). 1981. Homestake Mining Company (HMC). 1981. Appendix B Groundwater Discharge Plan for Homestake's Mill Near Milan, New Mexico, DP-200, Consulting Report for Homestake Mining Company, Grants, New Mexico. (ML20203B988)

Homestake Mining Company of California (HMC). 1982. State of New Mexico Environmental Improvement Division Uranium Mill License Renewal Application, Environmental Report.

Homestake Mining Company of California (HMC). 1987. Letter from Edward E. Kennedy, Director of Environmental Affairs, Homestake Mining Company, Grants, New Mexico to Harry J. Pettengill, Chief, Licensing Branch 2, Uranium recovery Field Office, U.S. NRC Region IV, Denver, Colorado. September. (ML20235N106)

Homestake Mining Company of California (HMC). 1996. Appendix D of Groundwater Monitoring for Homestake's Mill Discharge Plan DP-200 and NRC License SUA-1471, 1995, Consulting Report for Homestake Mining Company, Grants, New Mexico. (ML20112J132)

Homestake Mining Company of California (HMC). 1998. Letter from Roy Cellan to Joseph Holonich. January. (ML12291A910)

Homestake Mining Company of California (HMC). 2001. Request to Change Background Concentrations at the Homestake Grants Reclamation Site. December (ML02008006, ML020080104, ML020350329)

Homestake Mining Company of California (HMC). 2005a. Correspondence from Alan D. Cox to Jerry Schoeppner, NMED, concerning Homestake's response to NMED 1/20/05 Comments on Proposed Ground Water Background Concentrations for HMC Grants Millsite. June 9, 2005. (ML060790062)

Homestake Mining Company of California (HMC). 2005b. Correspondence from Alan D. Cox to Gary Janosko, NRC concerning Grants Mill Site Reclamation Project - Aquifer Site Standards. December 5, 2005. (ML053550352)

Homestake Mining Company of California (HMC). 2006. Correspondence from Alan D. Cox to Paul Michalak, NRC, concerning Grants Mill Site Reclamation Project - Aquifer Site Standards. January 19, 2006. (ML060250273)

Homestake Mining Company of California (HMC). 2012. Grants Reclamation Project Updated Corrective Action Program (CAP). Prepared for the Nuclear Regulatory Commission. March. (ML12089A055)

Homestake Mining Company of California (HMC). 2013. Decommissioning and Reclamation Plan Update 2013 SUA-1471, Homestake Grants Reclamation Project, Cibola County, New Mexico, April. (ML13107A537, ML13107A539, ML13107A540, ML13107A541, ML13107A542)

Homestake Mining Company of California (HMC). 2018. Evaluation of Water Quality in Regard to Site Background Standards at the Grants Reclamation Project. Prepared by Arcadis U.S., Inc. (Highlands Ranch, CO). September. (ML19025A300)

Homestake Mining Company of California (HMC). 2019. Groundwater Corrective Action Program. Grants Reclamation Project. December. (ML19354B970)

Homestake Mining Company of California (HMC). 2020a. Environmental Report for the Groundwater Corrective Action Program (December 2019). February. (ML20080M078)

Homestake Mining Company of California (HMC). 2020b. Personal Email Communication with Brown and Caldwell. March.

Homestake Mining Company of California (HMC), 2020d, Homestake Mining Company of California Grants Reclamation Project – NRC License SUA-1471 - Groundwater Flow and Transport Model Report. October.

Homestake Mining Company of California (HMC). 2020e. Groundwater Corrective Action Program. Grants Reclamation Project. November. (ML20358A152)

Homestake Mining Company of California (HMC). 2020f. First-Order Decay Attenuation Analysis for Grants (Final); Technical Memorandum from Johnny Zhan, Ph.D. to Adam Arguello.

Homestake Mining Company of California and Hydro-Engineering, LLC. (HMC and Hydro-Engineering). 2003 Background Water Quality Evaluation of Chinle Aquifers. October 31, 2003. [ML033140212, 215, 218, 223, 239, and 242; and ML033160201, 203, 207, and 213]

Homestake Mining Company of California and Hydro-Engineering, LLC. (HMC and Hydro-Engineering). 2004 Background Water Quality Evaluation of Chinle Aquifers. (ML042080337)

Homestake Mining Company of California and Hydro-Engineering, LLC. (HMC and Hydro-Engineering). 2009. 2008 Annual Monitoring Report/Performance Review for Homestake's Grant Project Pursuant to NRC License SUA-1471 and Discharge Plan DP-200. Prepared for Homestake Mining Company of California. March. (ML093270309, ML093270451, ML093270310, ML093270312)

Homestake Mining Company of California and Hydro-Engineering, LLC. (HMC and Hydro-Engineering). 2010a. 2009 Annual Monitoring Report/Performance Review for Homestake's Grant Project Pursuant to NRC License SUA-1471 and Discharge Plan DP-200. Prepared for Homestake Mining Company of California. March. (ML101100723, ML101100724, ML101100725, ML101100726)

Homestake Mining Company of California and Hydro-Engineering, LLC. (HMC and Hydro-Engineering). 2010b. Ground-Water Hydrology, Restoration and Monitoring at the Grants Reclamation Site for NMED DP-200. Prepared for the New Mexico Environment Department. February. (ML100570171, ML100570179, ML100570169)

Homestake Mining Company of California and Hydro-Engineering, LLC. (HMC and Hydro-Engineering). 2013. 2012 Annual Monitoring Report/Performance Review for Homestake's Grant Project Pursuant to NRC License SUA-1471 and Discharge Plan DP-200. Prepared for Homestake Mining Company of California. March. (ML13109A400)

Homestake Mining Company of California and Hydro-Engineering, LLC. (HMC and Hydro-Engineering). 2014. 2013 Annual Monitoring Report/Performance Review for Homestake's Grant Project Pursuant to NRC License SUA-1471 and Discharge Plan DP-200. Prepared for Homestake Mining Company of California. March. (ML14093A306)

Homestake Mining Company of California and Hydro-Engineering, LLC. (HMC and Hydro-Engineering). 2016. 2015 Annual Monitoring Report/Performance Review for Homestake's Grant Project Pursuant to NRC License SUA-1471 and Discharge Plan DP-200. Prepared for Homestake Mining Company of California. March.

Homestake Mining Company of California and Hydro-Engineering, LLC. (HMC and Hydro-Engineering). 2017. 2016 Annual Monitoring Report/Performance Review for Homestake's Grant Project Pursuant to NRC License SUA-1471 and Discharge Plan DP-200. Prepared for Homestake Mining Company of California. March.

Homestake Mining Company of California and Hydro-Engineering, LLC. (HMC and Hydro-Engineering). 2018. 2017 Annual Monitoring Report/Performance Review for Homestake's Grant Project Pursuant to NRC License SUA-1471 and Discharge Plan DP-200. Prepared for Homestake Mining Company of California. March. (ML18102A970)

Homestake Mining Company of California and Hydro-Engineering, LLC. (HMC and Hydro-Engineering). 2019. 2018 Annual Monitoring Report/Performance Review for Homestake's Grants Project Pursuant to NRC License SUA-1471 and Discharge Plan DP-200. Prepared for the U.S. Nuclear Regulatory Commission and New Mexico Environment Department. March. (ML19101A375)

Homestake Mining Company of California and Hydro-Engineering, LLC. (HMC and Hydro-Engineering). 2020. 2019 Annual Monitoring Report/Performance Review for Homestake's Grants Project Pursuant to NRC License SUA-1471 and Discharge Plan DP-200. Prepared for the U.S. Nuclear Regulatory Commission and New Mexico Environment Department. March.

Homestake Mining Company of California and Hydro-Engineering, LLC (HMC and Hydro-Engineering). 2021. 2020 Annual Monitoring Report/Performance Review for Homestake's Grants Project Pursuant to NRC License SUA-1471 and Discharge Plan DP-200. Prepared for the U.S. Nuclear Regulatory Commission and New Mexico Environment Department. March. (ML21090A190)

Homestake Mining Company of California and Hydro-Engineering, LLC (HMC and Hydro-Engineering). 2025. 2024 Annual Monitoring Report/Performance Review for Homestake's Grants Project Pursuant to NRC License SUA-1471 and Discharge Plan DP-200. Prepared for the U.S. Nuclear Regulatory Commission and New Mexico Environment Department. March. (ML25114A153)

Homestake Mining Company of California, Hydro-Engineering, LLC, and Environmental Restoration Group (HMC et al). 2017. Land Application Impact Assessment. September.

Homestake Mining Company of California, Hydro-Engineering, LLC, Environmental Restoration Group, and RIMCON (HMC et al). 2014. Evaluation of Years 2000 Through 2013 Irrigation with Alluvial Ground Water. March. (ML14120A176)

Homestake Mining Company of California (HMC) and New Mexico Environment Department (NMED). 2009. Memorandum of Agreement Between Homestake Mining Company of California and the New Mexico Environment Department, Agreement Regarding Provision of Access to Drinking Water System. January 12.

Hsi, C-K.D. and D. Langmuir. (Hsi and Langmuir). 1985. Adsorption of uranyl onto ferric oxyhydroxides: Application of the surface complexation site binding model. Geochimica et Cosmochimica Acta. 49(11):2423-2432.

Hydro-Engineering, LLC (Hydro-Engineering). 1983. Ground-Water Discharge Plan for Homestake's Mill near Milan. (ML20217P436)

Hydro-Engineering, LLC (Hydro-Engineering). 1989. Corrective Action Amendment Request. Corrective Action Plan for Homestake's Tailings. September 15. ML12222A088

Hydro-Engineering, LLC (Hydro-Engineering). 1998. Evaluation of Injection of Reverse Osmosis Product Water, Consultant's report for Homestake Mining Company. January. (ML12291A910)

Hydro-Engineering, LLC (Hydro-Engineering). 2001. Ground-Water Hydrology for Support of Background Concentration at the Grant's Reclamation Site. (ML020350329)

Hydro-Engineering, LLC (Hydro-Engineering). 2002. Grants Reclamation Project, 2001 Annual Monitoring Report/Performance Review for Homestake's Grants Project Pursuant to NRC License SUA-1471 and Discharge Plan DP-200. Consulting Report for Homestake Mining Company of California. (ML020910079, ML020950518, ML020950539)

Hydro-Engineering, LLC (Hydro-Engineering). 2003. Grants Reclamation Project, 2002 Annual Monitoring Report/Performance Review for Homestake's Grants Project Pursuant to NRC License SUA-1471 and Discharge Plan DP-200. Consulting Report for Homestake Mining Company of California. (ML030990439, ML030990378, ML030990389, ML030990414, ML030990994))

Hydro-Engineering, LLC (Hydro-Engineering). 2015. 1200 GPM Zeolite System Construction Plans. Plans prepared for Homestake Mining Company of California, Grants, New Mexico. (ML17361A008)

Hydro-Engineering, LLC (Hydro-Engineering). 2017. 1200 GPM Zeolite System Construction Completion Report, Consultant's report for Homestake Mining Company, Grants, New Mexico. (ML17361A008)

Hydro-Engineering, LLC (Hydro-Engineering). 2019. Memorandum – Reformulated Mixing Model: Concept, Development, Implementation and Updates. April 2. (ML2026H284)

Hydro-Engineering, LLC (Hydro-Engineering). 2020a. Memorandum – Drain Down Model Modifications and Predictions

Hydro-Engineering, LLC (Hydro-Engineering). 2020b. Memorandum – Drain Down Model Predictions, Baseline and Contingency. September.

Hydro-Engineering, LLC (Hydro-Engineering). 2025. Memorandum – Drain Down Model Predictions, Baseline and Contingency. October.

Idaho National Engineering and Environmental Laboratory (INEEL). 2002. Estimating uranium partition coefficients from laboratory adsorption isotherms. INEEL/CON-02-0016.

Integrated Risk Information System. (IRIS). 2007. Boron and boron compounds. Washington, DC: Integrated Risk Information System. U.S. Environmental Protection Agency. http://www.epa.gov/iris/subst/index.html. April 11, 2007.

Integrated Risk Information System. (IRIS). 2022. Nitrite (CASRN 14797-65-0), nitrate (CASRN 14797-55-8). Integrated Risk Information System. Washington, DC: U.S. Environmental Protection Agency. https://iris.epa.gov/static/pdfs/0076_summary.pdf/ (accessed January 2022).

International Agency for Research on Cancer. (IARC). 1987. Evaluation of Carcinogenic Risks to Humans, Overall Evaluations of Carcinogenicity: An Updating of IARC Monographs Volumes 1 – 43. France: International Agency for Research on Cancer. http://monographs.iarc.fr/ENG/Classification/index.php.

International Agency for Research on Cancer. (IARC). 2006. Agents reviewed by the IARC monographs. Volumes 1–96. Lyon, France: http://monographs.iarc.fr/ENG/Classification/index.php. April 11, 2007.

International Agency for Research on Cancer. (IARC). 2012. Arsenic, metals, fibres, and dusts. International Agency for Research on Cancer. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans 100(Pt C):11-465.

International Atomic Energy Agency (IAEA). 2014. The Environmental Behaviour of Radium: Revised Edition. Technical Reports Series No. 476. IAEA, Vienna.

International Commission on Radiological Protection. (ICRP). 2008. Environmental protection: the concept and use of reference animals and plants. Annals of the ICRP, ICRP Publication 108 (38) nos. 4-6. ISSN 0146-6453, ISBN 978-0-444-52934-3.

Institute of Medicine (US) Panel on Micronutrients. (Institute of Medicine). 2001. Dietary Reference Intakes for Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc. Washington (DC): National Academies Press (US. Available from: https://www.ncbi.nlm.nih.gov/books/NBK222310/ doi: 10.17226/10026).

ISCORS, 2004. RESRAD-BIOTA: A Tool for Implementing a Graded Approach to Biota Dose Evaluation, User's Guide, Version 1. Department of Energy report no., DOE/EH-0676; ISCORS Technical Report 2004—2)

Johnson, R.H., S. Morrison, S. Morris, A. Tigar, W.L. Dam, and J. Dayvault. (Johnson et al). 2016. Column testing and 1D reactive transport modeling to evaluate uranium plume persistence processes. IMWA Proceedings, Freiberg, Germany.

Jones, L.H.P. (Jones). 1957. The solubility of molybdenum in simplified systems and aqueous soil suspensions. Journal of Soil Science. 8:313-327.

Kaplan, D.I. and R.J. Serne. (Kaplan and Serne). 1995. Distribution Coefficient Values Describing Iodine, Neptunium, Selenium, Technetium, and Uranium Sorption to Hanford Sediments. PNL-10379, SUP. 1. Pacific Northwest Laboratory, Richland, Washington.

Kaufmann, R.D., G.G. Eadie, and C.R. Russell. (Kaufmann et al.). 1976. Effects of Uranium Mining and Milling on Groundwater in the Grants Mineral Belt, New Mexico. Groundwater. 14:296-308.

Kelley, V.C. (Kelley). Tectonics of the Zuni-Defiance Region, New Mexico and Arizona. In: F.D. Trauger (ed.), Guidebook of Defiance-Zuni-Mt. Taylor Region, Arizona and New Mexico. Eighteenth Field Conference, October 19, 20, and 21 1967. Pp. 27-32.

Kochkodan, V., N.B. Darwish, and N. Hilal. (Kochkodan et al.). 2015. Chapter 2 – The Chemistry of Boron in Water. In pp. 35-63. Boron Separation Processes. Elsevier B.V.

Koritnig, S. (Koritnig). 1978. Fluorine. pp. 9-B-1 to 9-O-4. In K.H. Wedepohl (ed.) Handbook of Geochemistry. II-1/90. Springer-Verlag, Berlin.

Kuhn, A.K. and W. E. Jenkins. (Kuhn and Jenkins). 1986. Tailings Stabilization and Site Reclamation Plan.

Kurttio P, Harmoinen A, Saha H, Karpas Z, Komulainen H, Auvinen H. (Kurttio et al.) 2006. Kidney toxicity of ingested uranium from drinking water. American J of Kidney Diseases 47(6):972-982. June.

LaFlamme, B.D. and J. W. Murray. (LaFlamme and Murray). 1987. Solid/solution interaction: The effect of dissolved carbonate alkalinity on adsorbed thorium. Geochimica et Cosmochimica Acta. 51:243-250.

Langman, J.B., Sprague, J.E., and Durall, R.A. (Langman et al.). 2012. Geologic framework, regional aquifer properties (1940s-2009), and spring, creek, and seep properties (2009-10) of the upper San Mateo Creek Basin near Mount Taylor, New Mexico: U.S. Geological Survey Scientific Investigations Report 2012-5019.

Langmuir, D. (Langmuir). 1978. Uranium solution-mineral equilibrium at low temperatures with applications to sedimentary ore deposits. Geochimica et Cosmochimica Acta. 42:547-569.

Langmuir, D.L. (Langmuir). 1997. Aqueous Environmental Chemistry. Prentice Hall, Inc., New Jersey. 600 pp.

Langmuir, D. and J.S. Herman. (Langmuir and Herman). 1980. The mobility of thorium in natural waters at low temperatures. Geochimica et Cosmochimica Acta. 44:1753-1766.

Langmuir, D. and A.C. Riese. (Langmuir and Riese). 1985. The thermodynamic properties of radium. Geochimica et Cosmochimica Acta. 49:1593-1601.

Laughlin, A.W., R. W. Charles, K. Reid, and C. White. 1993. Field-trip guide to the geochronology of El Malpais National Monument and the Zuni-Bandera volcanic field, New Mexico. New Mexico Bureau of Mines & Mineral Resources, Bulletin 149.

Lee, K. (Lee). 1983. Vanadium in the aquatic ecosystem. Advances in Environmental Science and Technology. 13:155-187.

Lee, M., S. Sohn, and M. Lee. (Lee et al.). 2011. Ionic equilibria and ion exchange of molybdenum(VI) from strong acid solution. Bulletin of the Korean Chemical Society. 32:3687-3691.

Lee, J.Y. and J.I. Yun. (Lee and Yun). 2013 Formation of ternary CaUO2(CO3)2- and Ca2UO2(CO3)3(aq) complexes under neutral to weakly alkaline conditions. Dalton Transactions. 42:9862-9869.

Lindsay, W.L. (Lindsay). 1979. Chemical Equilibria in Soils. John Wiley & Sons, New York. 449 pp.

Liu, C., J. Shang, and J.M. Zachara. (Liu et al.). 2011. Multispecies diffusion models: A study of uranyl species diffusion. Water Resources Research. 47:W12514.

Lone Mountain Archaeological Services, Inc. (Lone Mountain). 2018. An Intensive Cultural Resources Survey for Homestake Mining Company Grants Reclamation Project. March.

Masscheleyn, P.H., R.D. Delaune, and W.H. Patrick, Jr. (Masscheleyn et al.). 1991. Effect of Redox Potential and pH on Arsenic Speciation and Solubility in a Contaminated Soil. Environmental Science and Technology, Vol. 25, p. 414-1419.

McBride, M.B. (McBride). 1980. A comparative electron spin resonance study of VO2+ complexation in synthetic molecules and soil organics. Soil Science Society of America Journal. 44:495-499.

McComish, M.F. and Ong, J.H. (McComish and Ong). 1988. Trace Metals. Chapter 7 in: Environmental Inorganic Chemistry. Bodek, I., Lyman, W.J., Reehl, W.F. and Rosenblatt, D.H. (eds.). Pergamon, Amsterdam, pp. 71-7.15-11.

McLemore, V. T. and Chenoweth, W. L., (McLemore and Chenoweth). 1989. Uranium resources in New Mexico: New Mexico Bureau of Mines and Minerals Resources, Resource Map 18, 36 p.

McLemore, V.T., and W.L. Chenoweth. (McLemore and Chenoweth). 2003. Uranium resources in the San Juan Basin, New Mexico: New Mexico Geological Society Guidebook 54, p. 165-178.

McLemore, V.T. (McLemore). 2007. Uranium Resources in New Mexico. Pre-Print 07-111. Society of Mining Engineers Annual Meeting, February 25-28, 2007, Denver, Colorado. 13 p

Meeussen, J.C.L., A. Scheidegger, T. Hiemstra, W.H. Van Riemsdijk, and M. Borkovee. (Meeussen et al.). 1996. Predicting multicomponent adsorption and transport of fluoride at variable pH in a goethite-silica sand system. Environmental Science and Technology. 30:481-488.

Mendy A, Gasana J, Vieira ER. (Mendy et al.) 2012. Urinary heavy metals and associated medical conditions in the US adult population. Int J Environ Health Res 22(2):105-118. 10.1080/09603123.2011.605877. Cited by ATSDR (2017).

Meyer, M.L. and P.R. Bloom. (Meyer and Bloom). 1997. Boric and silicic acid adsorption and desorption by a humic acid. Journal of Environmental Quality. 26:63-69.

Nash, J.T., H.C. Granger, and S.S. Adams. (Nash et al.). 1981. Geology and Concepts of Important Types of Uranium Deposits. Economic Geology. 75th Anniversary Volume. 63-116.

National Academy of Sciences (NAS). 1971. Fluorides. Committee on the Biologic Effects of Atmospheric Pollutants. Division of Medical Sciences. National Research Council. Washington, D.C.

National Academy of Science (NAS). 1977. Arsenic: Medical and Biological Effects of Environmental Pollutants. Washington, DC: The National Academies Press. https://doi.org/10.17226/9003.

National Council on Radiation Protection and Measurements (NCRP). 1996. Screening Models for Releases of Radionuclides to Atmosphere, Surface Water and Ground. Report No. NCRP-123I., Bethesda, MD 20814-3095. January.

National Ground Water Association (NGWA). 2017. Dissolved Mineral Sources and Significance. https://www.ngwa.org/what-is-groundwater/About-groundwater/dissolved-mineral-sources-and-significance. Accessed July 2017.

National Institutes of Health. (NIH). 2020. Molybdenum, Fact Sheet for Health Professionals. February 28. (Available from: https://ods.od.nih.gov/factsheets/Molybdenum-HealthProfessional).

National Institutes of Health. (NIH). 2022. Wireless Information for Emergency Responders. (https://webwiser.nlm.nih.gov/substance?substanceId=464&catId=93)

National Resource Conservation Service. (NRCS). 2022. Gridded National Soil Survey Geographic (gNATSGO) Database for New Mexico. Accessed online January. (https://nrcs.app.box.com/v/soils)

NatureServe Explorer. 2021. NatureServe Explorer: An Online Encyclopedia of Life. Version 7.1. NatureServe, Arlington, Virginia. https://explorer.natureserve.org. Accessed September 2021.

Neuman, S.P. and Wierenga, P.J. (Neuman and Wierenga). 2003. A Comprehensive Strategy for Hydrogeologic Modeling and Uncertainty Analysis for Nuclear Facilities and Site, NUREG/CR-6805

Newman, W.L. 1962. Distribution of Elements in Sedimentary Rocks of the Colorado Plateau – A Preliminary Report. Geological Survey Bulletin 1107-F.

New Mexico Department of Agriculture. (NMDA). 2018. New Mexico Agricultural Statistics 2017 Bulletin. November, 2018. Accessed May 2020 at https://www.nass.usda.gov/Statistics_by_State/New_Mexico/Publications/Annual_Statistical_Bulletin/2017/2017-NM-AG-Statistics.pdf

New Mexico Climate Center (NMCC) 2013. RAWS data for Grants, New Mexico for the year 2012. [Online Database]. http://weather.nmsu.edu/climate/ws/data/XGRA/.

New Mexico Environment Department (NMED). 2000. Assessing Human Health Risks Posed by Chemical: Screening-level Risk Assessment. Santa Fe, New Mexico.

New Mexico Environment Department. (NMED). 2005. New Mexico Environment Department Acceptance of Proposed Site Ground Water Contaminant Standards for the Homestake Mining Company Mill Site (CERCLIS ID NMD007860935), Milan, New Mexico. Letter to Sai Appaji, Superfund Division. EPA. April. (ML052490411).

New Mexico Environment Department. (NMED). 2014. New Mexico Environment Department Ground Water Discharge Permit DP-200 Renewal and Modification. September.

New Mexico Environment Department. (NMED). 2019. https://aqi.air.env.nm.gov Accessed February 2019

New Mexico Office of the State Engineer (NMOSE). 2018. State Engineer Order in the Matter of New Ground Water Appropriations and Applications to Transfer Water Rights to Existing Ground Water Wells in the Vicinity of the Bluewater/Homestake Former Milling Area of Cibola County within the Rio Grande Underground Basin. May.

New Mexico State University (NMSU). 2019. Climate in New Mexico. New Mexico Climate Center. https://weather.nmsu.edu/climate/about/.

National Oceanic and Atmospheric Association (NOAA). 2026. U.S. Climate Normals Quick Access. Accessed https://www.ncei.noaa.gov/access/us-climate-normals/#dataset=normalsannualseasonal&timeframe=30&location=NM&station=USC00293682, April 25, 2026

Novak-Szabo, T., Sipos, A.A., Shaw, S., Bertoni, D., Pozzebon, A., Grottoli, E., Sarti, G., Ciavola, P., Domokos G., and Jerolmack, D.J. (Novak-Szabo et al.). 2018. Universal characteristics of particle shape evolution by bedload chipping. Science Advances. 4:1-11.

Organization for Economic Co-Operation and Development (OECD). 2002. Environmental Remediation of Uranium Production Facilities. OECD, France.

Pacific Institute, 2003. Waste Not, Want Not: The Potential for Urban Water Conservation in California. November 2003. Appendix C: Industrial and Commercial Water Use: Table C-1 Water Use Coefficients by SIC Code, Industrial Sector. (https://pacinst.org/publication/waste-not-want-not/)

Panday, S. 2025. USG-Transport Version 2.6.0: Transport and Other Enhancements to MODFLOW-USG, GSI Environmental, October. http://www.gsi-net.com/en/software/free-software/USGTransport.Panday, Sorab, C.D. Langevin, R.G. Niswonger, M. Ibaraki, and J.D. Hughes. (Panday, et al) 2013. MODFLOW-–USG version 1: An unstructured grid version of MODFLOW for simulating groundwater flow and tightly coupled processes using a control volume finite-difference formulation: U.S. Geological Survey Techniques and Methods, book 6, chap. A45, 66 p.

Parker, R.L. (Parker). 1967. Chapter D: Composition of the Earth's Crust. In M. Fleischer (ed.) Data of Geochemistry. Geological Survey Professional Paper 440-D. U.S. Government Printing Office, Washington, D.C.

Parkhurst, D.L. and C.A.J. Appelo. (Pankhurst and Appelo). 2013. Description of Input and Examples for PHREEQC Version 3 - A Computer Program for Speciation, Batch-Reaction, One-Dimensional Transport, and Inverse Geochemical Calculations: U.S. Geological Survey Techniques and Methods, Book 6, Chap. A43, 497 p., available only at http://pubs.usgs.gov/tm/06a43.

Parnell, J., X. Wang, A. Raab, J. Feldman, C. Brolly, R. Michie, and J. Armstrong. (Parnell et al.). 2021. Metal flux from dissolution of iron oxide grain coatings in sandstones. Geofluids. Special Issue, Volume 2021. 14 pp.

Peng, C.Y. and G.V. Korshin. (Peng and Korshin). 2011. Speciation of trace inorganic contaminants in corrosion scales and deposits formed in drinking water distribution systems. Water Research. 45:5553-5563.

Pierce, M.J. and C.B. Moore. (Pierce and Moore). 1982. Adsorption of arsenite and arsenate on amorphous iron hydroxide. Water Resources. 16:1247-1253.

Polomski, J., H. Flühler, and P. Blaser. (Polomski et al). 1982. Fluoride-induced mobilization and leaching of organic matter, iron, and aluminum. Journal of Environmental Quality. 11:452-456.

Powell, K., Brown, P., Byrne, R., Gajda, T., Hefter, G., Leuz, A-K., Sjoberg, S. and Wanner, H. (Powell et al). 2011. Chemical speciation of environmentally significant metals with inorganic ligands. Part 4: The Cd^{2+} + OH^-, Cl^-, CO_3^{2-}, $SO4^{2-}$, and $PO4^{3-}$ systems (IUPAC technical report). Pure Applied Chemistry. 83(5): 1163–1214.

PRISM Climate Group. (PRISM) 2004. Oregon State University, http://prism.oregonstate.edu, created 4 Feb 2004.

Rai, D. and J.M. Zachara. (Rai and Zachara). 1984. Chemical Attenuation Rates, Coefficients, and Constants in Leaching Migration – Volume 1: A Critical Review. Prepared by Battelle Pacific Northwest Laboratories (Richland, WA) for Electric Power Research Institute (Palo Alto, CA).

Rao, S.M. and A. Sridharan. (Rao and Sridharan). 1984. Mechanism of sulfate adsorption by kaolinite. Clays and Clay Minerals. 32(5):414-418.

Reddy, K.J. and S.P. Gloss. (Reddy and Gloss). 1993. Geochemical speciation as related to the mobility of F, Mo, and Se in soil leachates. Applied Geochemistry. Supplementary Issue No. 2:159-163.

Resource West. 2018. Evaporation Study Report.

Rietra, R.P.J.J, T. Hiemstra, and W.H. van Riemsdijk. (Rietra et al.) 1999. Sulfate adsorption on goethite. Journal of Colloid and Interface Science. 218:511-521.

RIMCON. 2009. Pilot Testing of Uranium Removal by Zeolite Process. Consultant's Report prepared for Homestake Mining Company of California, Grants, New Mexico. (ML17361A008)

RIMCON. 2013. 300 GPM Zeolite-Based Water Treatment System Test Results. Consultant's report prepared for Homestake Mining Company of California, Grants, New Mexico. (ML17361A008)

RIMCON and Hydro-Engineering, LLC. (RIMCON and Hydro-Engineering). 1998. Soil Characterization and Attenuation Studies. Consultant's report prepared for Homestake Mining Company of California, Grants, New Mexico.

RIMCON and Hydro-Engineering, LLC. (RIMCON and Hydro-Engineering). 2012. 300 GPM Zeolite System Plans and Drawings. Plans prepared for Homestake Mining Company of California, Grants, New Mexico. (ML17361A008)

Rivett, M.O., S.R. Buss, P. Morgan, J.W.N. Smith, and C.D. Bemment. (Rivett et al). 2008. Nitrate attenuation in groundwater: A review of biogeochemical controlling processes. Water Research. 42:4215-4232.

Rosenzweig, A. (Rosenzweig). 1961. Mineralogical notes on the uranium deposits of the Grants and Laguna District, New Mexico. New Mexico Geological Society 12th Annual Fall Field Conference Guidebook. pp. 168-171.

Ryan, J.L. and D. Rai. (Ryan and Rai). 1987. Thorium(IV) hydrous oxide solubility. Inorganic Chemistry. 26:4140-4142.

Sample BE, DM Opresko, and JW Suter II. (Sample, et al.). 1996. Toxicological Benchmarks for Wildlife: 1996 Revision. Report ES/ER/TM86-R3. Lockheed Martin Energy Systems. June. https://rais.ornl.gov/documents/tm86r3.pdf (accessed October 28, 2021).

Santillan-Medrano, J. and J. J. Jurinak. (Santillan-Medrano and Jurinak). 1975. The chemistry of lead and cadmium in soils: Solid phase formation. Soil Science Society of America Proceedings. 29: 851-856.

Savannah River Site. (SRS) 1999. Ecological Screening Values. Manual: ERD-AG-003. April. https://www.srs.gov/general/programs/soil/ffa/rdh/p71.PDF (accessed 1 Nov 2021).

Sims, K. W. W., R. P. Ackert, F. C. Ramos, R. A Sohn, M.T. Murrell, and D.J. DePaolo. 2007. Determining eruption ages and erosion rates of Quaternary basaltic volcanism from combined U-series disequilibria and cosmogenic exposure ages. Geology, 35(6), 471–474. https://doi.org/10.1130/g23381a.1.

Skiff, K.E. and J.P. Turner. (Skiff and Turner). 1981. A Report on Alkaline Carbonate Leaching at Homestake Mining Company. November 12.

Smedley, P.L. and D.G. Kinniburgh. (Smedley and Kinniburgh). 2017. Molybdenum in natural waters: A review of occurrence, distributions, and controls. Applied Geochemistry. 84:387-432.

Sokolova, T.A. and S.A. Alekseeva. (Sokolova and Alekseeva). 2008. Adsorption of sulfate ions by soils (a review). Eurasian Soil Science. 41(2):140-148.

Southwest Regional Gap Analysis Project. (GAP). 2004. Provisional Digital Land Cover Map for the Southwestern United States. Version 1.0. RS/GIS Laboratory, College of Natural Resources, Utah State University. [Webpage] Located at http://earth.gis.usu.edu/swgap/landcover.html. Accessed: January10, 2011.

Stantec. 2019. Grants Reclamation Project EP-1 Geotechnical Investigation Report. May

Stantec. 2025. Design Report Large Tailings Pile Evapotranspiration Cover Project. June (ML25163A319)

Stone, W.J., F.P Lyford, P.F. Frenzel, N.H. Mizell, and E.T. Padgett. 1983. Hydrogeology and water resources of San Juan Basin, New Mexico: Socorro, New Mexico Bureau of Mines and Mineral Resources, Hydrologic Report 6, 70 pp Suter, G.W. and J.B. Mabrey. (Suter and Mabrey). 1994. Toxicological Benchmarks for Screening Potential Contaminants of Concern for Effects on Aquatic Biota 1994 Revision. Oak Ridge National Laboratory, Oak Ridge, TN. ES/ER/TM-96/Rl.

Suter, GW and CL. Tsao (Suter and Tsao). 1996. Toxicological benchmarks for screening potential contaminants of concern for effects on aquatic biota: 1996 revision. Oak Ridge National Laboratory, Lockheed Martin Energy Systems, Inc. Report ES/ER/TM-96/R2. June.

Texas Commission on Environmental Quality. (TCEQ). 2021. Ecological screening benchmarks. https://www.tceq.texas.gov/assets/public/remediation/eco/TCEQ%20Ecological%20Screening%20Benchmarks.xlsx (accessed 7 February 2021).

United States Army Corps of Engineers (USACE). 2010. Focused Review of Specific Remediation Issues, An Addendum to the Remediation System Evaluation for the Homestake Mining Company (Grants) Superfund Site, New Mexico (https://www.epa.gov/sites/default/files/2015-05/documents/hmc-rse-addendum-final-report.pdf)

United States Bureau of Labor Statistics. (Bureau of Labor). 2022. CPI Inflation Calculator https://data.bls.gov/cgi-bin/cpicalc.pl?cost1=5200.00&year1=201401&year2=202201

United States Census Bureau (Census). 2019. State and County Quick Facts – Cibola County, New Mexico. https://www.census.gov/quickfacts/cibolacountynewmexico Accessed July 2019.

United States Department of Energy (DOE). 1996. Final Programmatic Environmental Impact Statement for the Uranium Mill Tailings Remedial Action Groundwater Project. Volume 1. October.

United States Department of Energy (DOE). 2005. Remediation of the Moab Uranium Mill Tailings, Grand and San Juan Counties, Utah, Final Environmental Impact Statement. Volume 2. DOE/EIS-0355. July.

United States Department of Energy (DOE) 2011. Gasbuggy Site Assessment and Risk Evaluation: U.S. DOE Legacy Management Doc No. S05374, 40 pp., March

United States Department of Energy. (DOE). 2014. Site Status Report: Groundwater Flow and Contaminant Transport in the Vicinity of the Bluewater, New Mexico, Disposal Site. U.S. Department of Energy, Office of Legacy Management. November

United States Department of Energy. (DOE). 2019. 2017 Uranium Plumes in the San Andres-Glorieta and Alluvial Aquifers at the Bluewater, New Mexico, Disposal Site, February. (ML19081A121)

United States Department of Energy (DOE). 2020a. Fact Sheet: Lakeview, Oregon, Disposal/Processing Sites. USDOE Office of Legacy Management. May.

United States Department of Energy. (DOE). 2020b. Evaluating the Influence of High-Production Pumping Wells on Impacted Groundwater at the Bluewater, New Mexico, Disposal Site, 94 pp., August. (ML20259A314)

United States Department of Energy. (DOE). 2026. Site Management Guide. March. https://www.energy.gov/lm/articles/site-management-guide

United States Environmental Protection Agency (EPA). 1975. Impact of Uranium Mining and Milling on Water Quality in the Grants Mineral Belt, New Mexico. EPA 906/9-75-002. USEPA Region 6, Dallas, Texas. September.

United States Environmental Protection Agency (EPA). 1988. Federal Guidance Report No. 11: Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion. Office of Radiation Programs. EPA 520/1-88-020. Washington, DC. September.

United States Environmental Protection Agency (EPA). 1990. Secondary Drinking Water Standards: Guidance for Nuisance Chemicals. https://www.epa.gov/sdwa/secondary-drinking-water-standards-guidance-nuisance-chemicals#table. (Accessed 12 February 2022).

United States Environmental Protection Agency (EPA). 1995. Supplemental Guidance to RAGS: Region 4 Bulletins Ecological Risk Assessment. (http://www.epa.gov/region4/wastepgs/oftecser/otsguid.htm)

United States Environmental Protection Agency (EPA). 1996. Ecotox Thresholds. ECO Update, Office of Solid Waste and Emergency Response, Intermittent Bulletin Vol. 3, No. 2. EPA 540/F-95-038 PB95-963324. January 1996. (http://www.epa.gov/superfund/oerr/r19/ecotox).

United States Environmental Protection Agency (EPA). 1998. MINTEQA2/PRODEFA2, A geochemical assessment model for environmental systems – User manual supplements version 4.0: Athens, GA. National Exposure Research Laboratory, Ecosystems Research Division, 76. pp. Revised September 1999.

United States Environmental Protection Agency (EPA). 1999a. Understanding Variation in Partition Coefficient, Kd, Values. Volume 2: Review of Geochemistry and Available K_d Values for Cadmium, Cesium, Chromium, Lead, Plutonium, Radon, Strontium, Thorium, Tritium (^3H), and Uranium. August. (https://www.epa.gov/sites/default/files/2015-05/documents/402-r-99-004b.pdf)

United States Environmental Protection Agency (EPA). 1999b. Federal Guidance Report No. 13: Cancer Risk Coefficients for Environmental Exposure to Radionuclides. Office of Air and Radiation. EPA 402-R-99-001. Washington, DC. September.

United States Environmental Protection Agency (EPA). 2005a. Ecological Soil Screening Levels for Cadmium: Interim Final. OSWER Directive 9285.7-65. March. https://www.epa.gov/sites/default/files/2015-09/documents/eco-ssl_cadmium.pdf

United States Environmental Protection Agency (EPA). 2005b. Letter from Sai Appaji (EPA) to William Von Till (NRC) dated September 27, 2005, U.S. EPA, Region 6, Dallas, Texas.

United States Environmental Protection Agency (EPA). 2006. Fact Sheet: Homestake Mining Company. May 1, 2006. https://semspub.epa.gov/work/06/859904.pdf

United States Environmental Protection Agency (EPA). 2010a. Ecoregions of New Mexico. map.ftp://newftp.epa.gov/EPADataCommons/ORD/Ecoregions/nm/nm_pg.pdf. Accessed 15 June 2020.

United States Environmental Protection Agency (EPA). 2010b. Ecoregions of New Mexico, Summary Table: Characteristics of the Ecoregions of New Mexico. ftp://newftp.epa.gov/EPADataCommons/ORD/Ecoregions/nm/nm_back.pdf. Accessed 15 June 2020.

United States Environmental Protection Agency (EPA). 2014. Radiation Risk Assessment at CERLCA Sites: Q & A. Directive 9200.4-40. May.

United States Environmental Protection Agency (EPA). 2019. Exposure Handbook Chapter 3 (Update): Ingestion of Water and Other Select Liquids.

United States Environmental Protection Agency (EPA). 2020. Regional Screening Levels (2020) https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables. Accessed July 2020.

United States Environmental Protection Agency (EPA). 2021. Memorandum: National Remedy Review Board Recommendations for the Homestake Mining Site. Feasibility Study Scoping Meeting. June 15, 2021.

United States Environmental Protection Agency (EPA). 2022a. Office of Solid Waste and Emergency Response, Policy Statement: Role of Background in the CERCLA Cleanup Program, OSWER 9285.6-07P (May 1, 2022).

United States Environmental Protection Agency (EPA). 2022b. Ecotox knowledgebase https://cfpub.epa.gov/ecotox/search.cfm.

United States Nuclear Regulatory Commission (NRC). 1989. License Amendment No. 4. (ML060400039, ML20012E459)

U.S. Nuclear Regulatory Commission (NRC). 1993. Environmental Assessment for the Decommissioning and Reclamation of the Grants Mill and Tailings Ponds. Docket no. 40-8903. May.

United States Nuclear Regulatory Commission (NRC). 1996. Staff Technical Position for Alternate Concentration Limits for Title II Uranium Mills. February.

United States Nuclear Regulatory Commission (NRC). 1999. Letter from N. King Stablein, NRC, Acting Chief, Uranium Recovery Branch to Roy Cellan, Homestake Mining Company Regarding Approval of Radiological Cleanup of Soil and Buildings at the Grants Mill site (Amendment No. 32). ML080030067. January 28.

United States Nuclear Regulatory Commission (NRC). 2003a. Standard Review Plan for the Review of a Reclamation Plan for Mill Tailings Sites Under Title II of the Uranium Mill Tailings Radiation Control Act of 1978. NUREG-1620. USNRC, Washington, D.C.

United States Nuclear Regulatory Commission (NRC). 2003b. NUREG-1748. Environmental Review Guidance for Licensing Actions Associated with NMSS Programs. August.

United States Nuclear Regulatory Commission (NRC). 2003c. Application of Surface Complexation Modeling to Describe U(VI) Adsorption and Retardation at the Uranium Mill Tailings Site at Naturita, Colorado. NUREG/CR-6820. USNRC, Office of Nuclear Regulatory Research. Washington, D.C.

United States Nuclear Regulatory Commission (NRC). 2006a. Tests of U(VI) Adsorption Models in a Field Setting. NUREG/CR-6911. Office of Nuclear Regulatory Research. Washington, D.C.

United States Nuclear Regulatory Commission (NRC). 2006b. Environmental Assessment Related To Issuance Of A License Amendment For Homestake Mining Company Of California Grants, New Mexico Project. May.

United States Nuclear Regulatory Commission (NRC). 2008. Environmental Assessment Related to the Issuance of a License Amendment for Construction of a Third Evaporation Pond, Homestake Mining Company of California, Grants, New Mexico Project. License SUA-1471, Docket no. 040-08903. July. (ML080920594).

United States Nuclear Regulatory Commission (NRC). 2017a. Confirmatory Order Modifying License. SUA-1471, Docket 040-08903; March 28, 2017. (ML170761A753, ML170761A455)

United States Nuclear Regulatory Commission (NRC). 2017b. U.S. Nuclear Regulatory Commission. Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission, Draft for Comment. NUREG/BR-0058. April 2017.

United States Nuclear Regulatory Commission (NRC). 2020. Acceptance Review and Request of Supplemental Information, Homestake Mining Company of California, Groundwater Corrective Action Program and Request for Amendment to License SUA-1471, Docket No. 04008903, EA-16-114 (ML20142A195)

United States Nuclear Regulatory Commission (NRC). 2021a. Safety Evaluation Report (SER) Review of Reports for Compliance with Confirmatory Order EA-16-114, Conditions 15 and 15, for Release of Former Groundwater Land Application Areas, April (ML21032A306)

United States Nuclear Regulatory Commission (NRC). 2021b. Acceptance Review and Request of Supplemental Information, Homestake Mining Company of California, Groundwater Corrective Action

Program and Request for Amendment to License SUA-1471, Docket No. 04008903, EA-16-114, April. (ML21112A051)

United States Nuclear Regulatory Commission (NRC). 2022. Reassessment of NRC's Dollar Per Person-Rem Conversion Factor Policy Final Report. NUREG-1530, Rev. 1. February 2022.

United States Nuclear Regulatory Commission (NRC). 2022a. NUREG-1757 Volume 2 Revision 2. Consolidated Decommissioning Guidance Characterization, Survey, and Determination of Radiological Criteria, Final Report. Office of Nuclear Material Safety and Safeguards, Date Published: July 2022.

Voss, C.I. (Voss). 1984. *SUTRA – A finite-element simulation model for saturated-unsaturated, fluid-density-dependent ground-water flow with energy transport or chemically-reactive single-species solute transport*: U.S. Geological Survey Water-Resources Investigations Report 84-4369, 409 p.

Waite, T.D., J.A. Davis, T.E. Payne, G.A. Waychunas, and N. Xu. (Waite et al). 1994. Uranium(VI) adsorption to ferrihydrite: Application of a surface complexation model. Geochimica et Cosmochimica Acta. 58:5465-5478.

Waychunas, G.A., B.A. Rea, C.C. Fuller, and J.A. Davis. (Waychunas et al.). 1993. Surface chemistry of ferrihydrite – Part 1. EXAFS studies of the geometry of coprecipitated and adsorbed arsenate. Geochemica et Cosmochimica Acta. 57:2251-2269.

Wehrli, B. and W. Stumm. 1989. (Wehrli and Stumm). Vanadyl in natural waters: Adsorption and hydrolysis promote oxygenation. Geochimica et Cosmochimica Acta. 53:69-77.

Western Regional Climate Center (WRCC). 2019. New Mexico Prevailing Wind Summary. https://wrcc.dri.edu/cgi-bin/rawMAIN.pl?nmXGRA.

Weston Solutions, Inc. (Weston). 2016. Expanded Site Inspection Phase 1 - Groundwater Investigation Report for The San Mateo Creek Basin Uranium Legacy Site Cibola and McKinley Counties, New Mexico. Prepared for the U.S. Environmental Protection Agency Region 6. August.

Weston Solutions, Inc. (Weston). 2018. Phase 2 Ground-Water Investigation Report for The San Mateo Creek Basin Legacy Uranium Mines Site Cibola and McKinley Counties, New Mexico. Prepared for the U.S. Environmental Protection Agency Region 6. September 26. (https://semspub.epa.gov/work/06/100012366.pdf)

Wilson, John L. and Haude Guan. (Wilson and Guan), 2004. Mountain-Block Hydrology and Mountain-Front Recharge in Groundwater Recharge in A Desert Environment: The Southwestern United States, edited by Fred M. Phillips, James Hogan, and Bridget Scanlon, 2004, AGU, Washington, DC. (https://www.researchgate.net/publication/251871304_Mountain-Block_Hydrology_and_Mountain-Front_Recharge)

World Health Organization (WHO). 2004. Sulfate in Drinking Water.

Worthington Miller Environmental LLC (WME). 2020a. Geochemical Characterization of Tailings, Alluvial Solids and Groundwater Grants Reclamation Project. May.

Worthington Miller Environmental LLC (WME). 2020b. Conceptual Geochemical Model for the Alluvial Aquifer. Prepared for Homestake Mining Company. September.

Worthington Miller Environmental LLC (WME). 2021. Geochemical Conditions Affecting COC Transport in the San Andres/Glorieta Aquifer System, Cibola County, New Mexico, April

Worthington Miller Environmental, Arcadis, and Jacobs. (WME et al.), 2020. 2019 Supplemental Tailings and Characterization Study. Grants Reclamation Project. April.

Zheng, C., and Bennett, G.D. (Zheng and Bennett). 2002. Applied Contaminant Transport Modeling – Second Edition. John Wiley & Sons, Inc. New York. 621 pp.

Zhu, C., G.M. Anderson, and D.S. Burden. (Zhu et al). 2002. Natural attenuation reactions at a uranium mill tailings site, western U.S.A. Ground Water. 40:5-13.

Table 1.1-1 Current Groundwater Protection Standards, Other Agency Standards and Screening Criteria

Constituents	NRC STANDARDS															10 CFR 40 Appendix A, Criterion 5C	Other Agency Standards and Criteria Referenced						
	Alluvial Aquifer			Chinle Mixing Zone			Upper Chinle Non-Mixing Zone			Middle Chinle Non-Mixing Zone			Lower Chinle Non-Mixing Zone										
	Background[1]	NRC License	EPA/NMED BG Reassessment[4]	Background[1]	NRC License	EPA/NMED BG Reassessment[4]	Background[1]	NRC License	EPA/NMED BG Reassessment[4]	Background[1]	NRC License	EPA/NMED BG Reassessment[4]	Background[1]	NRC License	EPA/NMED BG Reassessment[4]		NMAC 20.6.2.3103.A Human Health	NMAC 20.6.2.3103.B Other Domestic	NMAC 20.6.2.3103.C Irrigation	EPA 40 CFR 192.32(a)(2)	EPA MCLs 40 CFR 141.23	EPA Topwater Screening Level	Applicable Standard
Metals (mg/L)																							
Silver (Ag)																0.05	**0.05**	-	-	0.05	-	-	0.05
Aluminum (Al)																	-	-	5.0	-	-	2.00	5
Arsenic (As)																0.05	0.01	-	-	0.05	0.010	-	0.01
Boron (B)																	-	-	0.75	-	-	0.4	0.75
Barium (Ba)																1.0	2	-	-	1	2	-	1
Beryllium (Be)																	0.004	-	-	-	0.004	-	0.004
Cadmium (Cd)																0.01	0.005	-	-	0.01	0.005	-	0.005
Cobalt (Co)																	-	-	0.05	-	-	0.0006	0.05
Chromium (Cr)																0.05	0.05	-	-	0.05	0.1	-	0.05
Copper (Cu)																	-	1.0	-	-	-	-	1
Fluorine (F)																	1.6	-	-	-	-	-	1.6
Iron (Fe)																	-	1.0	-	-	-	1.4	1
Mercury (Hg)																0.002	0.002	-	-	0.002	0.002	-	0.002
Lithium (Li)																	-	-	-	-	-	0.004	NA
Manganese (Mn)																	-	0.2	-	-	-	-	0.2
Molybdenum (Mo)	0.04	0.1		0.1	0.1	1	0.08	0.1	1	0.05	0.1	1	0.03	0.1	1		-	-	1.0	-	-	-	0.1
Nickel (Ni)																	-	-	0.2	-	-	0.039	0.2
Lead (Pb)																0.05	0.015	-	-	0.05	-	-	0.015
Antimony (Sb)																	0.006	-	-	-	0.006	-	0.006
Selenium (Se)	0.32	0.32	0.05	0.14	0.14	0.05	0.06	0.06	0.05	0.07	0.07	0.05	0.32	0.32	0.05	0.01	0.05	-	-	0.01	0.05	-	0.05
Tin (Sn)																	-	-	-	-	-	1.2	NA
Strontium (Sr)																	-	-	-	-	-	1.2	NA
Thallium (Tl)																	0.002	-	-	-	0.002	-	0.002
Uranium (U)	0.16	0.16	0.049	0.18	0.18	0.03	0.09	0.09	0.03	0.07	0.07	0.03	0.02	0.03	0.03	0.03	0.03	-	-	-	0.03	-	0.03
Vanadium (V)		0.02			0.01			0.01			*			*			-	-	-	-	-	-	0.01
Zinc (Zn)																	-	-	-	-	-	0.6	NA
Zirconium (Zr)																	-	-	-	-	-	0.00016	NA
Other Compounds/Parameters (mg/L unless noted otherwise)																							
pH (s.u.)																	-	6 to 9	-	-	-	-	NA
Chloride (Cl)[1]	71	250	250	96	250	250	412	412	250	63	250	250	634	634	250		-	250	-	-	-	-	250
Cyanide (CN)																	0.2	-	0.2	-	-	-	0.20
Ammonia (NH3-N)																	-	-	-	-	-	**NA**	NA
Nitrite (NO2-N)																	1	-	-	-	1	-	1
Nitrate (NO3-N)		12	10	15	15	10		*		4	*		3	*	10		10	-	-	-	10	-	10
Sulfate (SO4)[1]	1500	1,500	600	1,750	1,750	1,070	914	914	600	857	857	975	2,002	2,000	1,130		-	600	-	-	-	-	600
Sulfide																	-	-	-	-	-	NA	NA
Total Dissolved Solids[1]	2,734	2,734	1,350	3,140	3,140	2,620	2,010	2,010	2,400	1,557	1,560	1,000	4,140	4,140	3,870		-	1,000	-	-	-	-	1000
Radionuclides - Dissolved (pCi/L)																							
Adjusted Gross Alpha (GA)																15	-	-	-	-	-	-	15
Thorium-230 (Th-230)		0.3			*			*			*			*			-	-	-	-	-	-	0.3
Radium-226+228 (Ra-226+228)		5			*			*			*			*		5	5	-	-	-	-	-	5

*No current standard specified.

[1]Grants Reclamation Project Background Water Quality Evaluation Of The Chinle Aquifers, HMC 2003, revised June 2004.

[2]Constituent is not a hazardous constituent per 10 CFR 40 Appendix A, Criterion 5B(2).

[4]Groundwater Background Reassessment Technical Memorandum May 30, 2023 EPA/NMED

Table 1.2-1 Land Cover within Five Miles of the GRP

Land Use Type	Area (square meters)	Area (acres)	Percent of Total Area
Madrean Encinal	295,200	73	0.12
Madrean Pinyon-Juniper Woodland	900	0	0.00
Southern Rocky Mountain Ponderosa Pine Woodland	508,500	126	0.21
Great Basin Pinyon-Juniper Woodland	3,600	1	0.00
Inter-Mountain Basins Juniper Savanna	61,200	15	0.03
Colorado Plateau Pinyon-Juniper Woodland	971,015	240	0.41
Colorado Plateau Pinyon-Juniper Shrubland	56,169,000	13880	23.49
Rocky Mountain Lower Montane Riparian Woodland and Shrubland	194,400	48	0.08
Mogollon Chaparral	86,400	21	0.04
Rocky Mountain Subalpine-Montane Riparian Shrubland	146,572	36	0.06
Inter-Mountain Basins Greasewood Flat	6,667,886	1648	2.79
Inter-Mountain Basins Playa	25,200	6	0.01
Madrean Juniper Savanna	900	0.2	0.00
Inter-Mountain Basins Mat Saltbush Shrubland	24,912,975	6156	10.42
Inter-Mountain Basins Mixed Salt Desert Scrub	10,394,043	2568	4.35
Inter-Mountain Basins Big Sagebrush Steppe	616,991	152	0.26
Inter-Mountain Basins Semi-Desert Grassland	111,013,155	27432	46.43
Inter-Mountain Basins Semi-Desert Shrub Steppe	7,666,513	1894	3.21
Rocky Mountain Cliff, Canyon and Massive Bedrock	900	0.2	0.00
North American Warm Desert Bedrock Cliff and Bedrock	367,200	91	0.15
Colorado Plateau Mixed Bedrock Canyon and Tableland	15,300	4	0.01
Inter-Mountain Basins Volcanic Rock and Cinder Land	392,400	97	0.16
Cultivated Cropland	2,788,200	689	1.17
Disturbed/Successional - Grass/Forb Regeneration	76,500	19	0.03
Disturbed/Successional - Shrub Regeneration	1,940,400	479	0.81
Open Water (Fresh)	1,130,358	279	0.47
Developed, Open Space	5,861,863	1448	2.45
Developed, Low Intensity	5,930,474	1465	2.48
Developed, Medium Intensity	826,399	204	0.35
Developed, High Intensity	31,500	8	0.01

Table 1.2-2 Land Use within Five Miles of the GRP

Land Use	Percentage
Shrubland	87
Grassland/Pasture	3
Evergreen Forest	3
Developed/Open Space	3
Developed/Low Density	2
Developed/Medium Density	1
Open Water	1

NRCS, 2022

Table 1.2-3 Land Occupancy in Subdivisions near GRP

Subdivision	Number of Lots	Vacant	Percent Occupied
Broadview Acres	60	39	35%
Felice Acres	24	15	38%
Murray Acres	35	24	31%
Pleasant Valley Acres	36	18	50%
Valle Verde	110	93	15%

Source: HMC and Hydro-Engineering, 2025

Table 1.2-4 2020 Cibola County Demographics

Population Groups	New Mexico		Cibola County		McKinley County	
	Population	Percentage	Population	Percentage	Population	Percentage
Population	2,117,522.00		27,172		72,902	
Under 5 years		5.4		5.9		6.1
Under 18 years		22.6		23.6		27.7
65 years and over		18.5		17.3		13.4
Population per square mile	17		6		13	

	New Mexico		Cibola County		McKinley County		Grants		Milan		San Rafael	
	Population	Percentage	Population	Percentage	Population	Percentage	Population	Percentage	Population	Percentage	Population	Percentage
Total population (5-Year Estimate)	2,117,522		27,172		72,902		9,163		2,456		1,164	
Hispanic or Latino	1,010,811	47.7	8,644	31.8	8,611	11.8	4,566	50	1,180	48	714	61
White alone	1,485,973	70.2	11,322	41.7	10,776	14.8	5,204	57	1,458	59	806	69
Black or African American alone	68,409	3.2	444	1.6	793	1.1	217	2	75	3	12	1
American Indian and Alaska Native alone	263,615	12.4	12,898	47.5	58,845	80.7	2,311	25	613	25	87	7
Asian alone	55,997	2.6	332	1.2	1,200	1.6	219	2	19	1	13	1
Native Hawaiian and Other Pacific Islander alone	6,012	0.3	67	0.2	114	0.2	26	0	9	0	1	0
White alone not Hispanic or Latino.	772,952	36.5	5,538	20.4	5,946	8.2	2,147	23	649	26	450	39
Two or More Races not Hispanic or Latino	59,767	2.8	565	2.1	1,525	2.1	197	2	63	3	19	2

Labor	New Mexico	Cibola County	McKinley County
In civilian labor force, total percent of population over 16years (2019-2024)	58.7	43.8	50
In civilian labor force, female percent of population over 16years (2019-2024)	54.4	42.3	48.9

Income and Poverty	New Mexico	Cibola County	McKinley County	Grants	Milan	San Rafael
Median household income (in 2024 dollars)	$67,816	$50,759	$45,307	$47,183	$36,133	$83,423
Individuals below the poverty line	13.2	25.9	23.4	34.1%	32.2%	13.4%

Source: 2020 Census Data data.census.gov

Table 1.2-5 Grants-Milan Municipal Airport Temperature and Precipitation

Month	Maximum Average Temperature	Minimum Average Temperature	Mean Total Precipitation Inches
	Degrees Fahrenheit		
January	14.3	46.4	0.5
February	18.6	51.6	0.43
March	23.8	58.8	0.52
April	30.3	67.6	0.45
May	39.1	76.7	0.51
June	47.7	86.9	0.56
July	55.3	88.7	1.72
August	53.2	85.7	2.01
September	44.7	80.1	1.29
October	32.7	69.9	1.09
November	22	56.9	0.55
December	14.5	47.4	0.67
Annual Average 1953-2012	68.1	33	10.29

Source: https://wrcc.dri.edu/cgi-bin/cliMAIN.pl?nm3682
5/1953-11/2012

Table 1.2-6 2024 GRP Meteorological Data

Month		Wind Speed	Air Temperature	Relative Humidity	Monthly Precipitation	Average Daily Temperature
		(m/s)	(Degrees Celsius)	(%)	(in)	(Degrees Celsius)
January	maximum	11.1	13.5	95.2	0.46	0
	minimum	0.1	-15.1	14.4		
	average	2.8	-0.4	63.1		
February	maximum	14.0	16.8	91.2	0.29	2.76
	minimum	0.3	-10.0	6.6		
	average	3.7	2.8	48.5		
March	maximum	12.8	18.6	95.0	0.78	4.6
	minimum	0.3	-8.2	9.9		
	average	3.7	4.6	51.3		
April	maximum	12.5	24.0	93.1	0.32	9.41
	minimum	0.4	-5.1	6.2		
	average	3.5	9.4	34.3		
May	maximum	12.9	28.4	88.4	0.26	14.52
	minimum	0.3	-0.9	5.4		
	average	4.2	14.5	25.4		
June	maximum	15.5	32.9	90.7	3.66	21.47
	minimum	0.3	7.0	4.9		
	average	3.5	21.5	35.2		
July	maximum	14.2	33.0	90.1	0.44	22.62
	minimum	0.2	6.8	5.3		
	average	3.0	22.6	36.5		
August	maximum	9.3	33.0	91.9	0.82	21.56
	minimum	0.2	10.1	9.3		
	average	2.7	21.6	46.2		
September	maximum	11.4	29.5	89.6	0.61	18.21
	minimum	0.2	1.9	7.0		
	average	2.7	18.2	34.8		
October	maximum	11.6	27.4	91.1	0.95	12.95
	minimum	0.1	-8.4	6.6		
	average	2.8	13.0	34.6		
November	maximum	12.8	19.3	95.1	1.06	1.63
	minimum	0.2	-12.2	4.2		
	average	2.5	1.6	53.3		
December	maximum	9.6	16.8	86	0	0.94
	minimum	0	-13.8	7		
	average	2.1	0.9	44.6		

Source: HMC and Hydro-Engineering, 2025

Table 1.2-7 Wildlife Species Known to Occur in the GRP Area

Mammals	
Desert Cottontail	*Sylvilagus audubonii*
Black-tailed jackrabbit	*Lepus californicus*
Silky pocket mouse	*Perognathus flavus*
Botta's pocket gopher	*Thomomys bottae*
Deer mouse	*Peromyscus maniculatus*
Ord's kangaroo rat	*Dipodomys ordii*
White-throated woodrat	*Neotoma abigula*
Mexican woodrat	*Neotoma mexicana*
Spotted ground squirrel	*Spermophilus spilosoma*
Rock squirrel	*Spermophilus verigatus*
Black-tailed prairie dog	*Cynomys ludovicianus*
Coyote	*Canis latrans*
Mule deer	*Ordocoileus hemionus*
Birds	
American robin	*Turdus migratorius*
American kestrel	*Falco sparverius*
Barn swallow	*Hirundo rustica*
Bewick's wren	*Thryomanes bewickii*
Brewer's sparrow	*Spizella breweri*
Brown-headed cowbird	*Molothrus ater*
Bullock's oriole	*Icterus bullockii*
Burrowing owl	*Athene cunicularia*
Common raven	*Corvus corax*
Eastern meadowlark	*Sturnella magna*
Eurasian collared-dove	*Streptopelia decaocto*
Europeran starling	*Sturnus vulgaris*
Ferruginous hawk	*Buteo regalis*
Golden eagle	*Aquila chrysaetos*
Great blue heron	*Ardea herodias*
Hermit thrush	*Catharus guttatus*
Horned lark	*Eremophila alpestris*
House finch	*Haemorhous mexicanus*
House sparrow	*Passer domesticus*
Loggerhead shrike	*Lanius ludovicianus*
Mourning dove	*Zanaida macroura*
Northern mockingbird	*Mimus polyglottos*
Olive-sided flychatcher	*Contopus cooperi*
Red-tailed hawk	*Buteo jamaicensis*
Red-winged blackbird	*Agelaius phoeniceus*
Sage thrasher	*Orescoptes montanus*
Sagebrush sparrow	*Artemisiospiza nevadensis*
Say's phoebe	*Syornis saya*
Scaled quail	*Callipepla squamata*
Turkey vulture	*Cathartes aura*
Vesper sparrow	*Pooecetes gramineus*
Violet-green swallow	*Tachycineta thalassina*
Western kingbird	*Tyrannus verticalis*
Western meadowlark	*Sturnella neglecta*
White-crowned sparrow	*Zonotrichia leucophrys*
Yellow-rumped warbler	*Setophaga coronata*
Reptiles	
Western rattlesnake	*Crotalus oreganus*
Lesser earless lizard	*Holbrookia maculata*
Horned lizard	*Phrynosoma spp.*

Source: HDR, 2016

Table 1.2-8 Plant Species of Interest

Common Name	Scientific Name	Federal Status	State Status	Habitat/Seasonal Occurrence	Flowering Period	Likelihood of Occurrence
Cinder Phacelia	*Phacelia serrata*		NM rare	Primarily in deep volcanic cinders associated with volcanic cones, but also roadcuts and abandoned quarries in open, exposed, sunny locations; near ponderosa pine and piñon-juniper woodlands; 1,800-2,200 m (5,900-7,200 ft).	Flowers July to October, primarily late August and early September.	**Low** - More typical of coarse, rocky, highly well drained substrates; though limited potential may occur in areas of roadcuts, presence is unlikely in survey parcels.
Laguna Fame Flower	*Talinum brachypodum*		NM rare	Very shallow pockets of calcareous silt to clay soils overlying limestone or travertine, or fine silty sand overlying calcareous sandstones; open piñon-juniper woodland with little understory and scattered cacti and shrubs or Chihuahuan desert scrub. Preference for substrates of fine-grained non-calcareous iron rich red sandstone of the "Rimrock Country" of the Colorado Plateau.	Flowers June to August.	**Low** - Iron rich red sandstone typical of habitat areas not present, and vegetation associations are lacking (Chihauhuan desert scrub and cacti areas lacking).
New Mexico Sunflower	*Helianthus praetermissus*		NM rare	This species is known only from the type specimen collected in 1851. The locality was the head of the Rio Laguna (now Rio San Jose) at Ojo de la Gallina, on the north side of the Zuni Mountains. This species may have been named from a depauperate specimen of Helianthus paradoxus. Based on limited information, habitats may include perhaps wet ground.	Flowers in September.	**Low** - Species has not been observed since 1851.
Parish's Alkali Grass	*Puccinellia parishii*		E	Alkaline springs, seeps, and seasonally wet areas that occur at the heads of drainages or on gentle slopes at 800-2,200 m (2,600-7,200 ft) range-wide. The species requires continuously damp soils during its late winter to spring growing period. It frequently grows with Distichlis stricta (salt grass), Sporobolus airoides (alkali sacaton), Carex spp. (sedges), Scirpus spp. (bulrushes), Juncus spp. (rushes), Eleocharis spp. (spike rushes), and Anemopsis californica (yerba mansa).	Flowers May to June.	**Low to Medium** -Localized areas of wetted soils occur where piping and pumping persists and contain similar plant associations.
Pecos Sunflower (Puzzle Sunflower)	*Helianthus paradoxus*	T	E	Saturated saline soils of desert wetlands. Usually associated with desert springs (cienegas) or the wetlands created from modifying desert springs; 1,000-2,000 m (3,300-6,600 ft). Helianthus paradoxus is a true wetland species that requires saturated soils; adult plants still grow well when inundated	Flowers August to October.	**Low to Medium** - Localized areas of wetted soils occur where piping and pumping persists; however, likelihood of occurrence even in these areas is extremely low due to dominance of thick cattails.

Table 1.2-8 Plant Species of Interest

Common Name	Scientific Name	Federal Status	State Status	Habitat/Seasonal Occurrence	Flowering Period	Likelihood of Occurrence
Todilto Stickleaf	*Mentzelia todiltoensis*		NM rare	Outcrops of gypsum in the Todilto Formation; 1,700-1,910 m (5,600-5,840 ft).	Flowers open in the evening hours, late June through September.	**Low** - No gypsum outcrops occur in the study area.
Yeso Twinpod	*Physaria newberryi var. yesicola*		NM rare	The habitat is nearly barren badlands and canyon sides of various slopes and exposures between the elevations of 1700 and 2100 m. It occurs on sandy gypsum and other silty strata in short grass steppe and juniper savanna; in the Permian age Yeso Formation. The Yeso formation is comprised of a soft, silty sandstone interbedded with gypsum, limestone, shale and siltstone strata of various thickness.	Flowers April and May.	**Low** - May occur in shortgrass steppe, however Yeso formation not known to occur underlying area. Other ecological information indicates this species occurs in barren badlands and canyon sides.
Zuni Fleabane (Acoma Fleabane)	*Erigeron acomanus*	T	E	Steep, sandy slopes and benches beneath sandstone cliffs of the Entrada Sandstone Formation in piñon-juniper woodland; 2,100-2,170 m (6,900-7,100 ft). Vegetation cover is usually high; prefers north facing slopes. Typical of high selenium soils.	Flowers in July.	**Low -** No suitable habitat in survey areas.
Zuni Milkvetch	*Astragalus missouriensis var. accumbens*		NM rare	Habitats include gravelly clay banks and knolls, in dry, alkaline soils derived from sandstone, in piñon-juniper woodlands; 1,890-2,410 m (6,200-7,900 ft).	Flowers (March) May through June (August).	**Medium** - May be locally abundant within its limited range. Alkaline soils derived from sandstone occur in study area parcels.

Notes: Queried from NMNHP, http://nmrareplants.unm.edu/rarelist.php, January 2018, and USFWS IPAC for Cibola County, https://ecos.fws.gov/ipac/, January 2018.

T = threatened; E = endangered; NM = New Mexico

Source: Lone Mountain, 2018

Table 1.2-9 Wildlife Species of Interest

Type of Wildlife	Common Name	Scientific Name	Federal Status	State Status	Habitat/Seasonal Occurrence	Likelihood of Occurrence
Bat	Big Free-tailed Bat	*Nyctinomops macrotis*		NM sensitive	Seasonal migrant through much of its range. Found in urban areas, dry forests, and pine forests.	**Low** - May forage or pass through on a seasonal basis, but no suitable habitat is present.
Bat	Fringed Myotis	*Myotis thysanodes*		NM sensitive	Found at middle elevations of 1,200-2,150 m in desert, grassland, and woodland habitats. Roosts in caves, mines, rock crevices, buildings, and other protected sites.	**Low** - Study area is outside species elevation range.
Bat	Long-eared Myotis	*Myotis evotis*		NM sensitive	Widespread throughout the western U.S. in a wide range of habitats but most commonly found in coniferous forests. Prefer snags that reach high into or above the forest canopy and roost in crevices of sandstone boulders, stumps of clear-cut stands, abandoned buildings, cracks in the ground, caves, mines, and loose bark on living and dead trees.	**Low** - May forage or pass through on a seasonal basis.
Bat	Long-legged Myotis	*Myotis volans*		NM sensitive	Found in forested regions and roost in trees, rock crevices, fissures in stream banks, and buildings.	**Low** - May forage or pass through, but no suitable habitat in the study area.

Table 1.2-9 Wildlife Species of Interest

Type of Wildlife	Common Name	Scientific Name	Federal Status	State Status	Habitat/Seasonal Occurrence	Likelihood of Occurrence
Bat	Pale Townsend's Big-eared Bat	*Corynorhinus townsendii*		NM sensitive	Occurs in semi-desert shrublands, desert scrub, sagebrush, chaparral, piñon-juniper woodlands, and open montane forests. Roosts mostly in caves or mines; at night may roost in abandoned buildings. Will also use rock crevices and hollow trees as roost sites. In summer, this species occurs widely across the state.	**Medium** - Suitable habitat within study area. Species occurs widely in New Mexico during summer months over desert scrub and other habitats.
Bat	Southwestern Little Brown Myotis	*Myotis occultus*		NM sensitive	Found in a variety of habitats including urban and agricultural areas, riparian habitats, grasslands, and forests. Hibernates in caves and mines, and roosts in buildings in New Mexico. Typically found near lakes or streams as they prefer to forage over water, but will also forage among trees in open areas.	**Low** - May forage over ponds or roost in abandoned structures near study area.

Table 1.2-9 Wildlife Species of Interest

Type of Wildlife	Common Name	Scientific Name	Federal Status	State Status	Habitat/Seasonal Occurrence	Likelihood of Occurrence
Bat	Spotted Bat	*Euderma maculatum*		T	Forages in forest openings, piñon-juniper woodlands, riparian habitats, meadows, and agricultural fields. It is a broad-ranging species; however, its distribution is highly associated with prominent rock features. Rocky cliffs with suitable roosting substrate (e.g., crevices, cracks) are critical to this species. Perennial water sources also are important for this species.	**Low** - No suitable habitat in study area. May be found in forests or rocky cliffs outside study area.
Bat	Western Small-footed Myotis	*Myotis ciliolabrum*		NM sensitive	Common in arid desert, badland, and semiarid habitats. Occurs at low to moderate elevations as high as 9,500 ft in New Mexico. Wide ecological range from rock outcrops in open grasslands to canyons and woodlands. Roosts include cracks and crevices in cliffs, behind tree bark, mines, caves, tunnels, and other man-made structures.	**Medium** - Potential habitat for foraging within study area.

Table 1.2-9 Wildlife Species of Interest

Type of Wildlife	Common Name	Scientific Name	Federal Status	State Status	Habitat/Seasonal Occurrence	Likelihood of Occurrence
Bat	Yuma Myotis	*Myotis yumanensis*		NM sensitive	Found in a variety of habitats from juniper and riparian woodlands to desert regions near open water. Almost guaranteed to find near rivers, streams, ponds, and lakes. Roost in caves, attics, buildings, mines, underneath bridges, and other similar structures.	**Low** - No suitable aquatic habitat present. May roost in abandoned structures near study area.
Bird - MBTA	Bendire's Thrasher	*Toxostoma bendirei*	BCC		Desert species found in various dry, semi-open habitats, particularly areas of tall vegetation, cholla cactus, creosote bush and yucca, and in juniper woodlands.	**Medium -** Potential for breeding and foraging habitat to be present.
Bird - MBTA	Black-chinned Sparrow	*Spizella atrogularis*	BCC		Occupies brushy mountain slopes, open chaparral, and sagebrush habitats. Found mostly in arid scrub on hillsides from low foothills to 7,000 ft elevation.	**Medium -** Potential for breeding and foraging habitat to be present.
Bird - MBTA	Brewer's Sparrow	*Spizella breweri*	BCC		Occurs in the arid intermountain western U.S. Breeds on sagebrush flats and open scrubby areas. Sometimes found in stands of saltbush, on open prairie, or in pinyon-juniper woodland.	**High** - Suitable habitat present and within the common breeding range of the species.

Table 1.2-9 Wildlife Species of Interest

Type of Wildlife	Common Name	Scientific Name	Federal Status	State Status	Habitat/Seasonal Occurrence	Likelihood of Occurrence
Bird - MBTA	Chestnut-collared Longspur	*Calcarius ornatus*	BCC		Found along the plains and prairies, breeding in shortgrass prairies containing slightly longer grass and scattered taller weeds. Overwinters in shortgrass prairies and fields.	**Medium** - Habitat present for overwintering and migration route.
Bird - MBTA	Grace's Warbler	*Dendroica graciae*	BCC		Occupies pine-oak forests of mountain regions. Breeds in the tops of pine trees, spruce, fir, and oak thickets. Overwinters in pine-oak woodlands in the mountains.	**Low** - Potential to occur in nearby forests, not likely within project area due to lack of suitable habitat in the study area.
Bird - MBTA	Gray Vireo	*Vireo vicinior*	BCC	T	Open woodlands/shrublands, mountain slopes, mesas, open chaparral, scrub oak, and junipers; occurs in New Mexico only in warmer months (April-September). Found in elevations between 3,000 to 6,500 ft.	**Medium** - Habitat present for breeding during spring and summer.
Bird - MBTA	Lesser Yellowlegs	*Tringa flavipes*	BCC		Migrates through New Mexico and found in marshes, mudflats, shores, ponds, and open boreal woods.	**Medium** - Potential to pass through during migration.

Table 1.2-9 Wildlife Species of Interest

Type of Wildlife	Common Name	Scientific Name	Federal Status	State Status	Habitat/Seasonal Occurrence	Likelihood of Occurrence
Bird - MBTA	Lewis's Woodpecker	*Melanerpes lewis*	BCC		Prefers scattered or logged forests, river groves, burns, and foothills. During the summer requires open country for foraging so is often found in Cottonwood groves, open pine-oak woods, burned or cut-over woods. Overwinters in oak groves and orchards.	**Low -** No suitable habitat present within the study area. Likely present in forests outside the study area so may pass through incidentally.
Bird - MBTA	Loggerhead Shrike	*Lanius ludovicianus*	BCC	NM sensitive	Found in semi-open country with lookout posts, wires, trees, and scrub. Breeds in semi-open terrain from large clearings in wooded regions to open grasslands or desert with a few scattered trees or large shrubs.	**High/Confirmed** - Species observed and identified within the study area.
Bird - MBTA	Long-billed Curlew	*Numenius americanus*	BCC		Migrates through New Mexico and breeds only in the northeastern corner of New Mexico. Found on the high plains, and breeds in native dry grassland and sagebrush prairie.	**Medium** - Potential to pass through during migration.
Bird - MBTA	Marbled Godwit	*Limosa fedoa*	BCC		Migrates through New Mexico. Found in prairies, pools, shores, and tideflats. Breeds in the northern Great Plains in native prairies containing marshes or ponds.	**Low -** Potential for species to occur within the study area during migration.

Table 1.2-9 Wildlife Species of Interest

Type of Wildlife	Common Name	Scientific Name	Federal Status	State Status	Habitat/Seasonal Occurrence	Likelihood of Occurrence
Bird - MBTA	Mountain Plover	*Charadrius montanus*		NM sensitive	This species is a native of the short-grass prairie. Breeds on open plains at moderate elevations and overwinters in short-grass plains and fields, plowed fields, and sandy deserts.	**Medium** - Suitable habitat present for breeding and overwintering.
Bird - MBTA	Olive-sided Flycatcher	*Contopus cooperi*	BCC		Occupies coniferous forests, burns, and clearings. Breeds in coniferous forests in the mountains, particularly around the edges of open areas including bogs, ponds, and clearings.	**None** - No suitable habitat within the study area. Only suitable habitat is in the nearby forests.
Bird - MBTA	Pinyon Jay	*Gymnorhinus cyanocephalus*	BCC		Found in New Mexico year-round in pinyon pines and junipers. Seldom found outside of pinyon pines in pinyon-juniper woods, but may be seen in streamside groves, oak woods, or other habitats if the pinyon cone crop fails.	**None** - No suitable habitat within the study area. Only suitable habitat is in the forests outside the study area.
Bird - MBTA	Rufous Hummingbird	*Selasphorus rufus*	BCC		Migrates through New Mexico. Found along forest edges, streamsides, and mountain meadows. Occur at all elevations but more common in lowlands during spring, and mountain meadows during late summer and fall.	**Medium** - Potential to pass through during migration.

Table 1.2-9 Wildlife Species of Interest

Type of Wildlife	Common Name	Scientific Name	Federal Status	State Status	Habitat/Seasonal Occurrence	Likelihood of Occurrence
Bird - MBTA	Southwestern Willow Flycatcher	*Empidonax traillii extimus*	E	E	Riparian habitat consisting primarily of native trees such as willow; nest in shrubs and small trees in willow thickets, shrubby mountain meadows and deciduous woodlands along streams. Habitat patches must be at least 0.25 acres in size and at least 30 ft wide (USFWS 2014).	**Low** - No suitable riparian habitat is present for nesting or foraging. However, species known to use habitat patches so area containing willows should be assessed.
Bird - MBTA	Virginia's Warbler	*Vermivora virginiae*	BCC		Occupies oak canyons, brushy slopes, and pinyons. Breeds in New Mexico in dry mountainsides in scrub oak, chaparral, pinyon-juniper woods, or other low brushy habitats.	**Medium** - Suitable habitat present and project area within common breeding range for species.
Bird - MBTA	Yellow-billed Cuckoo (western pop)	*Coccyzus americanus occidentalis*	T	T	Mature riparian habitats most commonly associated with cottonwood or other native forests; associated with lowland deciduous woodlands, willow and alder thickets, second-growth woods, deserted farmlands and orchards.	**None** - No suitable riparian habitat is present within the study area.
Bird - Raptor	Arctic Peregrine Falcon	*Falco peregrinus tundrius*		T	Hunting habitats include croplands, meadows, riverbottoms, marshes and lakes; breeds in the Arctic tundra.	**Low** - Hunting habitat may be present during migration.

Table 1.2-9 Wildlife Species of Interest

Type of Wildlife	Common Name	Scientific Name	Federal Status	State Status	Habitat/Seasonal Occurrence	Likelihood of Occurrence
Bird - Raptor	Bald Eagle	*Haliaeetus leucocephalus*		T	Forested areas along coasts, large lakes, and rivers. Year-round occurrence	**Low** - May hunt or pass through incidentally, but study area does not contain suitable aquatic habitat preferred by species.
Bird - Raptor	Burrowing Owl	*Athene cunicularia*	BCC		Found in open grasslands, prairies, farmland, deserts, steppe environments, and airfields. Favors areas of flat, open ground with very short grass or bare soil. Most often associated with high densities of burrowing mammals, such as prairie dogs, but also airports, golf courses, vacant lots, industrial parks, and other open areas when prairie dog colonies are not present.	**High** - Suitable habitat present in prairie dog colonies within the study area.

Table 1.2-9 Wildlife Species of Interest

Type of Wildlife	Common Name	Scientific Name	Federal Status	State Status	Habitat/Seasonal Occurrence	Likelihood of Occurrence
Bird - Raptor	Golden Eagle	*Aquila chrysaetos*	BCC		Found in open mountains, foothills, plains, and open country. Require open terrain for hunting. Avoid developed areas and primarily found in the mountains up to 12,000 ft, canyonlands, rimrock terrain, and riverside cliffs and bluffs. Nest on cliffs and steep escarpments near open grasslands, chaparral, shrubland, and forests.	**High/Confirmed** - Suitable hunting habitat present within the study area, and nesting habitat present along cliffs outside of the study area. Incidental observations of this species have were noted previously.
Bird - Raptor	Long-eared Owl	*Asio otus*	BCC		Inhabit woodlands and conifer groves, favoring dense trees for nesting and roosting, and open country for hunting. Found in forests with extensive meadows, groves of conifers or deciduous trees in prairie country, or streamside groves in the desert. Typically avoids unbroken forests.	**Low** - May hunt or pass through, but will predominately nest and hunt outside study area in forested areas.

Table 1.2-9 Wildlife Species of Interest

Type of Wildlife	Common Name	Scientific Name	Federal Status	State Status	Habitat/Seasonal Occurrence	Likelihood of Occurrence
Bird - Raptor	Mexican Spotted Owl	*Strix occidentalis lucida*	T		Inhabits canyon and montane forests and rocky canyons from southern Utah, Colorado, Arizona, New Mexico, and western Texas. The highest densities of this species occur in mixed-conifer forests with minimal human disturbance.	**Low** - May hunt or pass through, but will predominately nest and hunt outside study area in forested, undisturbed areas.
Bird - Raptor	Northern Goshawk	*Accipiter gentilis*			Occupy coniferous and mixed forests, and are generally restricted to wooded areas but may also be found in open woods or edges. In the western U.S. they are found in the forest along riparian corridors and in more open habitat such as sagebrush steppes. Nest in mature, old-growth forests with more than 60% closed canopy throughout their entire range.	**Low** - May hunt or pass through incidentally, but will predominately nest and hunt outside study area in dense, forested areas.
Bird - Raptor	Peregrine Falcon	*Falco peregrinus*		T	Breeding territories located on cliffs in wooded/forested habitats; hunting habitats include croplands, meadows, riverbottoms, marshes and lakes.	**High** - Suitable hunting habitat present within the study area, and nesting habitat present along cliffs outside of the study area.

Table 1.2-9 Wildlife Species of Interest

Type of Wildlife	Common Name	Scientific Name	Federal Status	State Status	Habitat/Seasonal Occurrence	Likelihood of Occurrence
Fish	Rio Grande Chub	*Gila pandora*		NM sensitive	Most commonly found in flowing pools of headwaters, creeks, and small rivers near inflow of riffles, undercut banks, aquatic vegetation, and plant debris. Can also occur in impoundments.	**None -** No suitable habitat present within the study area.
Fish	Zuni Bluehead Sucker	*Catostomus discobolus yarrowi*	E	E	Most frequently occurs in stream reaches with cobble and bedrock substrates with slow- to moderate-velocity water. In New Mexico, the sucker currently is limited to the headwaters of the Zuni River drainage.	**None -** No suitable habitat present within the study area.
Invertebrate	Socorro Mountainsnail	*Oreohelix neomexicana*		NM sensitive	Occupies a variety of habitats from lush forested canyons to extreme conditions. Found in New Mexico in scant cover under loose stones, limestone rocks, and other single stones in areas of rich leaf litter.	**None -** No suitable habitat present within the study area.
Mammal	Cebolleta Pocket Gopher	*Thomomys bottae paguatae*		NM sensitive	Currently known only from a small area in Cibola County. Prefers perennial riparian vegetation including willow, cottonwood, alder, and maple. Surrounding uplands in known locality include large sandstone cliffs with juniper, piñon, and sage.	**Low** - Evidence of gophers identified in the project area, but unlikely this species due to its preference for riparian habitat.

Table 1.2-9 Wildlife Species of Interest

Type of Wildlife	Common Name	Scientific Name	Federal Status	State Status	Habitat/Seasonal Occurrence	Likelihood of Occurrence
Mammal	Common Hog-nosed Skunk	*Conepatus leuconotus*		NM sensitive	Inhabits a variety of habitats including sycamore, cottonwood, and rabbitbrush riparian habitats, pinion-juniper woodlands, and montane shrublands. Prefers rocky areas. Uses rock crevices, hollow logs, underground burrows, caves, mines, woodrat houses, or buildings as dens.	**Medium -** Potential for habitat to be present.
Mammal	Gunnison's prairie dog (prairie subspecies)	*Cynomys gunnisoni zuniensis*		NM sensitive	Found in plains and desert grassland, and to a lesser extent the Great Basin desert scrub. Occurs in low valleys, but also is common in parks and meadows in the montane forests up to at least 10,000 feet.	**Medium** - Potential for habitat to be present as there are numerous prairie dog colonies. Species needs to be confirmed.
Mammal	Northern Pocket Gopher	*Thomomys talpoides taylori*		NM sensitive	Found in a wide variety of habitats ranging from sagebrush steppe, mountain meadows, tundra, agricultural fields, grasslands, and gardens or lawns. Prefer deep soils along streams, meadows, and cultivated fields. Also found in rocky soils and clay.	**High** - Evidence of gophers identified in the project area.

Table 1.2-9 Wildlife Species of Interest

Type of Wildlife	Common Name	Scientific Name	Federal Status	State Status	Habitat/Seasonal Occurrence	Likelihood of Occurrence
Mammal	Red Fox	*Vulpes vulpes*		NM sensitive	Occupies a wide range of habitats including grasslands, deserts, mountains, forests, and suburban areas. Prefer wooded areas but can adapt to different environments.	**Medium -** Potential for habitat to be present.
Mammal	Ringtail	*Bassariscus astutus*		NM sensitive	Found in a variety of habitats such as semi-arid oak forests, pinyon pine or juniper woodlands, montane conifer forests, chaparral, desert, dry tropical habitats, and rocky or cliff areas. This species adapts well to disturbed areas and frequently found in human populated areas.	**Medium -** Potential for habitat to be present.
Reptile	Southwestern Fence Lizard	*Sceloporus cowlesi*		NM sensitive	Found in a variety of habitats including semidesert grasslands, woodlands, rocky canyons, and forested slopes. Usually encountered in open, sunlit areas with plenty of basking sites such as rock piles, wood piles, and fallen logs.	**Medium -** Potential for habitat to be present.

Notes: Queried from Bison-M, http://bison-m.org/index.aspx, January 2018, and USFWS IPAC for Cibola County, https://ecos.fws.gov/ipac/, January 2018.

T = threatened; E = endangered; BCC= bird of conservation concern; NM = New Mexico

Source: Lone Mountain, 2018

Table 1.5-1 Proposed Alternate Concentration Limits

Constituents (mg/L unless noted)	Applicable Standard	[a]Proposed ACL
Arsenic (As)	0.01	0.3
Cadmium (Cd)	0.005	0.03
Molybdenum (Mo)	0.1	116
Selenium (Se)	0.01	4.2
Uranium (U)	0.03	50.0
Vanadium (V)	0.01	0.3
Fluoride (F)	1.6	9
Nitrate (NO3-N)	1	41
Combined Radium-226+228 (Ra-226+228) (pCi/L)	5	11
Thorium-230 (Th-230) (pCi/L)	0.3	51

[a]For POC wells C2, D1, M3, SB, SZ, X.

Table 2.1-1 Estimated Concentrations in the Large Tailings Pile

Parameter	Uranium	Molybdenum
Mass of Tailings (kg)	1.91×10^{10}	
Bulk Density (kg/m^3)	1,600	
Bulk Porosity	0.2	
Pore Volume (L)	2.38×10^{9}	
Median Mass Released[1] (mg/kg)	0.291	0.108
Maximum Mass Released[1] (mg/kg)	11.2	3.6
Calculated Median Pore Volume Concentration[2] (mg/L)	2.3	0.86
Calculated Maximum Pore Volume Concentration[2] (mg/L)	89.9	28.8
2024 Large Tailings Pile Average Saturated Concentration[3] (mg/L)	5.06	12.85
2020 Large Tailings Pile Maximum Sump Concentration[4] (mg/L)	20.4	46.7
Reasonable Upper Bound Average Unsaturated Tailings Concentration (mg/L)	10	25

[1] Median and maximum values from weekly tests during the 20-week humidity cell test (Appendix 2.1-A).

[2]Concentration = (mg/kg released x kg tailings)/1 PV.

[3]HMC and Hydro-Engineering, 2025 Table 3.3-1

[4]HMC and Hydro-Engineering, 2025, Table B.1-2

Table 2.1-2 Simulated Large Tailings Pile Seepage Recharge Rates

Simulation Time	Large Tailings Pile Seepage Recharge Volumetric Rate (gpm)
Pre-2002 initialization	40.4
2002	62.5
2003	151
2004	201
2005	187
2006	142
2007	142
2008	138
2009	184
2010	178
2011	150
2012	139
2013	154
2014	200
2015	131.7
2016	76.6
2017	46.7
2018	29.7
2019	19.7
2020	13.6
2021	9.8
2022	7.3
2023	5.7
2024	4.6

Table 2.2-1 Summary of Constituent Characterization in Large Tailings Pond and Groundwater

			NRC & HMC Large Tailings Pile Sampling		HMC Large Tailings Pile Sampling			Groundwater Sampling	
	EPA Tapwater Screening Level	Lowest Promulgated Standard	Not Retained	Retained	Excluded	Retained	Indeterminate	Not Retained	Retained
Metals (mg/L)									
Silver (Ag)		0.05	✓		✓			✓	
Aluminum (Al)		5	✓		✓			✓	
Arsenic (As)		0.01		✓		✓			✓
Boron (B)		0.75		✓			✓	✓	
Barium (Ba)		1	✓		✓			✓	
Beryllium (Be)		0.004		✓			✓	✓	
Cadmium (Cd)		0.005		✓	✓				✓
Cobalt(Co)		0.05	✓		✓			✓	
Chromium (Cr)		0.05	✓		✓			✓	
Copper (Cu)		1	✓		✓			✓	
Iron (Fe)		1	✓			✓		✓	
Gallium (Ga)	NA	NA	✓		✓			✓	
Mercury (Hg)		0.002	✓			✓		✓	
Lithium (Li)	0.004	NA		✓			✓	✓	
Manganese (Mn)		0.2	✓			✓		✓	
Molybdenum (Mo)		0.1		✓		✓			✓
Nickel (Ni)		0.2	✓		✓			✓	
Lead (Pb)		0.015		✓			✓	✓	
Antimony (Sb)		0.006		✓			✓	✓	
Selenium (Se)		0.01		✓		✓			✓
Silica (Si)	NA	NA	✓		✓			✓	
Tin (Sn)	1.2	NA	✓				✓	✓	
Strontium (Sr)	1.2	NA	✓				✓	✓	
Titanium (Ti)	NA	NA	✓		✓			✓	
Thallium (Tl)		0.002	✓				✓	✓	
Uranium (U)		0.03		✓			✓		✓
Vanadium (V)		0.02		✓		✓			✓
Zinc (Zn)	0.6	NA	✓		✓			✓	
Zirconium (Zr)	0.00016	NA					✓		
Major Ions (mg/L)									
Bromine (Br)	NA	NA	✓		✓			✓	
Calcium (Ca)	NA	NA	✓		✓			✓	
Magnesium (Mg)	NA	NA	✓		✓			✓	
Sodium (Na)	NA	NA	✓		✓			✓	
Other Compounds/Parameters (mg/L unless noted otherwise)									
Cyanide (CN)		0.2	✓		✓			✓	
Carbonate	NA	NA	✓		✓			✓	
Bicarbonate	NA	NA	✓		✓			✓	
Chloride (Cl)		250		✓		✓		✓	
Fluoride (F)		1.6		✓		✓			✓
Ammonia as Nitrogen	NA	NA		✓		✓		✓	
Nitrite as Nitrogen		1				✓			
Nitrate as Nitrogen		10		✓		✓			✓
Phosphorus	NA	NA	✓		✓			✓	
Phospate	NA	NA	✓		✓			✓	
Sulfate	-	600		✓		✓		✓	
Total Organic Halides	NA	NA	✓		✓			✓	
Total Kjeldahl Nitorigen (TKN)	NA	NA	✓		✓			✓	
Total Organic Carbon (TOC)	NA	NA	✓		✓			✓	
Total Dissolved Solids		1000	✓				✓	✓	
Total Suspended Solids	NA	NA	✓		✓			✓	
Radionuclides (pCi/L)									
Adjusted Gross Alpha		15	✓				✓	✓	
Lead-210 (diss)	NA	NA		✓			✓		
Thorium-230 (diss)		0.3		✓		✓			✓
Combined Radium-226 + Radium-228 (diss)		5		✓		✓			✓
Organics									
All organics		Varies	✓		✓			✓	

Table 3.1-1 GRP Model Layering Approach

Hydrostratigraphic Unit	Model Layer	Geologic Period	Hydrogeologic Characteristics
Alluvium and Basalt	1	Quaternary	Limited Areas of Saturation in the San Mateo Creek Basin (Weston, 2018)
Alluvium	2	Tertiary/Quaternary	Limited Areas of Saturation in the San Mateo Creek Basin (Weston, 2018)
Upper Chinle Shale	3	Triassic	Aquitard (HDR, 2020)
Upper Chinle Water-yielding Unit	4	Triassic	Water-yielding (HDR, 2020)
Upper Middle Chinle Shale	5	Triassic	Aquitard (HDR, 2020)
Middle Chinle Water-yielding Unit	6	Triassic	Water-yielding (HDR, 2020)
Lower Middle Chinle Shale	7	Triassic	Aquitard (HDR, 2020)
Lower Chinle Water-yielding Unit	8	Triassic	Water-yielding (HDR, 2020)
Lower Chinle Shale	9	Triassic	Aquitard (HDR, 2020)
Upper San Andres Limestone	10	Permian	Water-yielding (HDR, 2021)
San Andres Limestone/ Glorieta Sandstone (SAG)	11	Permian	Primary Aquifer (Stone et al., 1983)

Table 3.1-2 San Andres - Glorieta Aquifer Pumping Rates for Model Calibration

Model Period	B-18	B-19	949	Milan 1	Milan 3	Milan4	Grants 1	Grants 3
Steady State	247	807	858	67	245	105	109	1438
2002	267	768	800	90	311	113	97	1427
2003	353	635	768	90	322	106	55	1334
2004	561	520	850	78	288	98	131	1053
2005	774	236	710	88	313	111	194	1144
2006	646	435	462	65	332	139	65	1323
2007	685	373	776	111	227	134	39	1214
2008	589	411	757	114	206	139	80	1231
2009	660	329	801	120	132	142	154	1113
2010	530	535	755	105	166	115	251	907
2011	542	386	730	116	148	126	496	627
2012	420	663	575	115	181	110	31	1134
2013 1st Half	255	488	628	127	208	58	35	1235
2013 2nd Half	255	488	628	127	208	58	35	1235
2014 1st Half	503	479	530	101	138	58	44	1242
2014 2nd Half	503	479	530	101	138	58	44	1242
2015 1st Half	275	472	737	142	70	126	5	1096
2015 2nd Half	275	472	737	142	70	126	5	1096
2016 1st Half	438	345	719	130	105	102	23	1176
2016 2nd Half	438	345	719	130	105	102	23	1176
2017	348	262	547	96	75	82	266	981
2018	474	185	464	130	57	55	81	1018
2019	278	0	501	119	95	85	175	999
2020	324	0	203	94	61	68	53	1032
2021	0	0	0	164	85	139	419	686

Table 3.1-3 Hydraulic Parameterization Summary

Model Layer Number	Hydrostratigraphy	GRP Model Hydraulic Parameter Values			
		Horizontal Hydraulic Conductivity (ft/day)	Vertical Hydraulic Conductivity (ft/day)	Specific Yield (unitless)	Specific Storage (1/ft)
1	Basalt	395	172.0	0.03	3×10^{-7}
1	Alluvium	18.4 - 29	0.8 - 15.3	0.20	1×10^{-6}
2	Alluvium	13 - 154	0.5 - 66.7	0.2	1×10^{-6} - 3×10^{-6}
3	Chinle Shale	3.2×10^{-3}	3.2×10^{-4}	0.02	1×10^{-6}
4	Upper Chinle Water-Yielding Unit	0.7 – 29.8	0.1 – 0.6	0.02	1×10^{-6}
5	Chinle Shale	3.2×10^{-3}	3.2×10^{-4}	0.02	1×10^{-6}
6	Middle Chinle Water-Yielding Unit	0.66 – 5.5	0.013 – 0.11	0.02	1×10^{-6}
7	Chinle Shale	3.2×10^{-3}	3.2×10^{-4}	0.02	1×10^{-6}
8	Lower Chinle Water-Yielding Unit	0.62 - 25.6	0.012 - 0.5	0.02	1×10^{-6}
9	Chinle Shale	3.2×10^{-3}	3.2×10^{-4}	0.02	1×10^{-6}
10	Upper San Andres Limestone	1.8	0.04	0.06	3×10^{-7}
11	San Andres – Glorieta Aquifer	600	12	0.05	3×10^{-7}

Table 3.1-4 Bulk Simulated Groundwater Elevation Calibration Statistics

Statistic	All Layers	Model Layer 1 (Alluvial Aquifer)
Correlation	0.96	0.96
Average Residual (ft)	-2.00	-2.70
Absolute Avg Residual	5.6	5.1
Maximum Residual (ft)	84	84
Minimum Residual	-98	-52
Number of Observations	41,652	19,000
SSE (Sum of Squares for Errors)	1,500,000	86,000
MSE (Mean Square Error)	65	46
RMSE (Root Mean Square Error)	8.1	6.8
Observation Range	240	190

Table 3.1-5 Alluvial Aquifer Simulated Water Balance

Inflows (acre-feet)																			
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Injection	2,029	2,228	2,316	2,335	2,240	1,905	2,067	2,115	2,014	1,860	2,077	2,591	2,451	2,292	1,921	1,551	1,764	912	769
Storage	2,586	2,075	1,982	1,769	1,405	1,381	1,771	1,509	982	1,219	794	506	523	438	1,140	1,479	1,235	1,450	1,248
Recharge	1,180	1,384	1,485	1,548	1,419	1,340	1,329	1,420	1,336	1,269	1,238	1,246	1,320	1,210	1,121	1,073	1,046	1,030	1,020
General Head Boundaries	190	188	187	187	189	191	193	195	197	199	201	203	204	204	204	204	205	206	207
Upper Chinle Water-Yielding Unit	49	42	45	53	46	51	49	48	45	45	44	44	46	59	41	38	39	46	32
Middle Chinle Water-Yielding Unit	63	57	51	44	42	42	40	38	38	39	40	38	37	43	41	46	38	38	39
Lower Chinle Water-Yielding Unit	81	72	73	74	72	70	71	73	71	69	67	66	66	67	68	68	67	66	65
San Andres Aquifer1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	20	24	0
Upper Chinle Shale	15	14	13	12	12	11	12	11	10	9	9	9	8	8	8	7	7	7	7
Upper Middle Chinle Shale	7	6	5	4	4	4	4	4	3	3	3	3	3	3	3	3	3	3	3
Lower Middle Chinle Shale	9	7	6	5	4	4	3	3	2	2	2	2	2	1	1	1	1	1	1
Lower Chinle Shale	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Outflows (acre-feet)																			
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Collection	1,736	1,663	1,662	1,390	1,112	1,269	1,510	1,284	720	696	840	750	840	444	953	1,133	1,099	636	356
Storage	432	420	639	847	643	351	119	271	508	484	339	745	508	705	234	78	178	187	64
General Head Boundaries	24	24	24	24	24	24	24	24	24	24	24	23	23	23	23	23	23	23	23
Drains	178	177	176	175	174	172	171	168	166	163	161	158	155	152	149	146	143	141	138
Upper Chinle Water-Yielding Unit	216	248	245	256	289	264	297	273	270	238	264	261	278	156	242	268	294	206	233
Middle Chinle Water-Yielding Unit	147	170	175	193	187	167	169	181	169	158	162	161	177	162	182	185	173	168	155
Lower Chinle Water-Yielding Unit	62	67	75	95	99	98	111	109	103	103	106	113	117	119	117	107	106	103	99
San Andres Aquifer1	2,277	2,047	1,836	1,688	1,501	1,230	1,653	1,596	1,239	1,296	1,037	955	960	919	958	878	822	789	830
Upper Chinle Shale	238	247	246	245	246	241	240	239	239	236	237	235	235	227	231	234	234	232	233
Upper Middle Chinle Shale	128	135	138	143	146	145	145	146	143	144	145	143	141	140	142	141	138	136	134
Lower Middle Chinle Shale	155	156	160	161	159	164	171	171	167	169	170	172	175	177	178	176	173	169	165
Lower Chinle Shale	617	719	785	816	852	874	929	951	951	1,001	989	993	1,051	1,104	1,140	1,106	1,041	992	961
Inflows - Outflows	0.1	0.1	0.0	0.0	-0.1	-0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	-0.1	0.1	0.0	0.0

Note: (1). For purposes of the water balance calculation, the upper 20 feet of the San Andres Limestone is considered part of the San Andres – Glorieta Aquifer

Table 3.1-6 Ambient Concentrations for Transport Model Calibration

Unimpacted Area Unit	Uranium (mg/L)	Molybdenum (mg/L)	Selenium (mg/L)
Alluvial Aquifer	0.02	0.005	0
Upper Chinle	0.02	0.005	0
Middle Chinle	0.02	0.005	0
Lower Chinle	0.02	0.005	0
San Andres Aquifer	0.005	0.005	0

Table 3.1-7 Modeled Dispersivity Values by Hydrostratigraphic Unit

Unit	Model Layer	Longitudinal Horizontal (feet)	Longitudinal Vertical (feet)	Transverse Horizontal (feet)	Transverse Vertical (feet)
Alluvium	1,2	50	0.5	0.5	0.05
Chinle Sandstones	4, 6, 8	20	0.2	0.2	0.02
Chinle Shales	3, 5, 7, 9	2	0.02	0.02	0.0002
San Andres-Glorieta	10, 11	200	20	20	2

Table 3.1-8 Modeled Dual Domain Parameters

Parameter		Uranium	Molybdenum	Selenium	Conservative Surrogate Constituent
Geometry Coefficient (β)		3	3	3	3
Characteristic Half Width of Immobile Domain Blocks (a) in meters		0.61	0.61	0.61	0.61
[1]Effective Diffusion Coefficient (D_e) (m^2/day)		1.47E-05	2.94E-05	2.06E-05	1.47E-05
Mass Transfer Rate Coefficient (1/day)		**Uranium**	**Molybdenum**	**Selenium**	**Conservative Surrogate Constituent**
Hydrstratigraphic Unit	**Immobile Domain Porosity (θ_{im})**				
Alluvium	0.3	1.07E-05	2.13E-05	1.49E-05	1.07E-05
Basalt	0.1	1.18E-06	2.37E-06	1.66E-06	1.18E-06
Chinle Water-Yielding Units	0.1	1.18E-06	2.37E-06	1.66E-06	1.18E-06
San Andres - Glorieta	0.2	4.74E-06	9.47E-06	6.66E-06	4.74E-06

Equation Used for Mass Transfer Coefficient: $\alpha = \beta * D_{e*}\Theta_{im}^{2} / a^{2}$, where: (Gerke and van Genuchten, 1993)

α = mass transfer rate coefficient (1/time)

β = geometry coefficient for rectangular slabs (dimensionless)

D_e = effective diffusion coefficient (length^2/time)

θ_{im} = immobile domain porosity (dimensionless)

a = characteristic half width of immobile domain blocks (length)

Notes: Effective diffusion coefficients from HDR 2024, equation for mass transfer coefficient adopted from Gerke and van Genuchten 1993.

Table 3.4-1 Element-Independent Intake Parameters for each Pathway Depicted in Conceptual Model

Pathway	Amount	Unit	Reference
Resident intake of water, Iw	1.277	L/day	EPA, 2019 Table 3-1 , adult consumer age 21 - 50 (21May2019)
Length of consumption period	30	yr	NCRP-123I, Table 5.1 (1996)
Irrigation rate, IR	5	$L/m^2/day$	NCRP-123I, Table 5.1 (1996)
Soil mixing depth, MD	1.50E-01	m	Assumed
Irrigation period, IP	150	day/year	NCRP-123I, Table 5.1 (1996)
Soil density, ρ	1.5	g/cm^3	NCRP-123I, pg 50
Soil removal constant, λs	2.70E-05	d^{-1}	NCRP-123I

Table 3.4-2 Radionuclide Dose Conversion and Cancer Risk Factors

Radionuclide	Dose Conversion Factor (Sv/Bq)	Risk Factor (per Sv intake)			
		Drinking water		Foodstuffs	
		Mortality	Morbidity	Mortality	Morbidity
Radium-228	3.58E-07	7.17E-09	1.04E-08	9.56E-09	1.39E-08
Radium-226	3.88E-07	2.00E-08	2.81E-08	2.74E-08	3.86E-08
Thorium-230	1.38E-07	1.67E-09	2.46E-09	2.16E-09	3.22E-08
Uranium, natural	7.27E-08	1.19E-09	1.82E-09	1.59E-09	2.46E-09

Source: EPA, 1988 and 1999b

Table 3.4-3 Element-Specific Uptake Factors

Constituent of Concern	Vegetable Concentration Factor (Bq/kg plant per Bq/kg soil)
Arsenic	8.00E-02
Boron	1.00E-02
Cadmium	5.00E-01
Chlorine	2.00E+01
Fluorine	2.00E-02
Molybdenum	1.00E-01
Nitrogen	7.50E+00
Sulfur	6.00E-01
Selenium	1.00E-01
Uranium	2.00E-03
Vanadium	2.00E-03
Radium-226	4.00E-02
Radium-228	4.00E-02
Thorium-230	1.00E-03

Table 3.5-1 Estimated Dose and Cancer Risk from Radionuclides at Unit POE Concentrations

Exposure Pathway	Unit Concentration in well (Bq/L)	Calculated Dose (mrem/year)	30-year Risk Estimate	
			Mortality	Morbidity
Radium-226 + Radium-228*				
Drinking water	1.0E+00	1.7E+01	1.0E-04	1.5E-04
Eating vegetables	1.0E+00	3.3E+00	2.7E-05	3.9E-05
Radon inhalation - domestic water	1.0E+00	1.6E-01	6.3E-06	6.9E-06
	Total:	**2.0E+01**	**1.3E-04**	**1.9E-04**
Thorium-230				
Drinking water	1.00E+00	6.4E+00	2.3E-05	3.4E-05
Eating vegetables	1.00E+00	3.4E-02	1.5E-07	2.2E-06
	Total:	**6.5E+00**	**2.4E-05**	**3.7E-05**
Natural Uranium				
Drinking water	1.00E+00	3.39E+00	1.66E-05	2.5E-05
Eating vegetables	1.00E+00	1.69E-02	2.22E-07	3.4E-07
	Total:	**3.4E+00**	**1.7E-05**	**2.6E-05**

*Used radium-226 dose coefficient for both nuclides

Table 3.5-2 Summary of Intakes and Predicted Hazard Quotients from Predicted Maximum Well Water Concentration for Inorganic Constituents

Constituent	Units	Maximum Predicted POE Concentration	Intake (mg/day)			Average Daily Intake per 70 kg Adult (mg/kg/day)	Reference Dose (mg/kg/day)	Hazard Quotient (unitless)
			Water	Vegetables	Total			
Arsenic	mg/L	6.61E-04	8.4E-04	3.4E-04	1.2E-03	1.7E-05	3.0E-04	5.6E-02
Boron	mg/L	4.24E-01	5.4E-01	2.7E-02	5.7E-01	8.1E-03	2.0E-01	4.1E-02
Cadmium	mg/L	6.40E-05	8.2E-05	2.0E-04	2.9E-04	4.1E-06	5.0E-04	8.2E-03
Molybdenum	mg/L	3.80E-02	4.9E-02	2.4E-02	7.3E-02	1.0E-03	5.0E-03	2.1E-01
Selenium	mg/L	2.40E-02	3.1E-02	1.5E-02	4.6E-02	6.6E-04	5.0E-03	1.3E-01
Uranium	mg/L	2.66E-02	3.4E-02	3.4E-04	3.4E-02	4.9E-04	3.0E-03	1.6E-01
Vanadium	mg/L	6.40E-04	8.2E-04	8.2E-06	8.3E-04	1.2E-05	7.0E-03	1.7E-03
Chloride	mg/L	1.41E+02	1.8E+02	1.8E+04	1.8E+04	2.6E+02	1.0E-01	2.6E+03
Fluoride	mg/L	4.71E-01	6.0E-01	6.0E-02	6.6E-01	9.4E-03	4.00E-02	2.4E-01
Nitrate	mg/L	5.77E+00	7.4E+00	2.8E+02	2.8E+02	4.1E+00	4.0E+00	1.0E+00
Thorium-230	pCi/L	1.067E-02	background	background	background	background	NA	NA
Ra226+228	pCi/L	1.088E-01	background	background	background	background	NA	NA

* RfD is 1.6 mg nitrogen /kg/day, which converts to 7 mg/kg/day for nitrate

RfD - Reference Dose

Assumes 27 Kg/yr of vegetable intake

Assumes 1.277 L/day of water intake

Table 3.6-1 Biota Concentration Guide Results from RESRAD-BIOTA Water

Radionuclide	Well water concentration (pC/L)	Biota Concentration Guide (pCi/L)	Ratio	Potential Radiation Effect?
Deer Mouse				
Radium-226[a]	3.70E-02	8.16E+03	4.53E-06	no
Radium-228[a]	7.18E-02	7.49E+03	9.59E-06	no
Thorium-230	1.07E-02	4.55E+05	2.34E-08	no
Natural Uranium	1.78E+04	NA		
Uranium-234	8.70E+03	4.06E+05	2.14E-02	no
Uranium-235	3.90E+02	4.36E+05	8.94E-04	no
Uranium-238	8.80E+03	4.51E+05	1.95E-02	no
		Total	4.18E-02	no
Kit Fox				
Radium-226[a]	3.70E-02	8.16E+03	4.53E-06	no
Radium-228[a]	7.18E-02	7.49E+03	9.59E-06	no
Thorium-230	1.07E-02	4.55E+05	2.34E-08	no
Natural Uranium	1.78E+04			
Uranium-234	8.70E+03	4.06E+05	2.14E-02	no
Uranium-235	3.90E+02	4.38E+05	8.90E-04	no
Uranium-238	8.80E+03	4.55E+05	1.93E-02	no
		Total	**4.17E-02**	**no**

BCG - Biota Concentration Guide

[a]Assumes 34% of combined radium-226+228 is Ra-226, 66% is Ra-228

Table 3.6-2 Radioecological Screening Levels for GRP Radionuclides in a Terrestrial Ecosystem

Radionuclide	Soil (pCi/g)	Water (pCi/L)
Radium-226	5.00E+01	8.00E+03
Radium-228	4.00E+01	7.00E+03
Thorium-230[1,2]	3.96E+04	4.13E+02
Uranium-234	5.00E+03	4.00E+05
Uranium-235	3.00E+03	4.00E+05
Uranium-238	2.00E+03	4.00E+05

TCEQ, 2021 reference for all values except where noted

[1] Soil Reference NMED, 2000

[2] Water Reference - BJC, 1998 value for fish, not terrestrial animals

Table 3.6-3 Comparison of Maximum Predicted Well Water and Soil Concentrations to RESLs

Radionuclide	RESL Water (pCI/L)	Maximum Well Water Concentration (pCi/L)*	Hazard Quotient	RESL Soil (pCi/g)	Maximum Calculated Soil Concentration (pCi/g)**	Hazard Quotient
Radium-226	8.00E+03	3.70E-02	4.62E-06	5.00E+01	3.20E-03	6.40E-05
Radium-228	7.00E+03	7.18E-02	1.03E-05	4.00E+01	3.20E-03	8.01E-05
Thorium-230	4.13E+02	1.07E-02	2.58E-05	3.96E+04	9.23E-04	2.33E-08
Uranium-234	4.00E+05	8.70E+03	2.18E-02	5.00E+03	8.10E+00	1.62E-03
Uranium-235	4.00E+05	3.90E+02	9.75E-04	3.00E+03	3.70E-01	1.23E-04
Uranium-238	4.00E+05	8.80E+03	2.20E-02	2.00E+03	8.20E+00	4.10E-03
		Sum of fractions	**4.48E-02**			**5.99E-03**

* uranium concentrations apportioned assuming equilibrium

** soil values represent equilibrium after buildup from irrigation with well water

RESL = radioecological screening level

Table 3.6-4 Surface Water Ecological Screening Values for GRP Inorganic Constituents

Constituent	Ecological Screening Value (mg/L)	Predicted Maximum Concentration in Well (mg/l)	Hazard Quotient	Further Investigation Warranted
Arsenic	2.20E-03	6.61E-04	3.0E-01	No
Boron	7.50E-01	4.24E-01	5.6E-01	No
Cadmium	6.60E-01	6.40E-05	9.7E-05	No
Molybdenum	2.40E-01	3.80E-02	1.6E-01	No
Selenium[a]	8.83E-02	2.40E-02	2.7E-01	No
Uranium[b]	1.42E-01	2.66E-02	1.9E-01	No
Vanadium	1.90E-02	6.40E-04	3.4E-02	No
Chloride	2.30E+02	1.41E+02	6.1E-01	No
Fluoride[c]	9.80E-01	4.71E-01	4.8E-01	No
Nitrite[d]	6.00E-02	5.77E+00	9.6E+01	Yes

(from SRS, 1999, unless otherwise noted.)

[a] Value for Selenium is taken from EPA Ambient Water Quality Criteria

[b] ESV suggested by SRS is for aquatic animals; value shown is an approximation for all animals (Suter and Tsao, 1996).

ESV = ecological screening value

[c] Shown in ORNL RAIS (https://rais.ornl.gov/tools/eco_search.php, accessed 5/29/2026) attributed to EPA Region 4

[d] ESV for nitrite, but model results reported as nitrate.

Table 4.1-1 Summary of Groundwater Corrective Action NRC Licensing History

Amendment Number	License Condition	Date of Submittals	Subject	NRC ADAMS Document Accession Number
5	35	9/15/1989	HMC Groundwater CAP Submittal	ML12222A08
		3/16/1990	NRC Approval Groundwater CAP	9004050197
7	35	6/18/1990	HMC Evaporation Pond 1 Submittal	NA
		6/28/1990	HMC Evaporation Pond 1 Submittal	ML12291A914
		7/13/1990	NRC Approval of Evaporation Pond 1	ML20059C524
19	39	7/26/1994	HMC Evaporation Pond 2 Submittal	ML12291A905
		8/16/1994	HMC Evaporation Pond 2 Submittal	ML12291A620
		8/19/1994	HMC Evaporation Pond 2 Submittal	NA
		9/2/1994	HMC Evaporation Pond 2 Submittal	NA
		9/15/1994	HMC Evaporation Pond 2 Submittal	ML12291A907
		1/27/1995	NRC Approval of Evaporation Pond 2	9502020329
30	35	1/15/1998	HMC Groundwater RO Plant Submittal	ML12291A910
		3/5/1998	NRC Approval to add RO Plant	ML14203A023
41	35	10/25/2006	HMC Evaporation Pond 3 Submittal	ML063050641
		2/7/2007	HMC Evaporation Pond 3 Submittal	ML070470539
		7/18/2007	HMC Evaporation Pond 3 Submittal	ML072110267
		3/17/2008	HMC Evaporation Pond 3 Submittal	ML080800343
		7/31/2008	NRC Environmental Assessment for Evaporation Pond 3	ML080920594
		8/7/2008	NRC Approval and Technical Evaluation Report for EP3	ML080920548 ML080920562
55	35	12/11/2017	HMC Zeolite Submittal	ML17361A007 ML17361A008 ML17361A009 ML17361A010 ML17361A011
		2/22/2018	HMC Zeolite Submittal	ML18066A583
		5/17/2019	HMC Request for Additional Information Responses	ML19149A366
		12/2/2019	NRC Environmental Assessment for Zeolites	ML19263C623
		2/3/2020	NRC approval and Safety Evaluation Report for Zeolites	ML19323D122 ML19323D123 ML19323D125
58	35	2/8/2022	Replacing well CF4 with well in groundwater monitoring plan	ML21356B139 ML21356B141 ML21356B142

Table 4.1-2 Summary of Groundwater Restoration Corrective Action System Performance

Year	Ponds							RO System									Zeolite System								Land Application System		Total Annual Treatment Rate (gpm)	Total Annual Treatment Rate without Land Application (gpm)	Total Annual Waste Water Production Rate (gpm)
									RO Input (gpm)				RO Output (gpm)					Zeolite Input (gpm)			Zeolite Output (gpm)								
	Element	Total Annual Pumping Rate (gpm)	Evaporation Pond Storage Capacity (gallons)	Total Storage Capacity (gallons)	Pond Area for Evaporation (sq. ft.)	Total Area for Evaporation (sq. ft.)	Annual Average Evaporation Rate (gpm)	Element	On-Site Groundwater Collection Wells	Tailings Dewatering Wells	Tailings Sumps	Total	Compliant Effluent	Non-Compliant Effluent	Total	Annual Non-Compliant Effluent (gallons)	Element	300Z Zeolite	1200Z Zeolite	Total	Compliant Effluent	Non-Compliant Effluent	Annual Non-Compliant Effluent (gallons)	Applied Volume (gallons)	Average Annual Rate (gpm)			
1978	LTP/Mill	53																									53	53	
1979		88																									88	88	
1980		75																									75	75	
1981		174																									174	174	
1982		304																									304	304	
1983		318																									318	318	
1984		387																									387	387	
1985		369																									369	369	
1986	ECP/WCP	379	11,404,008	11,404,008	217,800	217,800	13																				379	379	
1987		344				217,800	13																				344	344	
1988		317				217,800	13																				317	317	
1989		334				217,800	13																				334	334	
1990	EP1	313	171,092,703	171,092,703	1,084,208	1,302,008	87																				313	313	
1991		326		171,092,703		1,302,008	87																				326	326	
1992		244		171,092,703		1,302,008	87				16																244	244	
1993		220		171,092,703		1,302,008	87				35																220	220	
1994		187		171,092,703		1,302,008	87																				187	187	
1995		206		171,092,703		1,302,008	87			11	34																206	206	
1996	EP2	232	99,963,408	271,056,111	744,646	2,046,654	152			17	29																232	232	
1997		180		271,056,111		2,046,654	171			41	23																180	180	
1998		142		271,056,111		2,046,654	188				20																142	142	
1999		224		271,056,111		2,046,654	167			0.2	17																224	224	
2000		No		271,056,111		2,046,654	180	Original RO	279	24	15	318	204	70	274	36,792,000									232,967,592	443	761	318	70
2001		Direct		271,056,111		2,046,654	159		276	60	18	354	222	59	281	31,010,400									226,451,016	431	785	354	59
2002		Pumping		271,056,111		2,046,654	158	RO Expansion 1	383	34	34	451	288	100	388	52,560,000									324,199,656	617	1068	451	100
2003		To		271,056,111		2,046,654	169		338	17	54	409	266	76	342	39,945,600									309,211,531	588	997	409	76
2004		Evap Ponds		271,056,111		2,046,654	170		294	85	51	430	249	64	313	33,638,400									334,952,006	637	1067	430	64
2005		All		271,056,111		2,046,654	181		249	87	39	375	198	49	247	25,754,400									336,906,979	641	1016	375	49
2006		Influent		271,056,111		2,046,654	194		252	83	39	374	184	48	232	25,228,800									272,718,706	519	893	374	48
2007		To		271,056,111		2,046,654	186		262	47	48	356	204	55	259	28,908,000									257,078,923	489	845	356	55
2008		Other		271,056,111		2,046,654	169		261	11	50	322	194	60	254	31,536,000									343,423,555	653	975	322	60
2009		Treatment		271,056,111		2,046,654	152		250	56	52	358	171	60	231	31,536,000	Pilot 1								238,180,853	453	811	358	60
2010	EP3	Systems.	78,035,998	349,092,109	1,154,340	3,200,994	146		239	25	35	299	166	59	225	31,010,400	up to 50 gpm								65,491,589	125	424	299	59
2011				349,092,109		3,200,994	223		252	104	28	384	170	58	228	30,484,800									69,401,534	132	516	384	58
2012				349,092,109		3,200,994	221		273	107	23	403	182	50	232	26,280,000									101,006,928	192	596	403	50
2013				349,092,109		3,200,994	153		234	60	18	311	148	47	195	24,703,200	Pilot 2										311	311	47
2014				349,092,109		3,200,994	188	2nd Clarifier	236	47	18	301	165	47	212	24,703,200	Added 300Z										301	301	47
2015				349,092,109		3,200,994	184	Microfiltration	208	16	19	244	112	52	164	27,331,200	Pilot 3										244	244	52
2016				349,092,109		3,200,994	168	RO Expansion 2	595	5	14	614	449	141	590	74,109,600	Added 1200Z	115	152	267	233	34	17,870,400			881	881	175
2017				349,092,109		3,200,994	225		497	1	10	508	407	108	515	56,764,800		56	247	303	253	50	26,280,000			811	811	158
2018				349,092,109		3,200,994	200		436	0	0	436	350	85	435	44,676,000		37	259	296	267	29	15,242,400			732	732	114
2019				349,092,109		3,200,994	174		324	0	6	330	236	57	293	29,959,200	Approved	0	160	160	126	34	17,870,400			490	490	91
2020				349,092,109		3,200,994	201		298	0	4	302	205	58	263	30,484,800		0	42	42	26	8	4,204,800			344	344	66
2021				349,092,109		3,200,994	208		562	0	0	562	394	98	492	51,508,800		0	106	106	80	26	13,665,600			668	668	124
2022				349,092,109		3,200,994	162		573	0	0	573	423	127	550	66,751,200		0	88	88	65	23	12,088,800			661	661	150
2023				349,092,109		3,200,994	158		528	0	0	528	363	98	461	51,508,800		0	0	0	0	0	-			528	528	98
2024				349,092,109		3,200,994	141		435	0	0	435	310	71	381	37,317,600		0	0	0	0	0	-			435	435	71
2025				349,092,109		3,200,994	126		433	0	0	433	313	68	381	35,740,800		0	0	0	0	0	-			433	433	68
														Total Volume:		980,265,619						Total Volume:	107,222,400		Total Volume:	12,094,696,945	8,982,706,076	1,087,466,400

1986-1995 are estimates

Table 4.1-3 Summary of Tailings Flushing and Dewatering Performance

Year	Annual Injection Rate (gpm)	Annual Volume Injected (gal)	Annual Dewatering Well Rate (gpm)	Annual Dewatering Well Volume (gal)	Annual Toe Drain Collection Rate (gpm)	Annual Toe Drain Collection Volume (gal)	Annual Total Tailings Water Recovered (gal)	Percent Injection Water Recovered
2000	61	32,061,600	24	12,446,810	15	8,032,870	20,479,680	64%
2001	162	85,147,200	60	31,465,370	18	9,606,280	41,071,650	48%
2002	302	158,731,200	34	17,817,840	34	17,975,520	35,793,360	23%
2003	267	140,335,200	17	8,890,076	54	28,418,871	37,308,947	27%
2004	280	147,168,000	85	44,745,696	51	26,720,928	71,466,624	49%
2005	228	119,836,800	87	45,685,786	39	20,704,320	66,390,106	55%
2006	269	141,386,400	83	43,707,760	39	20,374,782	64,082,542	45%
2007	224	117,734,400	47	24,561,680	48	25,037,779	49,599,459	42%
2008	300	157,680,000	11	5,950,324	50	26,140,850	32,091,174	20%
2009	284	149,270,400	56	29,403,070	52	27,238,830	56,641,900	38%
2010	193	101,440,800	25	12,953,960	35	18,444,330	31,398,290	31%
2011	270	141,912,000	104	54,713,150	28	14,777,020	69,490,170	49%
2012	264	138,758,400	107	56,486,600	23	12,201,316	68,687,916	50%
2013	232	121,939,200	60	31,489,800	18	9,211,575	40,701,375	33%
2014	308	161,884,800	47	24,487,100	18	9,427,490	33,914,590	21%
2015	79	41,522,400	16	8,644,000	19	10,222,310	18,866,310	45%
2016	0	0	5	2,678,400	14	7,553,090	10,231,490	NA
2017	0	0	0	674,300	10	5,455,170	6,129,470	NA
2018	0	0	0	0	9	4,530,130	4,530,130	NA
2019	0	0	0	0	6	3,024,380	3,024,380	NA
2020	0	0	0	0	4	2,152,800	2,152,800	NA
2021	0	0	0	0	4	2,073,770	2,073,770	NA
2022	0	0	0	0	3	1,465,140	1,465,140	NA
2023	0	0	0	0	3	1,580,890	1,580,890	NA
2024	0	0	0	0	2	1,014,011	1,014,011	NA
2025	0	0	0	0	1	773,970	773,970	NA
Total:		1,956,808,800	NA	456,801,722	NA	314,158,422	770,960,144	39%
Max:	308	161,884,800	107	56,486,600	54	28,418,871	71,466,624	64%
Min:	-	-	-	-	2	773,970	773,970	20%

Table 4.1-4 Constituent Concentrations Applied to the South Irrigation Fields

Constituent (mg/L)						
Year	**Uranium**	**Selenium**	**TDS**	**Sulfate**	**Chloride**	**Molybdenum**
2000	0.27	0.12	1549	624	107	<0.03
2001	0.28	0.11	1620	693	120	<0.03
2001	0.26	0.1	1570	642	113	0.04
2002	0.23	0.1	1564	705	126	<0.03
2003	0.22	0.08	1600	732	--	--
2004	0.26	0.09	1553	679	1.1	<0.03
2005	0.27	0.06	1546	732	162	<0.03
2006	0.29	0.07	1650	716	151	0.04
2007	0.28	0.06	1584	666	134	<0.03
2008	0.24	0.05	1550	712	137	<0.03
2009	0.24	0.05	1673	709	161	<0.03
2010	0.14	0.05	1711	739	167	<0.03
2011	No South Irrigation					
2012	0.12	0.04	1690	689	161	<0.03

Table 4.1-5 Constituent Concentrations Applied to the North Irrigation Fields

Constituent (mg/L)						
Year	**Uranium**	**Selenium**	**TDS**	**Sulfate**	**Chloride**	**Molybdenum**
2002	0.23	0.08	2070	881	--	--
2003	0.24	<0.005	2070	936	184	<0.03
2004	0.27	0.07	2115	919	185	<0.03
2005	0.35	0.08	2109	927	180	0.04
2006	0.35	0.08	1986	882	175	0.04
2007	0.36	0.08	2122	921	171	0.04
2008	0.36	0.07	1917	927	133	0.04
2009	0.39	0.07	2029	894	174	0.05
2010	No North Irrigation					
2011	0.14	0.03	1409	608	121	<0.03
2012	0.14	0.036	1846	756	189	<0.03

Table 4.1-6 Large Tailings Pile Dewatering Well Summary

Year	Well Volume Pumped			Sulfate		Uranium		Molybdenum		Selenium	
				Concentration	Amount	Concentration	Amount	Concentration	Amount	Concentration	Amount
	Increase (gal)	gpm	Cumulative (gal)	(mg/L)	(lb)	(mg/L)	(lb)	(mg/L)	(lb)	(mg/L)	(lb)
1995	5,905,740	11	5,905,740	8,191	403,680	36	1,778	89.7	4,420	0.15	7.0
1996	9,181,390	17	15,087,130	9,434	722,129	40	3,077	108.0	8,236	0.18	14
1997	21,292,900	41	36,380,030	10,284	1,827,575	46	8,139	92.4	16,420	0.14	25
1998	--	--	--	--	--	--	--	--	--	--	--
1999	120,550	0.2	36,500,580	9,420	9,478	41	41	111.5	112	0.19	0.2
2000	12,446,810	24	48,947,390	9,710	1,008,685	38	3,927	127.0	13,193	0.30	31
2001	31,465,370	60	80,412,760	8,688	2,281,555	35	9,086	89.2	23,425	0.19	50
2002	17,817,840	34	98,230,600	7,670	1,140,588	24	3,495	40.8	6,067	0.12	18
2003	8,890,076	17	107,120,676	9,800	727,126	28	2,078	92.0	6,826	0.30	22
2004	44,745,696	85	151,866,372	6,360	2,377,848	23	8,637	60.9	22,769	0.20	75
2005	45,685,786	87	197,552,158	4,389	1,673,497	19	7,130	56.3	21,467	0.18	69
2006	43,707,760	83	241,259,918	4,278	1,560,550	18	6,420	51.9	18,932	0.14	51
2007	24,561,680	47	265,821,598	4,130	846,616	20	4,079	61.1	12,525	0.15	31
2008	5,950,324	11	271,771,922	4,671	231,968	16	795	42.8	2,126	0.24	12
2009	29,403,070	56	301,174,992	3,850	944,782	14	3,362	38.6	9,472	0.24	59
2010	12,953,960	25	314,128,952	3,018	326,287	9.4	1,016	33.5	3,622	0.19	21
2011	54,713,150	104	368,842,102	2,887	1,318,308	10.5	4,795	33.5	15,297	0.18	82
2012	56,486,600	107	425,328,702	2,632	1,240,823	8.9	4,196	26.2	12,352	0.17	80
2013	31,489,800	60	456,818,502	2,448	643,368	7.5	1,958	23.6	6,202	0.12	32
2014	24,487,100	47	481,305,602	2,788	569,782	7.8	1,594	27.1	5,538	0.16	33
2015	8,644,000	16	489,949,602	2,891	208,565	8.2	592	28.0	2,020	0.11	7.9
2016	2,678,400	5.1	492,628,002	2,891	64,625	8.2	183	28.0	626	0.11	2.5
2017	674,300	1.3	493,302,302	4,918	27,677	14.7	83	32.5	183	0.70	3.9
2018	-	-	493,302,302	-	-	-	-	-	-	-	-
2019	-	-	493,302,302	-	-	-	-	-	-	-	-
2020	-	-	493,302,302	-	-	-	-	-	-	-	-
2021	-	-	493,302,302	-	-	-	-	-	-	-	-
2022	-	-	493,302,302	-	-	-	-	-	-	-	-
2023	-	-	493,302,302	-	-	-	-	-	-	-	-
2024	-	-	493,302,302	-	-	-	-	-	-	-	-
2025	-	-	493,302,302	-	-	-	-	-	-	-	-
	Total Tailings Wells:		**493,302,302**		**20,155,515**		**76,460**		**211,831**		**725**

Pre-Tailings Flushing Post-Tailings Flushing

from 2024 Annual Performance Report, Table 2.1-2

Table 4.1-7 Large Tailings Pile Dewatering Toe Drain Summary

Year	Toe Drain Volume Pumped			Sulfate		Uranium		Molybdenum		Selenium	
				Concentration	Amount	Concentration	Amount	Concentration	Amount	Concentration	Amount
	Increase (gal)	gpm	Cumulative (gal)	(mg/L)	(lb)	(mg/L)	(lb)	(mg/L)	(lb)	(mg/L)	(lb)
1992	8,544,670	16	8,544,670	12,117	864,006	53	3,793	107	7,595	1.73	123
1993	18,357,680	35	26,902,350	12,117	1,856,262	53	8,150	107	16,315	1.73	265
1994	18,337,680	35	45,240,030	12,117	1,854,240	53	8,141	107	16,299	1.73	264
1995	17,711,370	34	62,951,400	11,370	1,680,500	55	8,069	94	13,952	2.25	332
1996	15,431,810	29	78,383,210	11,537	1,484,295	46	5,970	105	13,509	1.29	166
1997	12,029,390	23	90,412,600	11,094	1,113,808	42	419	100	10,040	0.81	81
1998	10,321,780	20	100,734,380	9,870	850,257	43	3,665	95	8,203	0.73	63
1999	8,809,890	17	109,544,270	11,560	849,976	54	3,993	106	7,794	0.46	34
2000	8,032,870	15	117,577,140	9,734	652,590	59	3,929	118	7,911	0.34	23
2001	9,606,280	18	127,183,420	9,935	796,529	43	3,455	96	7,673	0.78	63
2002	17,975,520	34	145,158,940	9,210	1,381,718	33	5,011	89	13,307	0.76	114
2003	28,418,871	54	173,577,811	9,457	2,243,048	36	8,444	79	18,714	4.35	1,032
2004	26,720,928	51	200,298,739	8,007	1,787,722	32	7,115	68	15,102	2.78	622
2005	20,704,320	39	221,003,059	8,228	1,421,784	44	7,517	88	15,120	2.63	454
2006	20,374,782	39	241,377,841	7,432	1,263,796	38	6,462	76	12,958	1.09	185
2007	25,037,779	48	266,415,620	6,829	1,427,024	32	6,666	67	14,063	1.20	251
2008	26,140,850	50	292,556,470	7,847	1,711,992	32	6,894	69	14,945	1.58	345
2009	27,238,830	52	319,795,300	7,792	1,771,396	35	7,957	70	15,891	0.81	184
2010	18,444,330	35	338,239,630	6,848	1,054,156	33	5,065	52	8,020	0.51	79
2011	14,777,020	28	353,016,650	6,747	832,101	30	3,688	53	6,561	0.44	54
2012	12,201,316	23	365,217,966	6,476	659,465	27	2,729	49	4,980	0.43	44
2013	9,211,575	18	374,429,541	6,453	496,105	27	2,053	53	4,098	0.35	27
2014	9,427,490	18	383,857,031	5,683	447,149	21	1,668	46	3,619	0.15	12
2015	10,222,310	19	394,079,341	5,252	448,076	21	1,766	41	3,515	0.30	26
2016	7,553,090	14	401,632,431	4,756	299,809	17	1,085	37	2,310	0.15	9
2017	5,455,170	10	407,087,601	3,305	150,473	14	633	27	1,225	0.21	10
2018	4,530,130	9	411,617,731	4,708	178,002	18	662	37	1,384	0.27	10
2019	3,024,380	6	414,642,111	4,959	125,172	15	389	42	1,070	0.20	5
2020	2,152,800	4	416,794,911	4,952	88,974	16	289	40	713	0.52	9
2021	2,073,770	4	418,868,681	3,581	61,979	14	235	36	619	0.19	3
2022	1,465,140	3	420,333,821	3,370	41,209	13	162	36	438	0.10	1
2023	1,580,890	3	421,914,711	3,360	44,332	11	146	28	369	0.38	5
2024	1,014,011	2	422,928,722	2,955	25,008	11	91	26	221	0.16	1
2025	773,970	1	423,702,692	2,841	18,352	11	72	26	168	0.16	1
Total Tailings Toe Drains:			**423,702,692**		**29,981,307**		**126,381**		**268,700**		**4,897**
Total Tailings Wells:			**493,302,302**		**20,155,515**		**76,460**		**211,831**		**725**
Total from Tailings:			**917,004,994**		**50,136,821**		**202,841**		**480,531**		**5,622**

Pre-Tailings Flushing Post-Tailings Flushing

from 2024 Annual Performance Report, Table 2.1-2

3.78541 L/gal

4.54E+05 mg/lb

Table 4.1-8 Summary of Large Tailings Pile Well Water Quality

Well	Year		Uranium (mg/L)	Molybdenum (mg/L)	Selenium (mg/L)		Well	Year		Uranium (mg/L)	Molybdenum (mg/L)	Selenium (mg/L)
CS1	2000-2019	Max	33.10	85.20	3.61		CS2	1999-2019	Max	53.90	125.00	22.40
		Min	0.61	1.35	0.01				Min	0.30	0.57	0.00
		Avg	14.10	28.21	0.35				Average	12.25	30.25	2.97
ES4	2005-2020	Max	16.10	44.30	0.12		ES6	1997-2019	Max	52.10	104.00	0.25
		Min	3.87	10.40	0.03				Min	7.64	24.00	0.04
		Average	7.89	21.50	0.06				Average	15.46	52.13	0.11
WW3	2016-2019	Max	7.35	12.40	0.35		WME1	2016-2018	Max	13.00	52.00	0.10
		Min	2.57	8.58	0.01				Min	9.84	39.30	0.05
		Average	4.88	10.60	0.10				Average	11.21	43.06	0.07
WME3	2018-2019	Max	2.40	7.10	0.04		SW3	2016-2019	Max	3.52	14.80	0.06
		Min	1.45	3.69	0.01				Min	1.45	2.50	0.04
		Average	1.80	4.78	0.02				Average	2.33	6.94	0.05
E1	1996-2020	Max	92.50	173.00	7.04		W1	1995-2020	Max	59.90	141.00	6.57
		Min	0.44	0.94	0.01				Min	12.20	10.10	0.09
		Average	38.79	85.40	1.44				Average	26.48	49.35	0.79
N1	1995-2020	Max	67.55	118.00	5.33		S1	1996-2020	Max	39.82	135.00	5.71
		Min	16.20	31.80	0.08				Min	0.94	2.62	0.01
		Average	32.70	67.15	1.11				Average	17.71	39.64	0.52
W010	2006-2019	Max	24.00	83.40	0.71		W021	2009-2019	Max	1.70	6.12	0.11
		Min	2.56	9.99	0.02				Min	0.11	1.09	0.02
		Average	10.80	35.31	0.27				Average	0.61	2.87	0.06
WP10	2016-2019	Max	5.27	11.10	0.05		WME4	2018-2020	Max	58.00	170.00	0.25
		Min	2.96	3.79	0.02				Min	37.40	128.00	0.06
		Average	4.30	7.90	0.04				Average	42.48	141.63	0.16
WME5	2018-2020	Max	19.6	68	0.485		WME6	2018-2020	Max	11	34	0.09
		Min	6.9	29.7	0.031				Min	6.13	19.1	0.011
		Average	13.6375	50.9	0.1425				Average	7.67125	23.1	0.039375
CN1	2000-2017	Max	75.6	91.5	9.4		CN2	2000-2016	Max	60	102	0.932
		Min	20.5	7.44	0.044				Min	0.3	0.37	0.016
		Average	41.80714	59.57928571	1.856071429				Average	16.51425	22.7575833	0.19991667
EN1	2005-2017	Max	46	112	7.1		EN2	2000-2017	Max	56	188.9	0.392
		Min	15	40.7	0.18				Min	1.27	5.23	0.026
		Average	27.925	76.14166667	1.417333333				Average	19.0725	69.603125	0.1976875
WN1	2006-2017	Max	21.6	62.1	1.7		WN2	2008-2017	Max	29.8	75.5	0.119
		Min	1.4	5.32	0.01				Min	0.357	2.31	0.0025
		Average	8.306364	25.22545455	0.502818182				Average	6.3398	19.654	0.04995
WS1	2011-2018	Max	12.7	19	0.114		WS2	2010-2016	Max	12.6	29.2	0.7
		Min	3.68	0.7	0.022				Min	1.44	4.02	0.081
		Average	9.54	8.162	0.0586				Average	4.54333333	9.64833333	0.3095
WW1	2005-2018	Max	62.6	67.1	24.9		WW3	2016-2019	Max	7.35	12.4	0.348
		Min	12.2	25.8	1.17				Min	2.57	8.58	0.013
		Average	27.325	39.75833333	5.444166667				Average	4.8775	10.595	0.1035
WME2	2018-2019	Max	0.75	7.9	0.183		CS7	2000-2019	Max	21	64.5	0.386
		Min	0.465	4.94	0.005				Min	1.64	4.57	0.022
		Average	0.555143	6.152857143	0.039142857				Average	12.22	29.2911111	0.15077778
EI4	2016-2018	Max	1.4	1.23	0.025		ET20	2016-2019	Max	3.64	6.25	0.136
		Min	0.801	1.19	0.021				Min	1.45	1.42	0.085
		Average	1.1005	1.21	0.023				Average	2.82	4.58	0.113
EP23	2016-2019	Max	12.9	21.7	0.09		EP31	2016-2018	Max	6.93	11.2	0.123
		Min	6.7	12.2	0.061				Min	6.82	10.1	0.092
		Average	10.6	17.23333333	0.076666667				Average	6.875	10.65	0.1075
WE9	2009-2019	Max	3.1	10.7	0.152		WF2	2008-2019	Max	3.7	15.8	1.72
		Min	0.467	2.09	0.006				Min	0.478	2.19	0.004
		Average	1.037043	4.71	0.057608696				Average	1.66325	7.06107143	0.17842857
WF9	2009-2019	Max	2.5	7.4	0.173		WF11	2009-2019	Max	0.712	6.16	0.142
		Min	0.466	1.01	0.0025				Min	0.21	1.04	0.007
		Average	1.467483	3.961034483	0.038982759				Average	0.4535	2.33038462	0.02565385
WT6	2008-2016	Max	2.98	12.9	0.141		WT18	2016-2018	Max	3.99	4.89	0.09
		Min	0.795	0.97	0.0025				Min	3.4	4.13	0.049
		Average	1.522667	6.3375	0.03375				Average	3.695	4.51	0.0695

Tailings Wells Summary

		Uranium (mg/L)	Molybdenum (mg/L)	Selenium (mg/L)
Pre-Flushing				
	Max	53.90	125.00	0.31
	Min	46.70	86.40	0.04
	Average	50.90	105.13	0.14
Wells CS1, CS, ES4, ES6				
Post Flushing	Max	58.00	170.00	3.61
	Min	0.21	1.19	0.003
	Average	7.18	21.10	0.14
% of Pre-Flushing Average:		14%	20%	103%

Wells CS1, CS2, ,ES4, ES6, EE2, SE2, EE2, SE2, WW3, WME1, WME3, SW3, WO10, WO21, WP10, WME4, WME5, WME6, CN1, CN2, EN1, EN2, WN1. WN2, WS1, WS2, WW1, WW3, WME2, CS7, EI4, ET20, EP23, EP31, WE9, WF2, WF9, WF11, WT6, WT18

Tailings Sump Summary

		Uranium (mg/L)	Molybdenum (mg/L)	Selenium (mg/L)
Pre-Flushing				
	Max	67.55	118.00	2.86
	Min	27.80	75.80	0.34
	Average	43.45	102.29	0.93
Sumps E1, W1, N1, S1				
Post Flushing	Max	30.40	63.30	0.48
	Min	6.99	10.10	0.02
	Average	16.46	34.38	0.20
% of Pre-Flushing Average:		38%	34%	22%

Sumps E1, W1, N1, S1

Table 4.2-1 Groundwater Corrective Action Objectives, Actions, and Technology Type Summary

Media	Objective	Action	Remedial Technology Type	Process Options
Seepage to Groundwater from Large Tailings Pile	Reduce Seepage from the Tailings Piles	Tailings Water Removal/Treatment/Disposal	Water Extraction	Toe Drains
			In Situ Treatment	Chemical Precipitation
			Ex situ Treatment (requires water extraction)	Reverse Osmosis
				Membrane Filtration
				Ion exchange
				Evaporation
			Disposal	Evaporation
		Tailings Solids & Water Containment	Physical Barrier	Engineered Cover (Conventional, Evapotranspiration)
Groundwater Plume	Prevent Ingestion	Pathway Elimination	Control of Access and Use of Groundwater	Well Drilling Prohibition
				Public Health Advisory
				Restrictive Covenants
				Fee Title Land Ownership
			Engineering Controls	Alternate Water Supply (Municipal)
	Restore Groundwater Quality	Contaminant Removal/Treatment/Disposal	Hydraulic Containment	Groundwater Extraction Wells
				Groundwater Extraction Trenches
				Injection Wells
				Injection Trenches
			Groundwater Extraction	Groundwater Extraction Wells
				Groundwater Extraction Trenches
			In Situ Treatment	Hydroxyapatite - Permeable Reactive Barrier
				Chemical Precipitation
			Ex situ Treatment (requires groundwater extraction)	Reverse Osmosis
				Membrane Filtration
				Ion Exchange
				Evaporation
			Disposal	Evaporation
		Contaminant	Hydraulic Barriers	Groundwater Extraction Wells
				Water Injection Wells
				Water Injection Trenches

Table 4.2-2 Groundwater Corrective Action Alternatives Technology Type Summary

Alternative		Media	Action	Remedial Technology Type	Process Option	Comments
Alternative 1	Continued Groundwater Containment and Removal (No Action)	Seepage to Groundwater from Large Tailings Pile	Water Removal/Treatment Disposal	Water Extraction	Toe drains	Final tailings cover is placed on Large Tailings Pile per approved Reclamation and Decommissioning Plan, Small Tailings Pile remains available for disposal of corrective action waste materials, final cover not placed until year 1,001 per approved Reclamation and Decommissioning Plan. Fee title land ownership and municipal water supply prevents human access to and use of contaminated groundwater during the period of the action. Current groundwater corrective action continues for the period of compliance (at least 200 years and, to the extent reasonably achievable, 1,000 years). Groundwater monitoring and reporting continue per license.
				Ex situ Treatment (requires water extraction)	Reverse Osmosis	
					Membrane Filtration	
					Evaporation	
				Disposal	Evaporation	
			Water Containment	Physical Barrier	Engineered Cover (Conventional, Evapotranspiration)	
		Groundwater Plume	Pathway Elimination	Control of Access to and Use of Groundwater	Well Drilling Prohibition	
					Public Health Advisory	
					Restrictive Covenants	
					Fee Title Land Ownership	
				Engineering Controls	Alternate Water Supply (Municipal)	
			Contaminant Removal/Treatment/Disposal	Hydraulic Containment	Groundwater Extraction Wells	
					Groundwater Extraction Trenches	
					Injection Wells	
					Injection trenches	
				Groundwater Extraction	Groundwater Extraction Wells	
					Groundwater Extraction Trenches	
				Ex situ Treatment (requires water extraction)	Membrane Filtration	
					Evaporation	
				Disposal	Evaporation	
Alternative 2	Groundwater Containment and Removal and *In Situ* Treatment	Seepage to Groundwater from Large Tailings Pile	Water Removal/Treatment Disposal	Water Extraction	Toe Drains	Final tailings cover is placed on Large Tailings Pile per approved Reclamation and Decommissioning Plan, Small Tailings Pile remains available for disposal of corrective action waste materials, final cover not placed until year 1,001 per approved Reclamation and Decommissioning Plan. Current groundwater corrective action continues for approximately 35 years, then On-Site area groundwater remediation ceases and a permeable reactive barrier of hydroxyapatite is installed. Fee title land ownership and municipal water supply prevents human access to and use of contaminated groundwater during the period of the corrective action. Permeable reactive barrier of hydroxyapatite is installed near Large Tailings Pile in year 36 and replaced every 50 years for the period of compliance (at least 200 years and, to the extent reasonably achievable, 1,000 years) Groundwater monitoring and reporting continue per License.
				Ex situ Treatment (requires water extraction)	Reverse Osmosis	
					Membrane Filtration	
					Evaporation	
				Disposal	Evaporation	
			Water Containment	Physical Barrier	Engineered Cover (Conventional, Evapotranspiration)	
		Groundwater Plume	Pathway Elimination	Control of Access to and Use of Groundwater	Well Drilling Prohibition	
					Public Health Advisory	
					Restrictive Covenants	
					Fee Title Land Ownership	
				Engineering Controls	Alternate Water Supply (Municipal)	
			Contaminant Removal/Treatment/Disposal	Hydraulic Containment	Groundwater Extraction Wells	
					Groundwater Extraction Trenches	
					Injection Wells	
					Injection Trenches	
				Groundwater Extraction	Groundwater Extraction Wells	
					Groundwater Extraction Trenches	
				In Situ Treatment	Hydroxyapatite - Permeable Reactive Barrier	
				Ex situ Treatment (requires groundwater extraction)	Reverse Osmosis	
					Membrane Filtration	
					Evaporation	
				Disposal	Evaporation	
Alternative 3	Alternate Concentration Limits	Seepage to Groundwater from Large Tailings Pile	Water Containment	Physical Barrier	Engineered Cover (Conventional, Evapotranspiration)	Final tailings cover is placed on Large and Small Tailings Piles per approved Reclamation and Decommissioning Plan. Fee title land ownership and municipal water supply prevents human access to and use of contaminated groundwater during the period of compliance. Groundwater monitoring and reporting continue per proposed program.
		Groundwater Plume	Pathway Elimination	Control of Access to and Use of Groundwater	Well Drilling Prohibition	
					Public Health Advisory	
					Restrictive Covenants	
					Fee Title Land Ownership	
				Engineering Controls	Alternate Water Supply (Municipal)	

Table 4.2-3 Summary of Total Water Collection, Injection and Waste Water Production Rates and Volumes

Model Year	Total Collection Rate (gpm)	Total Injection Rate (gpm)	Total Waste Production Rate (gpm)
ALTERNATIVE 1			
1	477	386	91
20	333	269	63
100	173	140	33
150	144	116	27
200	123	100	23
500	101	82	19
1000	100	81	19
ALTERNATIVE 2			
1	477	386	90.6
20	333	269	63.2
36	266	215	50.5
37-1,000	0	0	0.0

Table 4.2-4 Summary of Total Water Collection, Injection and Waste Water Production Rates and Volumes

Model Year	Total Collection Rate (gpm)	Total Injection Rate (gpm)	Total Waste Production Rate (gpm)	Total Treatment Volume (gallons)	Total Injection Volume (gallons)	Total Waste Water Volume (gallons)
ALTERNATIVE 1						
1	477	386	91	250,641,449	203,019,574	47,621,875
20	333	269	63	3,819,211,615	3,093,561,408	725,650,207
100	173	140	33	9,392,170,265	7,607,657,915	1,784,512,350
150	144	116	27	4,089,160,831	3,312,220,273	776,940,558
200	123	100	23	3,460,072,813	2,802,658,979	657,413,835
500	101	82	19	16,662,608,937	13,496,713,239	3,165,895,698
1000	100	81	19	26,355,432,455	21,347,900,289	5,007,532,166
				64,029,298,365	**51,863,731,676**	**12,165,566,689**
ALTERNATIVE 2						
1	477	386	90.6	250,641,449	203,019,574	47,621,875
20	333	269	63.2	3,819,211,615	3,093,561,408	725,650,207
36	266	215	50.5	2,499,897,681	2,024,917,121	474,980,559
37-1,000	0	0	0.0	-	-	-
				6,569,750,745	**5,321,498,103**	**1,248,252,641**
ALTERNATIVE 3						
1 through 1000	0	0	0	0	0	0

Table 4.3-1 Base-Case and Bounding-Case Model Input Summary

Model Input Parameter	Base-Case Condition	Bounding-Case Condition	Modeled Hazardous Constituent	Rationale
Precipitation-Based Areal Groundwater Recharge	Areal groundwater recharge throughout the SMC Basin in the groundwater model was specified as approximately 2% of the long-term average precipitation at the GRP. This is the upper bound of estimated areal (diffuse) recharge rates for this region as estimated by the New Mexico Bureau of Geology and Mineral Resources (2017).	Areal recharge was constant at approximately 2% of long-term average precipitation. In addition, focused recharge of 2 inches was applied every 20 years on the floodplain of San Mateo Creek upstream of the LTP. The area where the focused recharge was applied is 5.25 square miles. The frequency of 20 years is the approximate frequency of annual precipitation exceeding 14 inches per year based on 1895-2024 PRISM data.	Uranium	Accounts for potential flow in San Mateo Creek during abnormally wet years and subsequent infiltration from water spread out on the floodplain.
Large Tailings Pile Seepage Recharge Rate	Base-case condition Large Tailings Pile seepage rate with asymptotic decline to 0.036 gpm (Hydro-Engineering, 2025)	Bounding-case condition Large Tailings Pile seepage rate with asymptotic decline to 2.4 gpm (Hydro-Engineering, 2025)	Uranium	Bounding-case condition of greater seepage rate than base-case rate. Bounding-case infiltration rates through tailings cover are comparable to native ground infiltration rates.
Large Tailings Pile Seepage Recharge Concentration	Base-case Large Tailings Pile seepage uranium concentration with asymptotic decline to 5.06 mg/L (Hydro-Engineering, 2025)	Bounding-case Large Tailings Pile seepage uranium concentrations set to 45 mg/L based on pre-flushing toe drain seepage concentrations	Uranium	Bounding-case condition of greater uranium concentrations in tailings seepage to alluvial groundwater recharge, basically assumes tailings concentrations rebound to roughly average pre-flushing concentrations. Concentration rebound is not indicated by site-specific tailings studies and characterization.
	Base-case Large Tailings Pile seepage molybdenum concentration with asymptotic decline to 12.84 mg/L (Hydro-Engineering, 2025)			
Small Tailings Pile Seepage Rate and Concentration	Seepage rate equal to approximately 2% of precipitation and uranium concentration of 40 mg/L.	Seepage rate equal to approximately 2% of precipitation and uranium concentration of 40 mg/L.	Uranium	Base-case condition approximately a bounding-case condition.
Freundlich Sorption-Based Retardation Factor	Freundlich sorption parameter values determined from geochemical modeling and used in calibration of historical period model.	Freundlich sorption parameter values that produce retardation factors that are approximately 80% of those produced by the calibrated parameter values across the observed range of aqueous uranium concentrations	Uranium	Bounding-case condition of greater advective transport than suggested by site data and calibration of the historical model. Generic conservative constituent is assumed to be non-reactive and non-sorptive, so sorptive processes were not simulated.
Initial Mobile Domain Concentration Conditions in Alluvial Aquifer Beneath the Large Tailings Pile and Small Tailings Pile	Historical period model simulated final concentrations adjusted based on measured data (end of 2024)	Same as base case except in alluvium beneath the Large and Small Tailings Piles where mobile domain initial concentrations were increased by 25%.	Uranium	Increases initial mobile domain mass beneath the Large and Small Tailings Piles to mimic the bounding-case condition of a under-characterization of uranium concentrations beneath the tailings piles.
San Andres-Glorieta Aquifer Municipal Groundwater Supply Extraction	Simulation of constant average 2012-2018 extraction rates presented in DOE 2020b at existing municipal wells	Same as in the base-case condition.	Uranium	Bounding-case condition same as in base-case condition as this minimizes downward vertical flow from alluvium into lower Chinle relative to a scenario with increased SAG pumping.
Dual-Domain Mass Transfer Coefficients	Mass transfer rate coefficient values determined during calibration of the historical period	Increased by one order of magnitude mass transfer rate coefficients determined during calibration of the historical period	Uranium	Bounding-case condition of greater back-diffusion of mass from the immobile domain to the mobile domain. (Note: observed to be a generally insensitive parameter)

Table 4.3-2 Summary of Base-Case Predictive Modeling by Alternative

Alternative 1: Base-Case Groundwater Uranium Concentrations For Collection and Injection Predictive Model

	Alluvial Aquifer	Upper Chinle	Middle Chinle	Lower Chinle Non-Mixing Mixing	San Andres-Glorieta Aquifer
POE Protective Limit (mg/L)	0.16	0.09	0.07	0.03	0.03
Maximum POE 1 Concentration (mg/L)	0.1807	absent	absent	absent	0.0067
Maximum POE 2 Concentration (mg/L)	0.0000	absent	0.0663	0.0203	0.0052
Maximum POE 3 Concentration (mg/L)	0.2118	0.0490	0.1820	0.0203	0.0052
Maximum POE 4 Concentration (mg/L)	0.0246	0.0231	0.0202	0.0200	0.0062
Maximum POE 5 Concentration (mg/L)	0.0000	0.0200	0.0210	0.0205	0.0089
Maximum POE 6 Concentration (mg/L)	0.0200	absent	absent	absent	0.0067
Maximum POE 7 Concentration (mg/L)	0.0266	absent	absent	absent	0.0070
Maximum POE Concentration	0.0266	0.0231	0.0210	0.0205	0.0089

Alternative 2: Base-Case Groundwater Uranium Concentrations For Collection and Injection with PRB Predictive Mode

	Alluvial Aquifer	Upper Chinle	Middle Chinle	Lower Chinle	San Andres-Glorieta Aquifer
POE Protective Limit (mg/L)	0.16	0.09	0.07	0.03	0.03
Maximum POE 1 Concentration (mg/L)	0.1807	absent	absent	absent	0.0067
Maximum POE 2 Concentration (mg/L)	0.0000	absent	0.0663	0.0203	0.0052
Maximum POE 3 Concentration (mg/L)	0.2118	0.0490	0.1820	0.0203	0.0052
Maximum POE 4 Concentration (mg/L)	0.0246	0.0231	0.0202	0.0200	0.0062
Maximum POE 5 Concentration (mg/L)	0.0000	0.0200	0.0210	0.0204	0.0089
Maximum POE 6 Concentration (mg/L)	0.0200	absent	absent	absent	0.0067
Maximum POE 7 Concentration (mg/L)	0.0266	absent	absent	absent	0.0070
Maximum POE Concentration	0.0266	0.0231	0.0210	0.0204	0.0089

Alternative 3: Base-Case Groundwater Uranium Concentrations For Natural Attenuation Predictive Model

	Alluvial Aquifer	Upper Chinle	Middle Chinle	Lower Chinle	San Andres-Glorieta Aquifer
POE Protective Limit (mg/L)	0.16	0.09	0.07	0.03	0.03
Maximum POE 1 Concentration (mg/L)	0.1807	absent	absent	absent	0.0067
Maximum POE 2 Concentration (mg/L)	0.0000	absent	0.0670	0.0203	0.0052
Maximum POE 3 Concentration (mg/L)	0.2201	0.0484	0.1825	0.0207	0.0052
Maximum POE 4 Concentration (mg/L)	0.0246	0.0234	0.0202	0.0200	0.0053
Maximum POE 5 Concentration (mg/L)	0.0000	0.0200	0.0210	0.0247	0.0064
Maximum POE 6 Concentration (mg/L)	0.0200	absent	absent	absent	0.0067
Maximum POE 7 Concentration (mg/L)	0.0266	absent	absent	absent	0.0070
Maximum POE Concentration	0.0266	0.0234	0.0210	0.0247	0.0070

NA = Saturated conditions in unit not present at this location

Excluded, value reflects upgradient inputs, not mill-related source

Table 4.3-3 Summary of Areas of Affected Groundwater and Areas of Restoration

	Square Feet	Acres	Square Miles	% Restored
Alternative 1				
2024 Uranium	49,905,433	1,146	1.79	
Alternative 1 200 Year Uranium	17,382,240	399	0.62	
Area Restored (200 years)	32,523,193	747	1.17	65%
Alternative 1 1000 Year Uranium	8,779,662	202	0.31	
Area Restored (1,000 years)	41,125,771	944	1.48	82%
Alternative 2				
Alternative 2 200 Year Uranium	39,442,270	905	1.41	
Area Restored (200 years)	10,463,163	240	0.38	27%
Alternative 2 1000 Year Uranium	31,700,030	728	1.14	
Area Restored (1,000 years)	18,205,403	418	0.65	46%
Alternative 3				
Alternative 3 200 Year Uranium	53,566,574	1,230	1.92	
Area Restored (200 years)	(3,661,141)	(84)	(0.13)	-7%
Alternative 3 1000 Year Uranium	49,399,067	1,134	1.77	
Area Restored (1,000 years)	506,366	12	0.02	1%

[1]Areas with groundwater above License groundwater protection standards in one or more water-yielding units

Negative value in parentheses means total area over which groundwater is not below License groundwater protection

Proposed Long Term Control Boundary = 6,830 acres

Table 4.3-4 Maximum Predicted Uranium POE Concentrations For Alternatives

	Alluvial Aquifer	Upper Chinle	Middle Chinle	Lower Chinle	San Andres-Glorieta
	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
Protective Limit	0.16	0.09	0.07	0.03	0.07
Alternative 1 Maximum Groundwater Uranium Concentration at POE	0.0266	0.0231	0.021	0.0205	0.0089
Alternative 2 Maximum Groundwater Uranium Concentration at POE	0.0266	0.0231	0.021	0.0204	0.0089
Alternative 3 Maximum Groundwater Uranium Concentration at POE	0.0266	0.0234	0.021	0.0247	0.007
Difference Alternative 2 to Alternative 1 (mg/L)	-	-	-	0.0001	-
Percent difference	0%	0%	0%	0%	0%
Difference Alternative 3 to Alternative 1 (mg/L)	-	(0.0003)	-	(0.0042)	0.0019
Percent difference	0%	-1%	0%	-20%	21%
Difference Alternative 3 to Alternative 2 (mg/L)	-	(0.0003)	-	(0.0043)	0.0019
Percent difference	0%	-1%	0%	-21%	21%

Percent Difference = Difference ÷ Max POE conc. of reference alternative

(-) = Alternative increase concentration relative to reference alternative

Table 4.3-5 Summary of Alternatives Analysis

Evaluation Criteria	Alternative 1 (No Action)		Alternative 2		Alternative 3 (Proposed Action)	
Alternative Ranking	**3**		**2**		**1**	
Human Health Protection						
Occupational Health and Safety Risks	◒	Highest potential for occupational exposure due to 1,000 year duration of action. Low overall risk, mitigated by use of SOPs, PPE, training, and monitoring	◒	Intermediate potential for occupational exposure due to 36 year duration of active pumping and periodic permeable reactive barrier replacement over 940 years. Low overall risk, mitigated by use of SOPs, PPE, training, and monitoring	●	Occupational exposures related to one-time decommissioning and reclaiming of corrective action infrastructure.
Public Health Protection	●	Exposure pathway eliminated through alternate water supply, groundwater access control, long-term active containment	●	Exposure pathway eliminated through alternate water supply, groundwater access control, plume area reduction	●	Exposure pathway eliminated through alternate water supply and groundwater access control
Environmental Protection						
Risks to Wildlife	◒	Highest relative risks, due to 1,000 year operation of evaporation ponds. Low overall risk, mitigated by best practices for wildlife use deterrents and monitoring	◒	Intermediate relative risks, due to 36 year operation of evaporation ponds. Low overall risk, mitigated by best practices for wildlife use deterrents and monitoring	●	Least risks, no wildlife pathway for groundwater exposure.
Preservation of Resource	○	Irretrievable commitment of 12.2 billion gallons of groundwater as treatment waste	◒	Irretrievable commitment of 0.96 billion gallons of groundwater as treatment waste	●	No additional irretrievable commitment of groundwater or waste water
Implementation						
Ability to Construct and Operate	●	Highly technically feasible, difficulties and unknowns relate to extreme duration of activity High technology reliability Additional corrective actions not precluded High ability to monitor effectiveness	◒	Moderately technically feasible, difficulties and unknowns relate to extreme duration of activity and ability install in heterogeneous geologic environment High technology reliability Additional corrective actions not precluded High ability to monitor effectiveness	●	Highly technically feasible, difficulties and unknowns relate to extreme duration of activity No technology applied Additional corrective actions not precluded High ability to monitor effectiveness
Administrative Feasibility	●	High administrative feasibility, permits from NMED and License Amendment from NRC.	◒	High administrative feasibility, permits from NMED and License amendment from NRC.	●	High administrative feasibility, License amendment from NRC.
Restoration of Resource	◒	Progressive restoration through 1,000 years	◒	Partial restoration through 1,000 years	○	No active restoration
Reduce Tailings Seepage and Migration	◒	Seepage and migration limited by approved tailings cover, impacted groundwater contained, plume migration continues	◒	Seepage and migration limited by approved tailings cover, impacted groundwater not contained, plume migration continues	◒	Seepage and migration limited by approved tailings cover, impacted groundwater not contained
Cost						
Capital Costs (Year 0 to 3)	$11,550,000	Reverse osmosis system capital replacements, evaporation pond relinings, monitoring well capital replacements, spray evaporation system capital replacements	$53,991,550	Reverse osmosis system capital replacements, permeable reactive barrier design/installation & capital replacements, evaporation pond relinings, monitoring well capital replacements, spray evaporation system capital replacements	$0	None
Operation and Maintenance Costs	$5,812,216,153	1,000 year operation	$3,162,794,100	36 year active removal/treatment 965 years passive in situ treatment	$23,103,683	Groundwater corrective action decommissioning, four years of monitoring and staffing
Decommissioning Costs	$3,735,130	Year 1001-1005	$3,735,130	Year 1001-1005	$3,139,382	Year 5-10
Total Nominal Costs	**$5,827,501,283**		**$3,220,520,780**		**$26,243,065**	
Total Present Value (3% Discount Rate)	**$245,163,000**		**$196,774,000**		**$23,504,000**	
Total Present Value (7% Discount Rate)	**$191,566,000**		**$99,359,000**		**$20,651,000**	

● Fully meets criteria
◒ Partially meets criteria
○ Does not meet criteria

Table 4.4-1 Summary of Private Wells Not Currently Owned by HMC

Use Code	Use Description	Quantity
DOL	Domestic and Livestock Watering	0
DOM	Domestic One Household	16
EXP	Exploration	0
IND	Industrial	0
IRR	Irrigation	1
MUL	Multiple Domestic Households	1
MUN	Municipal - City or County Supplied Water	0
SAN	Sanitary In Conjunction With A Commercial Use	0
STK	Livestock Watering	0
SUB	Subdivision	2
	Total:	**20**

All properties have access to existing municipal water lines

Table 4.4-2 Water Application Rates and Bases of Estimates

Water Use	Application or Use Rate	Basis of Estimate	Source
Irrigation			
Not precluded by proposed action	None		
Alfalfa	34.2 inches/yr (2.85 ft/yr)	Water Application and Requirements for Crops, New Mexico.	https://nmwrri.nmsu.edu/wp-content/uploads/2015/watcon/proc2/Diebold.pdf
Carrots	55 inches/yr (4.58 ft/yr)	Commercial Production and Management of Carrots, Bulletin 1175, University of Georgia	https://extension.uga.edu/publications/detail.html?number=B1175&title=Commercial%20Production%20and%20Management%20of%20Carrots
Stock Watering			
No Permitted Wells	None		
Domestic Well			
Full Domestic Use	100 gpd/person	EPA: How We use Water; Domestic Water Use in Gallons Per day Per Person and Percent Population Growth from 2000 to 2015	https://www.epa.gov/watersense/how-we-use-water
Outdoor Use Only	50 gpd/person (50% of Total use)	New Mexico Water Use by Categories Supplemental Report 2005	https://www.nrc.gov/docs/ML1030/ML103080984.pdf
Industrial/Commercial Sanitary			
10 staff per well	None	Industrial and Commercial Water Use: Table C-1 Miscellaneous manufacturing industries (SIC 39)	Pacific Institute, 2003, Appendix C
Exploration			
No diversion allocation	None	Exploration wells for natural resources are not used for groundwater diversion and are not considered a current or projected future point of groundwater diversion.	

AMU = Animal Management Unit, 1,000 lb cow ft = feet gal = gallon gpd = gallons per day yr = year lb = pounds

Table 4.4-3 Summary of Projected Water Use Demand and Water Resource Value

	1,000-year Projected Water Use (Gallons)			Nominal Water Resource Value ($)			Present Worth of Water Resource Value ($)					
	High Growth Rate (3.76%/yr)	No Growth	Low Growth Rate (-0.25%/yr)	High Growth Rate (3.75%/yr)	No Growth	Low Growth Rate (-0.23%/yr)	High Growth Rate (3.75%/yr)		No Growth		Low Growth Rate (-0.23%/yr)	
Water Use Type							3%	7%	3%	7%	3%	7%
Alternative 1	**NA**	12,191,593,859	**NA**	**NA**	$109,525,081	**NA**	**NA**	**NA**	$3,763,376	$1,880,984	**NA**	**NA**
Alternative 2	**NA**	1,248,252,641	**NA**	**NA**	$4,414,520	**NA**	**NA**	**NA**	$2,823,689	$1,778,614	**NA**	**NA**
Alternative 3	54,030,147,000	2,737,500,000	604,440,000	$2,147,569,004	$85,669,968	$6,922,503	$1,603,374	$360,733	$605,995	$221,060	$581,073	$147,524

3.15% annual inflation rate for water rates

Discounted Cash Flow basis for present value

3% and 7% Discount Rate per NUREG-1757, Vol. 2, Rev.2, Appendix N (NRC, 2022).

Table 4.4-4 Village of Milan, New Mexico Water Department 2026 Water Rates

Cost Element	Residential	Commercial	Cost Element
Deposit	$ 300.00	$ 1,500.00	Hydrant Meter
Fixed Fee, 1st 2,000 gal	$ 21.85	$ 147.00	Fixed Fee
Commodity Fee per 1,000 gal: 2,001 - 5,000 gal	$ 3.09	$ 3.26	Commodity Fee per 1,000 gal: 0 - 5,000 gal
Commodity Fee per 1,000 gal: 5,001 - 20,000 gal	$ 3.26	$ 3.34	Commodity Fee per 1,000 gal: 5,001 - 20,000 gal
Commodity Fee per 1,000 gal: 20,001 - 40,000 gal	$ 3.34	$ 3.42	Commodity Fee per 1,000 gal: 20,001 - 40,000 gal

Table 4.4-5 Dose, Present Worth, and Value of Averted Dose for Each Alternative (Resident Gardener)

Radionuclide	Alternative 1	Alternative 2	Alternative 3
Maximum Base-Case Modeled POE Concentrations			
CONC (mg/L)-Average of Maximums	0.053	0.069	1.018
Uranium* (pCI/L)	35.78	46.95	689.05
Th-230 (pCI/L)	background	background	background
Ra-226+228 (pCI/L)	background	background	background
Dose at base-case concentrations from all pathways (mrem/yr)			
Dose at Unit Concentration	3.41		
Dose from Uranium (person-mrem/yr)	4.51	5.92	86.91
Total person-rem/yr	0.005	0.006	0.087
30-year Lifetime Dose (rem)	0.135	0.178	2.607
30-year Lifetime Risk (Morbidity)	3.42E-05	4.48E-05	6.58E-04
30-year Lifetime Risk (Mortality)	2.23E-05	2.93E-05	4.30E-04
Unat			
$DCGL_W$ (pCi/L)	198.2		
$CONC/DCGL_W$	0.181	0.237	3.476

* converted from mg/L 677 pCi/mg

1 Bq ≈ 27 pCi

CONC = average of maximum exposure concentrations for all existing domestic wells in proposed boundary, over 1,000 yrs

†Calculated per NUREG-1757, Vol.2, Rev. 2, Appendix N (NRC, 2022), See Appendix 4.4-B

Table 4.4-6 Summary of Groundwater Corrective Action Alternative Costs and Benefits

	Alternative 1		Alternative 2		Alternative 3	
	Removal & Containment (No Action)		Removal and Containment with Permeable Reactive Barrier		ACLs	
	3% Discount Rate	7% Discount Rate	3% Discount Rate	7% Discount Rate	3% Discount Rate	7% Discount Rate
MONETIZED COSTS/BENEFITS RATIO (high)	**65**	**101**	**68**	**55**	**7.4**	**20.0**
MONETIZED COSTS/BENEFITS RATIO (low)	**67**	**103**	**70**	**56**	**10.9**	**25.2**
COSTS						
	3% Discount Rate	**7% Discount Rate**	**3% Discount Rate**	**7% Discount Rate**	**3% Discount Rate**	**7% Discount Rate**
Total Monetized Costs (Present Value)	**$248,771,919**	**$193,406,015**	**$199,533,798**	**$101,103,865**	**$23,504,000**	**$20,651,000**
Present Value of Total Direct Remedial Action Cost	$245,163,000	$191,566,000	$196,774,000	$99,359,000	$23,504,000	$20,651,000
Total Direct Remedial Action Cost (nominal)	$5,827,501,283		$3,220,520,780		$26,243,065	
Capital Costs	$11,550,000		$53,991,550		$0	
Operating and Maintenance Costs	$5,812,216,153		$3,162,794,100		$23,103,683	
Decommissioning Costs	$3,735,130		$3,735,130		$3,139,382	
Monetized Indirect Costs	$3,608,919	$1,840,015	$2,759,798	$1,744,865	$0	$0
Present Value of Irretrievable Waste Water	$3,608,919	$1,840,015	$2,759,798	$1,744,865	$0	$0
Volume of Irretrievable Waste Water	12,191,593,859		1,248,252,641		0	
Non-Monetized Indirect Costs	Low (highest cost)		Low (intermediate costs)		Low (lowest cost)	
Occupational Non-radiological and Transportation Risks	Low (highest)		Low		Low (Lowest)	
Environmental Impact	2 - Low/moderate		2 - Low/moderate		3- Low, lowest	
Loss of Economic Use	3-Low		3-Low		3-Low	
BENEFITS						
	3% Discount Rate	**7% Discount Rate**	**3% Discount Rate**	**7% Discount Rate**	**3% Discount Rate**	**7% Discount Rate**
Monetized Benefits (Present Value-high)	**$3,844,944**	**$1,915,942**	**$2,930,731**	**$1,824,489**	**$3,174,250**	**$1,033,966**
Monetized Benefits (Present Value-low)	**$3,690,487**	**$1,874,973**	**$2,866,840**	**$1,790,740**	**$2,151,949**	**$820,757**
Monetized Direct Benefits - [a]Present Value of Water Resource (1,000 yrs - high)	$3,608,919	$1,840,015	$2,759,798	$1,744,865	$1,603,374	$360,733
[a]Present Value of Water Resource (1,000 yrs) High Population Growth Rate	NA	NA	NA	NA	$1,603,374	$360,733
[a]Present Value of Water Resource (1,000 yrs) No Population Growth	$3,763,376	$1,880,984	$2,823,689	$1,778,614	$605,995	$221,060
[a]Present Value of Water Resource (1,000 yrs) Low Population Growth Rate	NA	NA	NA	NA	$581,073	$147,524
Monetized Indirect Benefits	$81,568	$34,958	$107,042	$45,875	$1,570,876	$673,233
Benefit of Avoided Dose (B_{AD}) ($)	$81,568	$34,958	$107,042	$45,875	$1,570,876	$673,233
Non-Monetized Indirect Benefits	Moderate (lowest benefit)		Moderate		Moderate (highest benefit)	
Land Value Depreciation	Moderate		Moderate		Moderate	
Timeliness of Remedy Completion	>1,000 years		>1,000 years		5-10 years	
Aesthetics	Minor: Most Impact		Minor		Minor: Least Impact	

[a]Based on replacing potential future groundwater demand with water from municipal water supply

Note: Quantity and value of water does not change based on population growth for Alternatives 1 and 2.

Table 5.1-1: Proposed Action: Maximum Predicted POE Groundwater Concentrations; Bounding Case

		Alluvial Aquifer			Upper Chinle		Middle Chinle		Lower Chinle		San Andres-Glorieta	
		Maximum Concentration	Time of Maximum	Attenuation Factor	Maximum Concentration	Time of Maximum	Maximum Concentration	Time of Maximum	Maximum Concentration	Time of Maximum	Maximum Concentration	Time of Maximum
URANIUM	[A]POC Maximum Modeled Concentration (mg/L)	45.69										
	POE Segment 1	0.181	1	NA	ABSENT		ABSENT		ABSENT		0.007	1
	POE Segment 2	0.000	0	NA	ABSENT		0.066	1	0.020	75	0.005	1001
	POE Segment 3	0.220	75	NA	0.046	6	0.180	1	0.020	1001	0.005	1001
	POE Segment 4	0.025	1	1857	0.023	**1**	0.020	1	0.020	1	0.005	1001
	POE Segment 5	0.000	0	NA	0.020	1	0.021	1	0.021	1001	0.006	570
	POE Segment 6	0.020	2	2285	ABSENT		ABSENT		ABSENT		0.006	700
	POE Segment 7	**0.0266**	1	**1718**	ABSENT		ABSENT		ABSENT		0.007	1
	Maximum:	**0.0266**			**0.0230**		**0.0210**		**0.0210**		**0.0070**	
MOLYBDENUM	[A]POC Maximum Concentration (mg/L)	77.3										
	POE Segment 1	0.008	5	NA	ABSENT		ABSENT		ABSENT		0.005	230
	POE Segment 2	0.000	0	NA	ABSENT		0.005	1001	0.005	715	0.005	275
	POE Segment 3	0.052	1	NA	0.007	1001	0.005	1001	0.005	826	0.005	1
	POE Segment 4	**0.038**	1	**2034**	**0.024**	12	0.005	1001	0.005	1	0.005	530
	POE Segment 5	0.000	0	NA	0.005	1	0.005	1	0.005	806	0.005	85
	POE Segment 6	0.005	1000	15460	ABSENT		ABSENT		ABSENT		**0.006**	80
	POE Segment 7	0.007	2	11043	ABSENT		ABSENT		ABSENT		0.005	215
	Maximum:	**0.038**			**0.024**		**0.005**		**0.005**		**0.006**	
SELENIUM	[A]POC Maximum Concentration (mg/L)	2.816										
	POE Segment 1	0.017	8	NA	ABSENT		ABSENT		ABSENT		0.001	1
	POE Segment 2	0.000	0	NA	ABSENT		0.029	1	0.005	160	0.000	1
	POE Segment 3	0.087	1	NA	0.073	105	0.031	1	0.005	1	0.000	1001
	POE Segment 4	**0.024**	1	**117**	0.005	1	0.007	1	0.005	1	0.001	1
	POE Segment 5	0.000	0	NA	0.005	1	0.007	14	**0.021**	120	0.006	1
	POE Segment 6	0.006	1	469	ABSENT		ABSENT		ABSENT		**0.008**	1
	POE Segment 7	0.006	1	469	ABSENT		ABSENT		ABSENT		0.003	1
	Maximum:	**0.024**			**0.005**		**0.007**		**0.021**		**0.008**	

NON-SORBED CONSTITUENTS (F, NO_2+NO_3)	Alluvial Aquifer			Upper Chinle			Middle Chinle			Lower Chinle			San Andres-Glorieta		
Maximum Concentration	Maximum Concentration	Time of Maximum	Attenuation Factor	Maximum Concentration	Time of Maximum	Attenuation Factor	Maximum Concentration	Time of Maximum	Attenuation Factor	Maximum Concentration	Time of Maximum	Attenuation Factor	Maximum Concentration	Time of Maximum	Attenuation Factor
UNIT CONCENTRATION															
POC Maximum Modeled Concentration (mg/L)	1.000														
POE Segment 1	0.0	1.0	117.1	ABSENT			ABSENT			ABSENT			0.0008	1	1325.5
POE Segment 2	0.0	0.0	NA	ABSENT			0.0000	125	NA	0.0013	199	773.0	0.0000	1	NA
POE Segment 3	0.0	14.0	NA	0.0000	16	NA	0.0000	1001	NA	0.0000	1001	NA	0.0000	1001	NA
POE Segment 4	**0.1569**	2	**6.4**	**0.0113**	395	**88.5**	0.0043	1001	231.0	0.0003	1001	3451.6	0.0006	1	1785.3
POE Segment 5	0.0000	0	NA	0.0000	5	NA	**0.0516**	1	**19.4**	**0.0549**	4	**18.2**	0.0062	1	161.6
POE Segment 6	0.0422	135	23.7	ABSENT			ABSENT			ABSENT			**0.0076**	1	**132.0**
POE Segment 7	0.0609	1	16.4	ABSENT			ABSENT			ABSENT			0.0026	1	383.1
Maximum:	**0.1569**			**0.0113**			**0.0516**			**0.0549**			**0.0076**		

SORBED CONSTITUENTS (As, Cd, V, Th-230, Ra-226+228)	Alluvial Aquifer			Upper Chinle			Middle Chinle			Lower Chinle			San Andres-Glorieta		
Maximum Concentration	Maximum Concentration	Time of Maximum	Attenuation Factor	Maximum Concentration	Time of Maximum	Attenuation Factor	Maximum Concentration	Time of Maximum	Attenuation Factor	Maximum Concentration	Time of Maximum	Attenuation Factor	Maximum Concentration	Time of Maximum	Attenuation Factor
UNIT CONCENTRATION															
POC Maximum Modeled Concentration (mg/L)	1.000														
POE Segment 1	0.0000	55	NA	ABSENT			ABSENT			ABSENT			0.0000	60	NA
POE Segment 2	0.0000	0	NA	ABSENT			0.0000	145	NA	0.0000	320	NA	0.0000	690	NA
POE Segment 3	0.0000	31	NA	0.0000	245	NA	0.0000	1001	NA	0.0000	1001	NA	0.0000	1001	NA
POE Segment 4	0.0000	1	NA	0.0000	1001	NA	0.0000	1001	NA	0.0000	1001	NA	0.0000	1001	NA
POE Segment 5	0.0000	0	NA	0.0000	1001	NA	**0.0049**	199	**202.6**	**0.0027**	1001	374.7	0.0002	100	4153.3
POE Segment 6	**0.0213**	155	**46.9**	ABSENT			ABSENT			ABSENT			**0.0005**	105	**2119.9**
POE Segment 7	0.0000	1	NA	ABSENT			ABSENT			ABSENT			0.0000	65	NA
Maximum:	**0.0213**			**0.0000**			**0.0049**			**0.0027**			**0.0005**		

[A]From Bounding Case Models, See Table 5.1-4

Up Gradient From Site Sources & POC

Formation absent along POE segment

Table 5.1-2 Current Source Area and POC Area Groundwater Constituent Concentrations

				[1]Point of Compliance (POC) Area		
Constituent	**Units**	**Lowest Promulgated Standard**	**License Standard**	**Measured Maximum (2022-2025)**	**Measured Average (2022-2025)**	**Count**
Arsenic	mg/L	0.01	--	0.031	0.007	21
Cadmium	mg/L	0.005	--	0.003	0.001	21
Molybdenum	mg/L	0.1	0.1	59.70	11.69	95
Selenium	mg/L	0.01	0.06 - 0.32	2.60	0.43	95
Uranium[a]	mg/L	0.03	0.03 - 0.18	36.50	7.85	96
Vanadium[b]	mg/L	--	0.01 - 0.02	0.03	0.02	24
Fluoride[3]	mg/L	1.6	--	3.0	0.6	41
Nitrate+Nitrite	mg/L	10	12 - 15	13.6	2.2	24
Thorium-230[c]	pCi/L	--	0.3	2.10	0.36	24
Radium-226+228	pCi/L	5	5	5.10	1.81	23

[1]Data Set = 40 POC area wells: B3, B4, B5, B6, B7, B8, B9, B15, B16, B19, B20, B31, B32, B35, B40, B42, B44, D1, DR, DT, K9, M3, S1, S3, S4, S5R, S11, S12, S19, SA, SB, SO, SQ, SSR, ST, SUR, SV, SW, SZ, and X

[2]Average of all values, included values Below Detection Limits at the limit of detection

[3]Fluoride Data from 2016-2020

[a]Only one value above 45 mg/L; 47 mg/L in well B44, 2025. Not representative of POC area

[b]Only one value above 0.03 mg/L; 0.43 mg/L in well B11 , 2023. Not representative of POC area

[c]Only one value above 0.5 pCi/L; 2.1 pCi/L in well SUR, 2024. Not representative of POC area

Table 5.1-3 Summary of Predicted POE Maxima

ALLUVIAL AQUIFER

				POE 1 Concentration	POE 2 Concentration	POE 3 Concentration	POE 4 Concentration	POE 5 Concentration	POE 6 Concentration	POE 7 Concentration	
Bounding Case Attenuation Factor (Sorbed)				NA	NA	NA	NA	NA	46.9	NA	
Bounding Case Attenuation Factor (Non-Sorbed)				NA	NA	NA	6.4	NA	23.7	16.4	
Lowest Promulgated Standard	**Units**	**Hazardous Constituent**	**2022-2025 POC Max**								**Maximum**
0.01	mg/L	Arsenic	0.031	**UP GRADIENT**	**UP GRADIENT**	**UP GRADIENT**	0.0000	0.0000	**0.0007**	0.0000	**0.0007**
0.005	mg/L	Cadmium	0.003				0.0000	0.0000	**0.0001**	0.0000	**0.0001**
0.1	mg/L	Molybdenum	59.70				**0.0380**	0.0000	0.0050	0.0070	**0.0380**
0.05	mg/L	Selenium	2.60				**0.0240**	0.0000	0.0060	0.0060	**0.0240**
0.03	mg/L	Uranium	36.50				0.0246	0.0000	0.0200	**0.0266**	**0.0266**
0.01	mg/L	Vanadium	0.03				0.0000	0.0000	**0.0006**	0.0000	**0.0006**
1.6	mg/L	Fluoride	3				**0.471**	0.0000	0.127	0.2	**0.4706**
10	mg/L	Nitrate+Nitrite	13.6				**2.13**	0.0000	0.574	0.8	**2.1333**
0.3	pCi/L	Thorium-230	2.1				0.0000	0.0000	**0.0448**	0.0000	**0.0448**
5	pCi/L	Ra226+228	5.1				0.0000	0.0000	**0.1088**	0.0000	**0.1088**

UPPER CHINLE

				POE 1 Concentration	POE 2 Concentration	POE 3 Concentration	POE 4 Concentration	POE 5 Concentration	POE 6 Concentration	POE 7 Concentration	
Bounding Case Attenuation Factor (Sorbed)				NA	NA	NA	NA	NA	NA	NA	
Bounding Case Attenuation Factor (Non-Sorbed)				NA	NA	NA	88.5	NA			
Lowest Promulgated Standard	**Units**	**Hazardous Constituent**	**2022-2025 POC Max**								**Maximum**
0.01	mg/L	Arsenic	0.031	**ABSENT**	**ABSENT**	**UP GRADIENT**	0.0000	0.0000	**ABSENT**	**ABSENT**	**0.0000**
0.005	mg/L	Cadmium	0.003				0.0000	0.0000			**0.0000**
0.1	mg/L	Molybdenum	59.7				**0.0240**	0.0050			**0.0240**
0.05	mg/L	Selenium	2.6				**0.0050**	**0.0050**			**0.0050**
0.03	mg/L	Uranium	36.5				**0.0200**	**0.0200**			**0.0200**
0.01	mg/L	Vanadium	0.03				0.0000	0.0000			**0.0000**
1.6	mg/L	Fluoride	3				0.0339	0.0000			**0.034**
10	mg/L	Nitrate+Nitrite	13.6				0.1537	0.0000			**0.1537**
0.3	pCi/L	Thorium-230	2.1				0.0000	0.0000			**0.0000**
5	pCi/L	Ra226+228	5.1				0.0000	0.0000			**0.0000**

MIDDLE CHINLE

				POE 1 Concentration	POE 2 Concentration	POE 3 Concentration	POE 4 Concentration	POE 5 Concentration	POE 6 Concentration	POE 7 Concentration	
Bounding Case Attenuation Factor (Sorbed)				NA	NA	NA	NA	202.6	NA	NA	
Bounding Case Attenuation Factor (Non-Sorbed)				NA	NA	NA	231.0	19.4	NA	NA	
Lowest Promulgated Standard	**Units**	**Hazardous Constituent**	**2022-2025 POC Max**								**Maximum**
0.01	mg/L	Arsenic	0.031	**ABSENT**	**UP GRADIENT**	**UP GRADIENT**	0.0001	**0.0002**	**ABSENT**	**ABSENT**	**0.0002**
0.005	mg/L	Cadmium	0.003				0.0000	**0.0000**			**0.0000**
0.1	mg/L	Molybdenum	59.7				0.0050	**0.0050**			**0.0050**
0.05	mg/L	Selenium	2.6				0.0070	**0.0070**			**0.0070**
0.03	mg/L	Uranium	36.5				0.0200	**0.0210**			**0.0210**
0.01	mg/L	Vanadium	0.03				0.0001	**0.0001**			**0.0001**
1.6	mg/L	Fluoride	3				0.0130	**0.1549**			**0.1549**
10	mg/L	Nitrate+Nitrite	13.6				0.0589	**0.7023**			**0.7023**
0.3	pCi/L	Thorium-230	2.1				0.0091	**0.0104**			**0.0104**
5	pCi/L	Ra226+228	5.1				0.0221	**0.0252**			**0.0252**

LOWER CHINLE

				POE 1 Concentration	POE 2 Concentration	POE 3 Concentration	POE 4 Concentration	POE 5 Concentration	POE 6 Concentration	POE 7 Concentration	
Bounding Case Attenuation Factor (Sorbed)				NA	NA	NA	NA	374.7	NA	NA	
Bounding Case Attenuation Factor (Non-Sorbed)				NA	NA	NA	3451.6	18.2	NA	NA	
Lowest Promulgated Standard	**Units**	**Hazardous Constituent**	**2022-2025 POC Max**								**Maximum**
0.01	mg/L	Arsenic	0.031	**ABSENT**	**UP GRADIENT**	**UP GRADIENT**	0.0000	**0.0001**	**ABSENT**	**ABSENT**	**0.0001**
0.005	mg/L	Cadmium	0.003				0.0000	**0.0000**			**0.0000**
0.1	mg/L	Molybdenum	59.7				**0.005**	**0.005**			**0.0050**
0.05	mg/L	Selenium	2.6				0.005	**0.021**			**0.0210**
0.03	mg/L	Uranium	36.5				0.020	**0.021**			**0.0210**
0.01	mg/L	Vanadium	0.03				0.0000	**0.0001**			**0.0001**
1.6	mg/L	Fluoride	3				**0.001**	**0.165**			**0.1648**
10	mg/L	Nitrate+Nitrite	13.6				**0.004**	**0.747**			**0.7471**
0.3	pCi/L	Thorium-230	2.1				0.0000	**0.0056**			**0.0056**
5	pCi/L	Ra226+228	5.1				0.0000	**0.0136**			**0.0136**

SAN ANDRES - GLORITA

				POE 1 Concentration	POE 2 Concentration	POE 3 Concentration	POE 4 Concentration	POE 5 Concentration	POE 6 Concentration	POE 7 Concentration	
Bounding Case Attenuation Factor (Sorbed)				NA	NA	NA	NA	4153.3	2119.9	NA	
Bounding Case Attenuation Factor (Non-Sorbed)				1325.5	NA	NA	1785.3	161.6	132.0	383.1	
Lowest Promulgated Standard	**Units**	**Hazardous Constituent**	**2022-2025 POC Max**								**Maximum**
0.01	mg/L	Arsenic	0.031	0.0000	0.0000	0.0000	0.0000	0.0000	**0.0000**	0.0000	**0.0000**
0.005	mg/L	Cadmium	0.003	0.0000	0.0000	0.0000	0.0000	0.0000	**0.0000**	0.0000	**0.0000**
0.1	mg/L	Molybdenum	59.7	0.0050	0.0050	0.0050	0.0050	0.0050	**0.0060**	0.0050	**0.0060**
0.05	mg/L	Selenium	2.6	0.0010	0.0000	0.0000	0.0010	0.0060	**0.0080**	0.0030	**0.0080**
0.03	mg/L	Uranium	36.5	0.0070	0.0050	0.0050	0.0050	0.0060	**0.0060**	0.0070	**0.0070**
0.01	mg/L	Vanadium	0.03	0.0000	0.0000	0.0000	0.0000	0.0000	**0.0000**	0.0000	**0.0000**
1.6	mg/L	Fluoride	3	0.0023	0.0000	0.0000	0.0017	**0.0186**	0.0000	0.0078	**0.0186**
10	mg/L	Nitrate+Nitrite	13.6	0.0103	0.0000	0.0000	0.0076	**0.0842**	0.0001	0.0355	**0.0842**
0.3	pCi/L	Thorium-230	2.1	0.0000	0.0000	0.0000	0.0000	0.0005	**0.0010**	0.0000	**0.0010**
5	pCi/L	Ra226+228	5.1	0.0000	0.0000	0.0000	0.0000	0.0012	**0.0024**	0.0000	**0.0024**

Table 5.1-4 Summary of Predicted POE Predicted Maximums

Column:		**A**					**B**		
Calculation:								**A x B**	
	Units	**Applicable Standard**	**POC Measured Maximum Concentration (2022-2025)**	**POC Modeled Maximum Concentration[B]**	**POE Predicted Maximum Concentration**	**Maximum Occurs In POE**	**Attenuation Factor[C]**	**Maximum Potential ACL**	**Proposed ACL**
Arsenic	mg/L	0.01	0.031	0.031	0.0007	POE 6	46.9	0.469	0.3
Cadmium	mg/L	0.005	0.003	0.003	0.0001	POE 6	46.9	0.234	0.03
Molybdenum	mg/L	0.1	59.7	77.3	0.0380	POE 4	2034	203.4	116
Selenium	mg/L	0.05	2.60	2.82	0.0240	POE 4	117	5.87	4.2
Uranium	mg/L	0.03	36.5	45.7	0.0266	POE 7	1718	51.5	50
Vanadium	mg/L	0.01	0.03	0.030	0.001	POE 6	46.9	0.469	0.3
Fluoride[A]	mg/L	1.6	3	3.0	0.47	POE 4	6.4	10.2	9
Nitrate+Nitrite	mg/L	10	13.6	13.6	2.1	POE 4	6.4	63.8	41
Thorium-230	pCi/L	0.3	2.1	2.100	0.0448	POE 6	46.9	14.1	11
Ra226+228	pCi/L	5	5.1	5.100	0.1088	POE 6	46.9	234	51

[A]Fluoride Data from 2016-2020

[B]From Bounding Case Models

[C]From Table 5.1-1

Bounding Case Attenuation Factor (Sorbed)
Bounding Case Attenuation Factor (Non-Sorbed)

Table 5.2 -1 Groundwater Compliance Monitoring Plan Summary

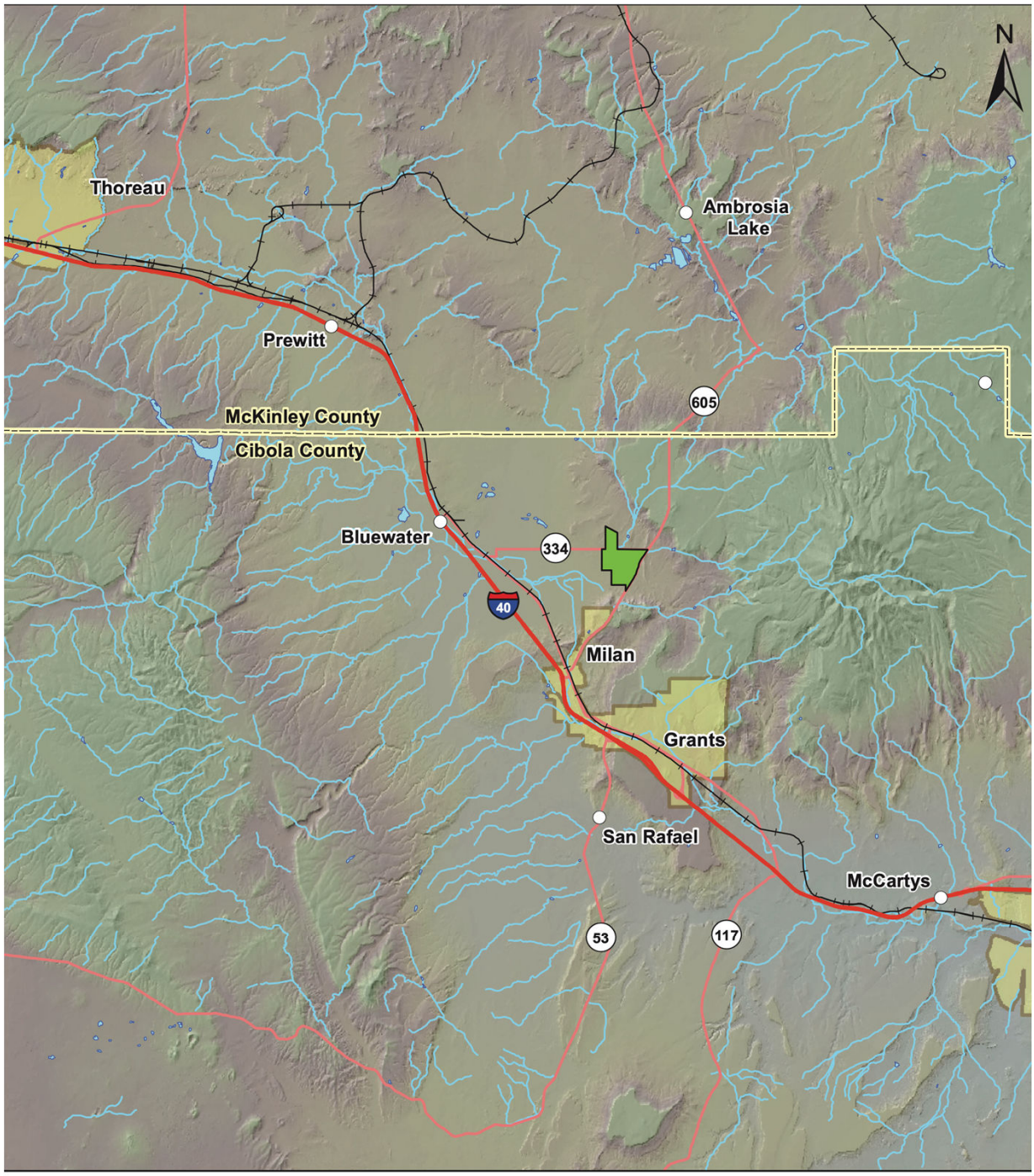
Monitoring Area/Unit	Constituents	ACLs	Methods	Reporting Limit	Frequency
Tailings	Arsenic (mg/L)	0.3	E200.8	0.005 mg/L	**Water Quality Sampling and Analysis for all Constituents:**
East 1 Sump, East 2 Sump, North 1 Sump, North 3 Sump, South 1 Sump, West 1 Sump	Cadmium (mg/L)	0.03	E200.8	0.001 mg/L	Annually (all listed wells)
Alluvial Aquifer	Molybdenum (mg/L)	116	E200.7 or E200.8	0.03 mg/L	
POC Wells:	Selenium (mg/L)	4.2	E200.8	0.005 mg/L	**Water Levels:**
C2, D1, M3, SB, SZ, X	Uranium (mg/L)	50	E200.8	0.02 mg/L	Quarterly for first year, annually, thereafter (all listed wells)
	Vanadium (mg/L)	0.3	E200.8	0.005 mg/L	
Upgradient Monitoring Wells:	Fluoride (mg/L)	9	4500-F	1 mg/L	
P, Q	Nitrate+Nitrite (mg/L)	41	E353.2	1 mg/L	
	Thorium-230 (pCi/L)	11	E908.0	0.3 pCi/L	
On-Site Monitoring Wells	Combined Radium-226+228 (pCi/L)	51	E903.0	0.2 pCi/L	
1A, 1K, 0639, 0802, B11, F, FB, GH, GN, L, L5, K9, MB, MQ, MX,	Total Dissolved Solids	NA	A2540 C	20 mg/L	
NC, S4, SUB3, T2, T19, T23, T41, T54	Chloride (mg/L)	NA	E300.0	1 mg/L	
	Sulfate (mg/L)	NA	E300.0	4 mg/L	
Off-Site Monitoring Wells					
0490, 0497, 0540, 0541, 0551, 0555, 0556, 0557, 0631, 0643, 0644, 0647, 0649, 0654,	Field Measurements[1]				
0659, 0688, 844, 0845, 0846, 0864, 0869, 0881, 0882, 0883, 0884, 0886, 0888, 0893,	Static Water Level*				
0899, 0996, H2A, MR, H55, MO, Q5, SUB2	pH				
Upper Chinle	Temperature				
0494, CE2, CE7, CE8, CE9, CE15, CW3, CW13, CW18, CW25	Conductivity				
Middle Chinle	Dissolved Oxygen				
0493, ACW, CW2, CW17, CW28, CW45, CW55, CW62, CW76, R3, Y7	ORP				
Lower Chinle					
CW29, CW32, CW41, CW42, CW43, V6					
San Andres					
Deep Well 1R, Deep Well 2R, 943M, 951R					

pCi/L - picocuries per liter, POC - point of compliance; POE - point of exposure

E - EPA

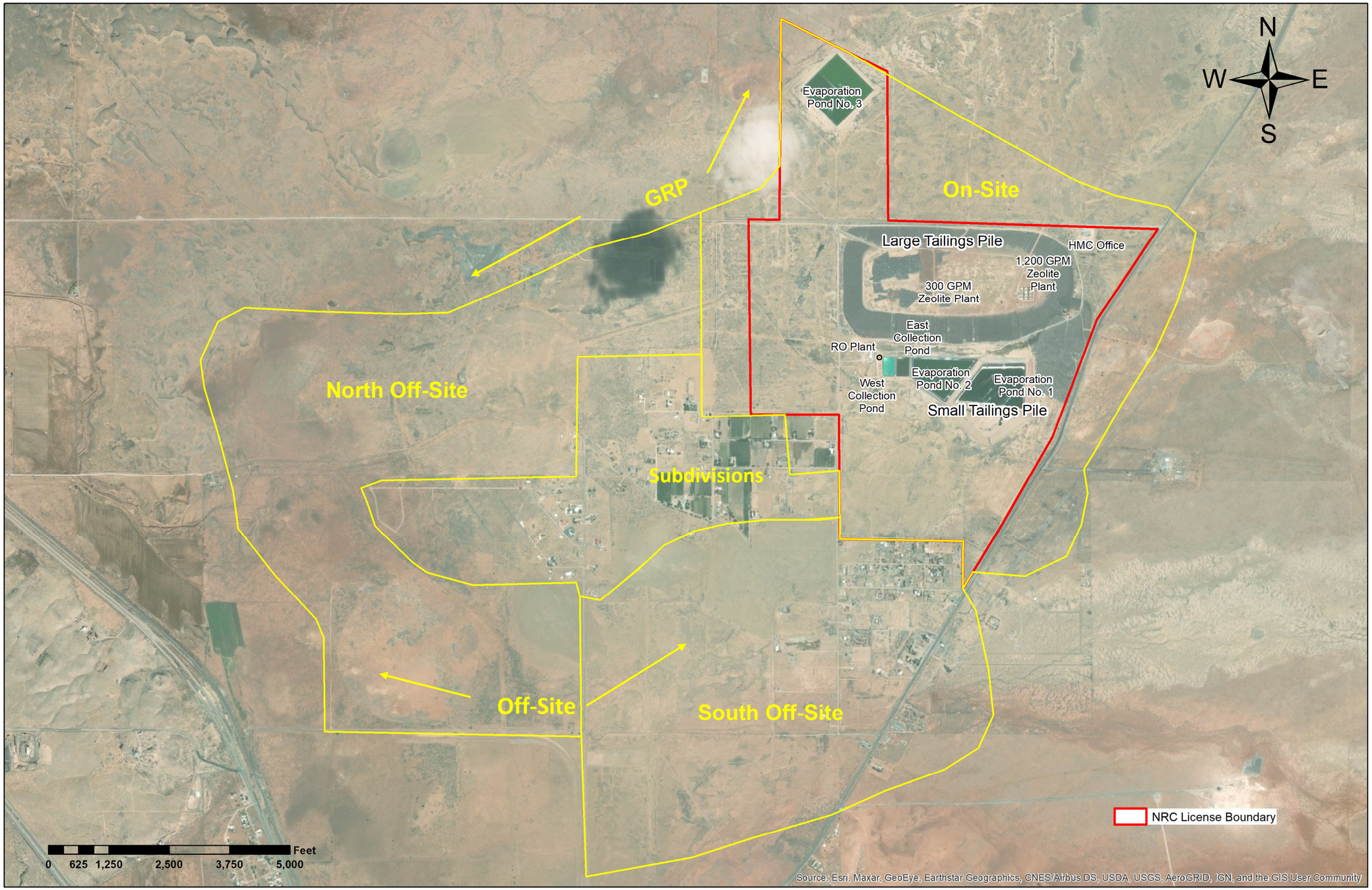
[1] Water quality indicator constituents only.

*Note: Water level measurements will be taken at each well prior to well purging and sampling.



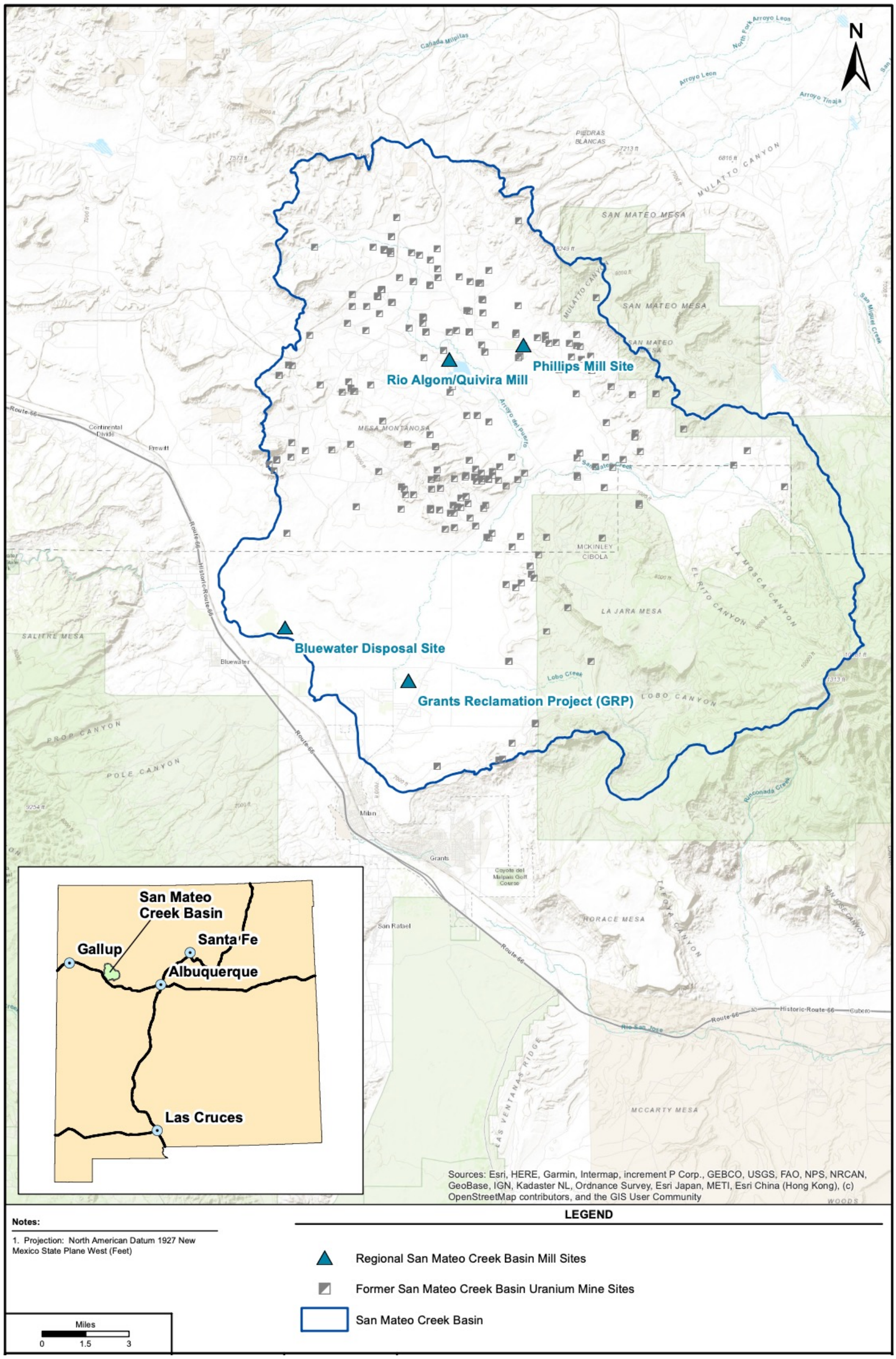
Grants Reclamation Project
Corrective Action Program

Figure 1.1-1
Location Map



Grants Reclamation Project
Corrective Action Program

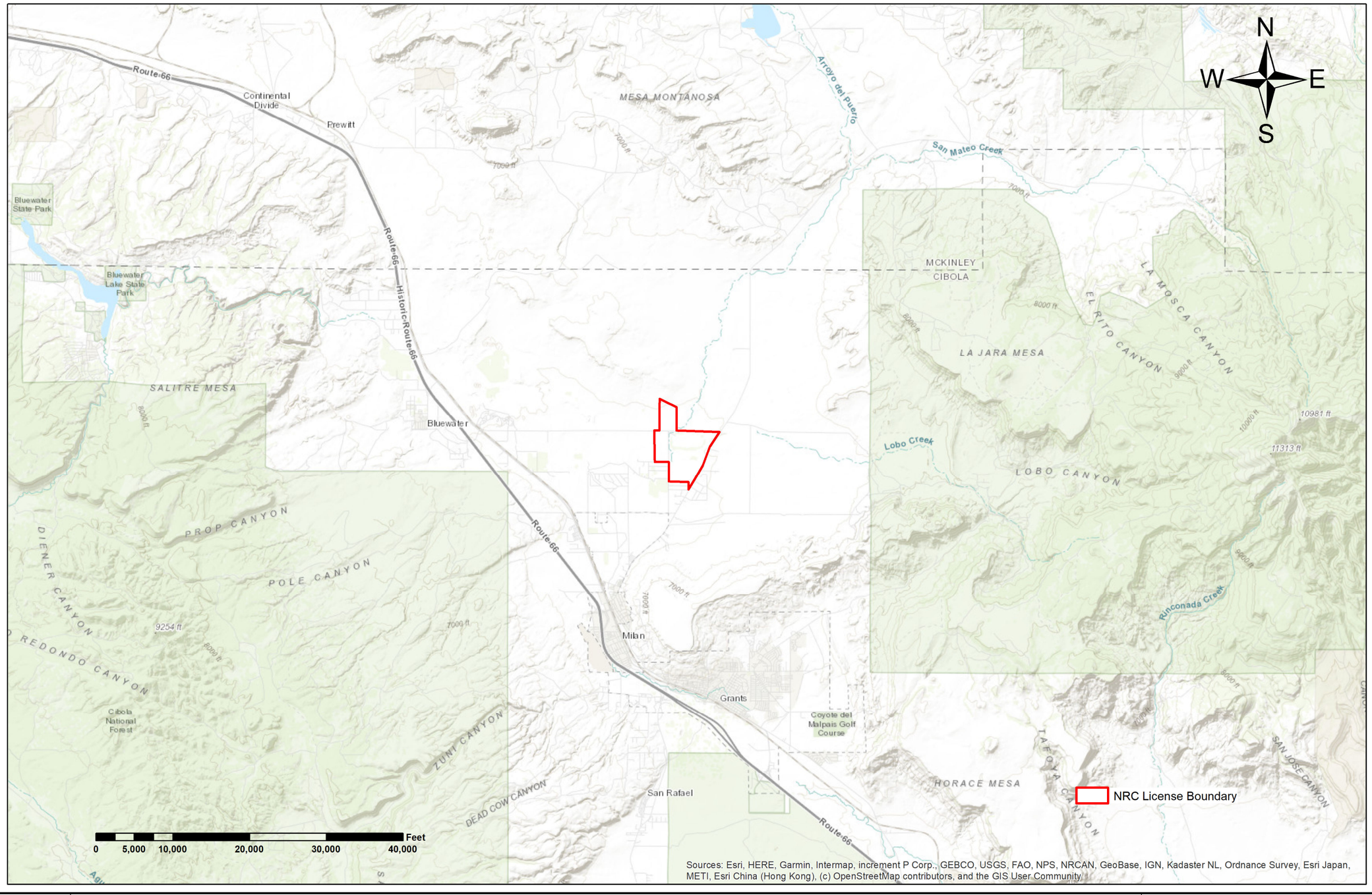
Figure 1.2-1
Current Facilities at the GRP



Grants Reclamation Project

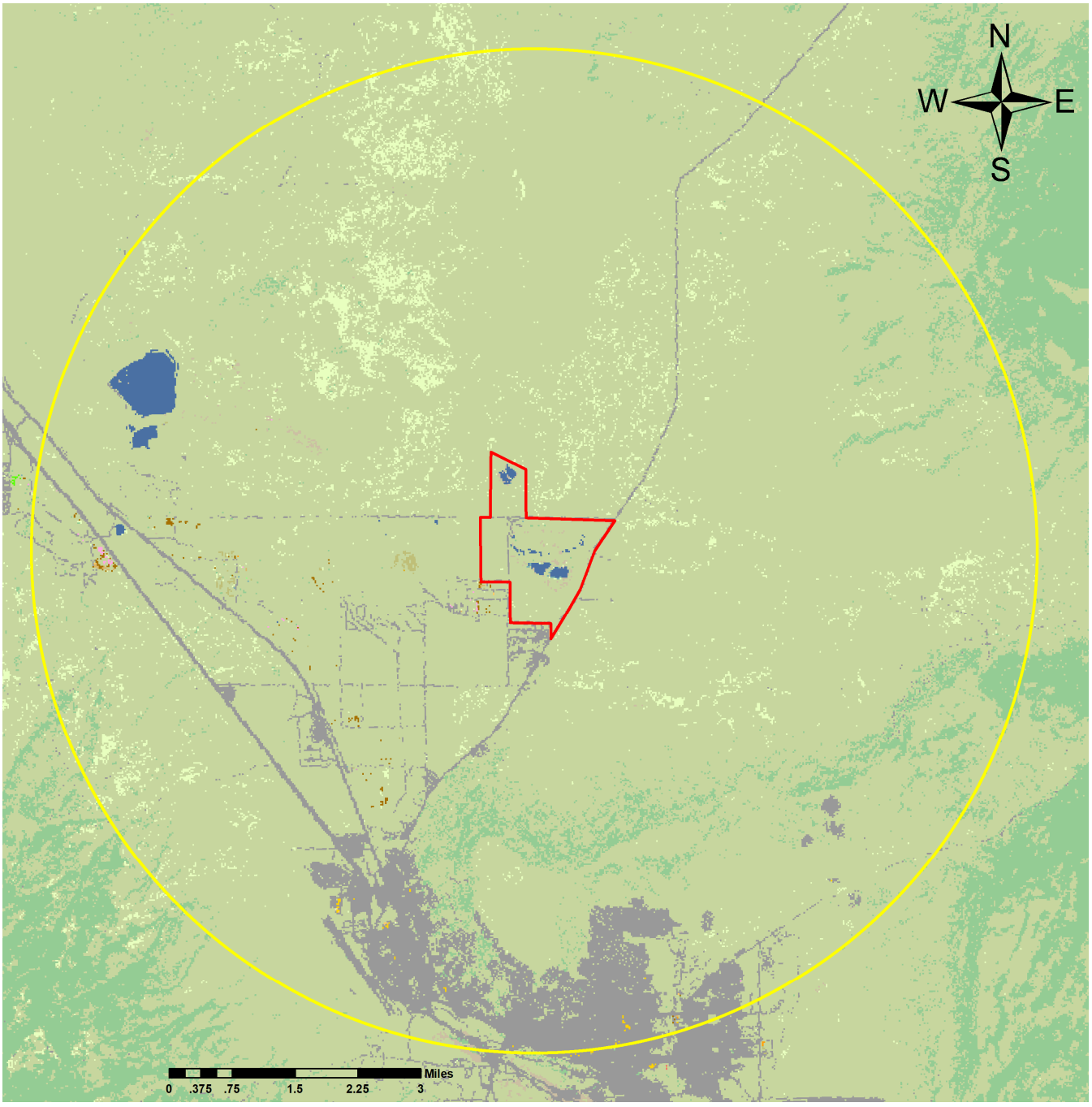
Source: Weston, 2016

Figure 1.2-2
Grants Mineral Belt



Grants Reclamation Project
Corrective Action Program

Figure 1.2-3
Topography



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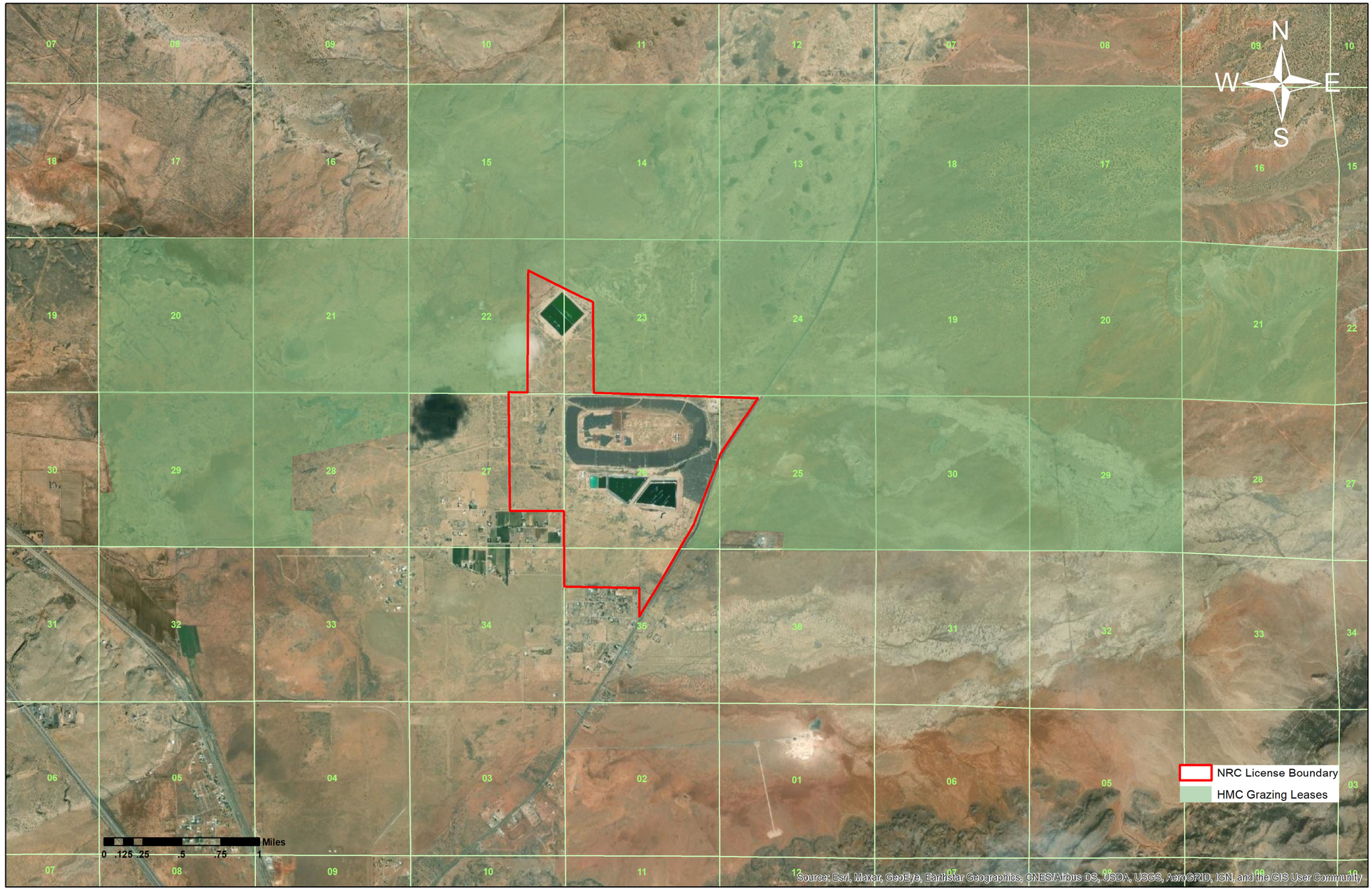
Grants Reclamation Project
Corrective Action Program

Figure 1.2-4
Land Use within Five Miles of the GRP



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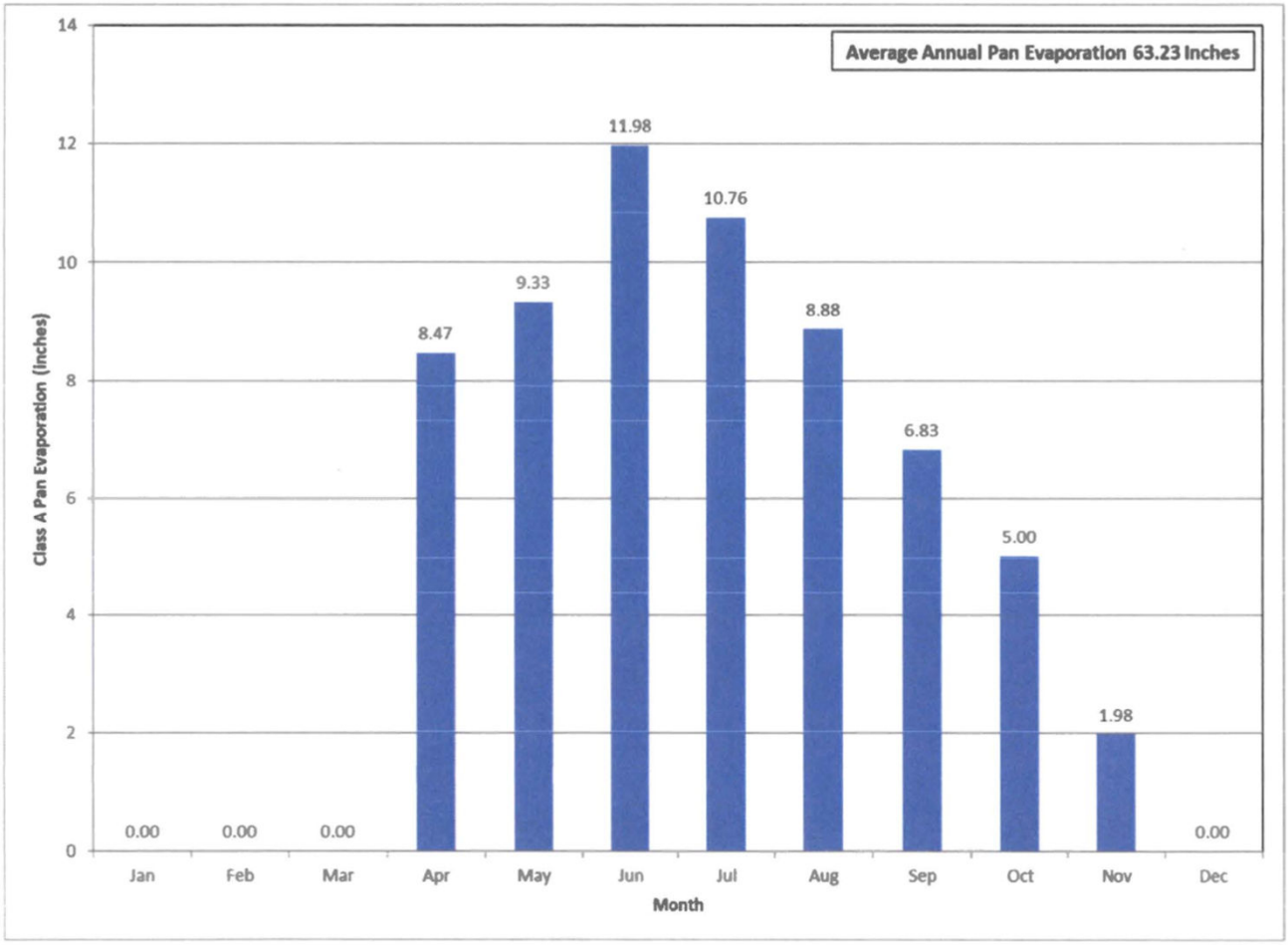
Corrective Action Program

Figure 1.2-5
GRP Grazing Leases

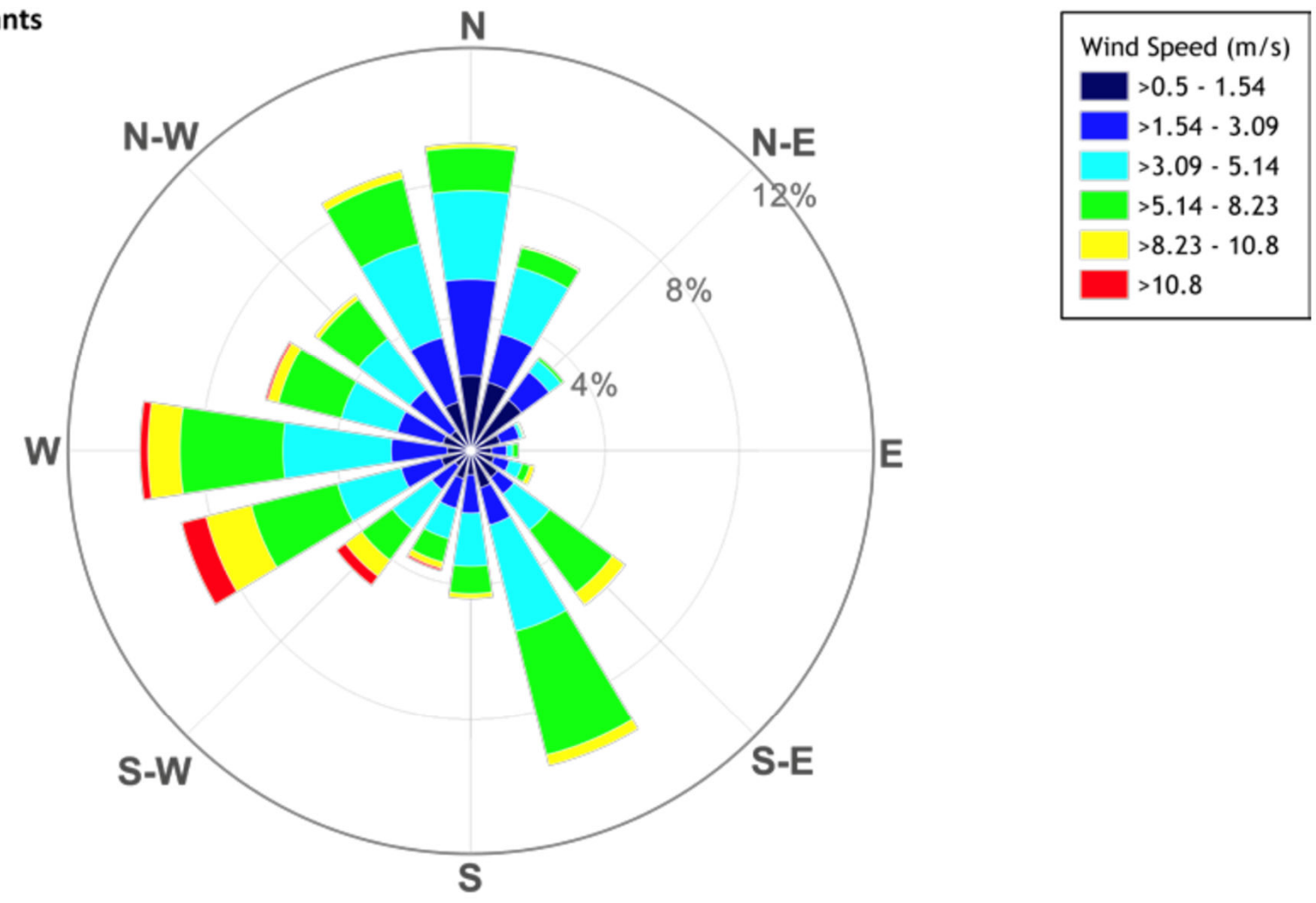


Source: WRCC, 2019

Grants Reclamation Project
Corrective Action Program

Figure 1.2-6
Class A Pan Evaporation at Laguna, New Mexico 1914-2005

Homestake Grants
Daytime 2025

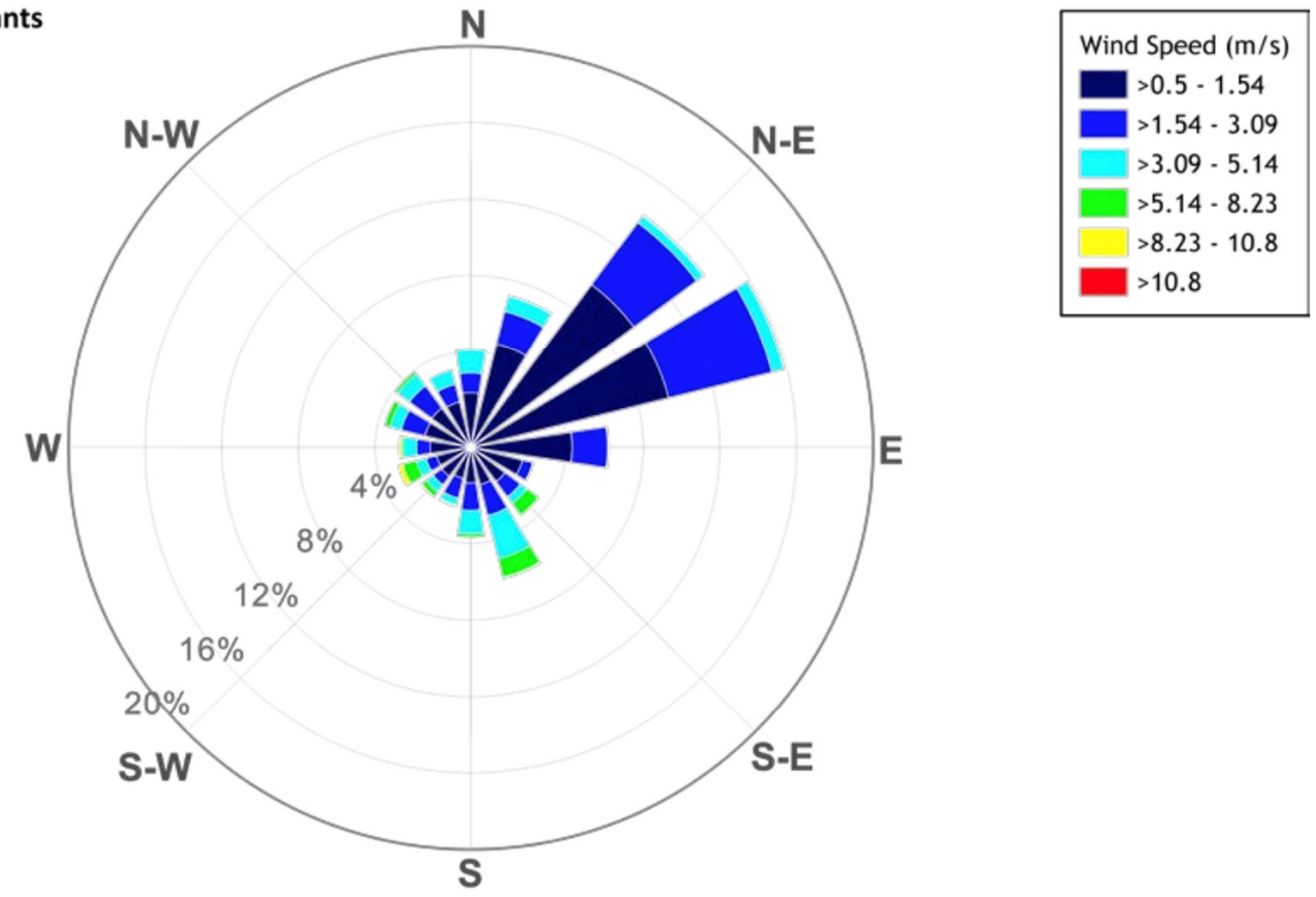


Daytime: 8am-8pm

Grants Reclamation Project
Corrective Action Program

Figure 1.2-7
Daytime Wind Rose

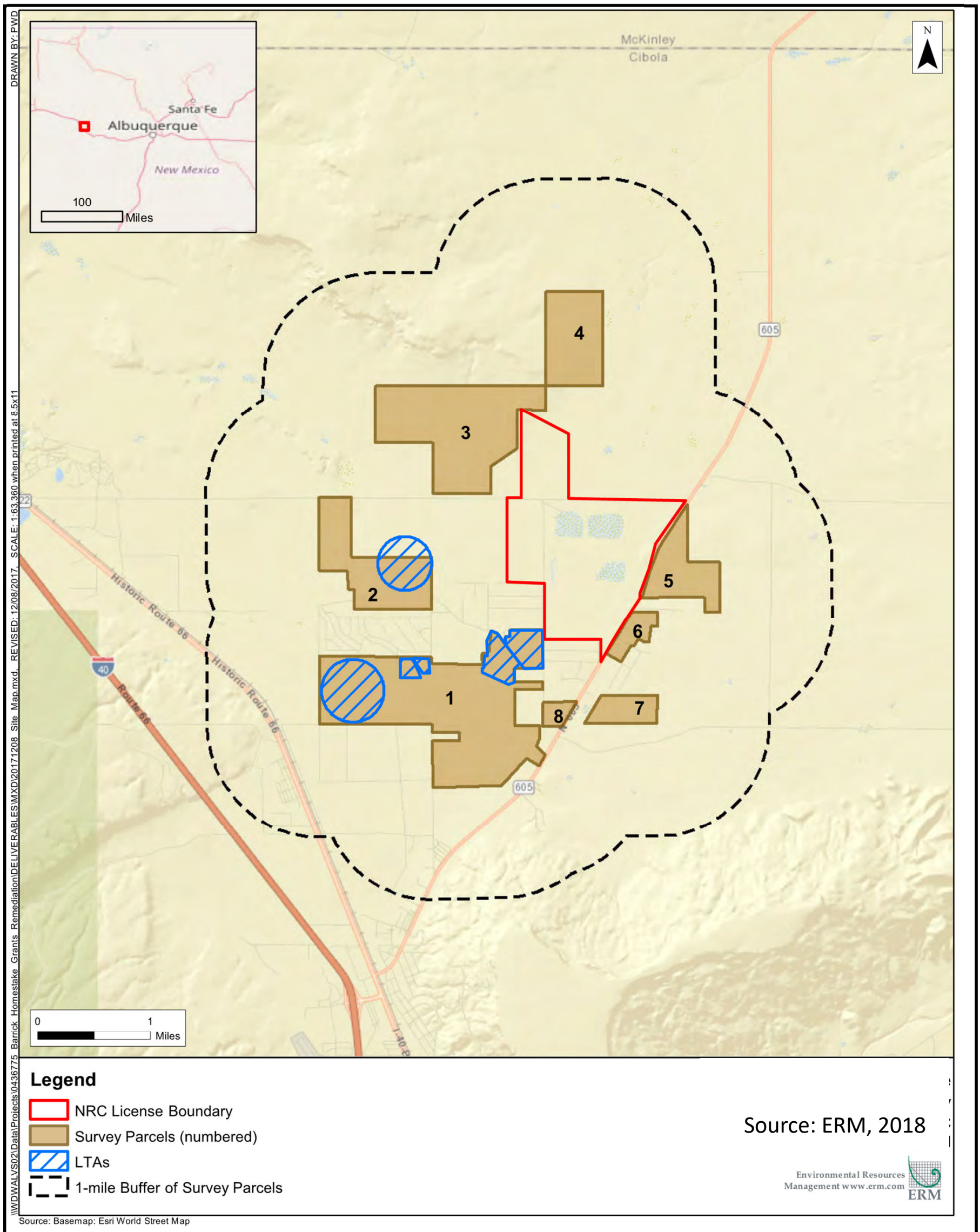
Homestake Grants
Nighttime 2025



Nighttime: 8pm-8am

Grants Reclamation Project
Corrective Action Program

Figure 1.2-8
Nighttime Wind Rose



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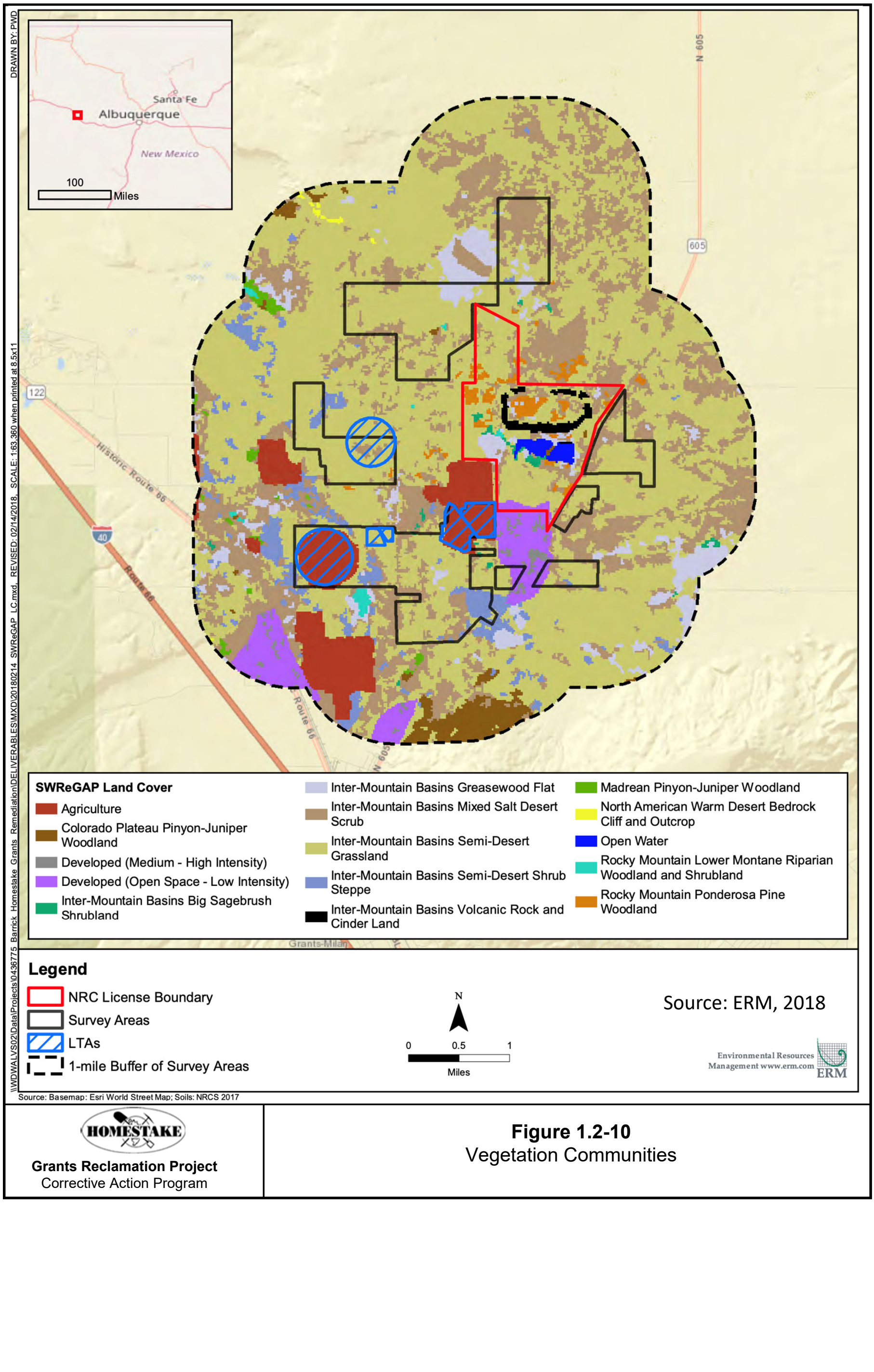
Corrective Action Program

Figure 1.2-9
Study Area for Environmental Survey



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Corrective Action Program

Figure 1.2-10
Vegetation Communities

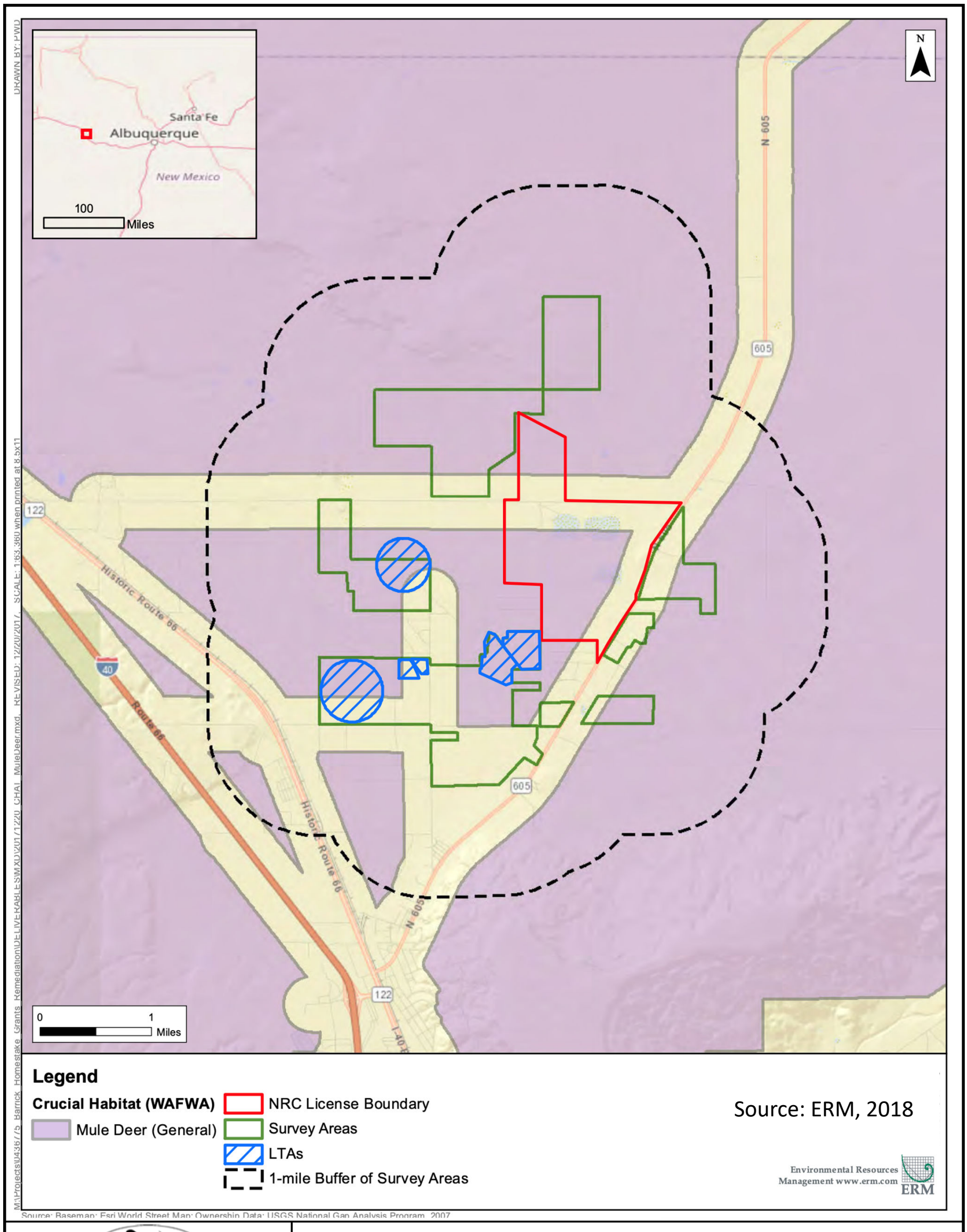

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Figure 1.2-11
Crucial Mule Deer Habitat

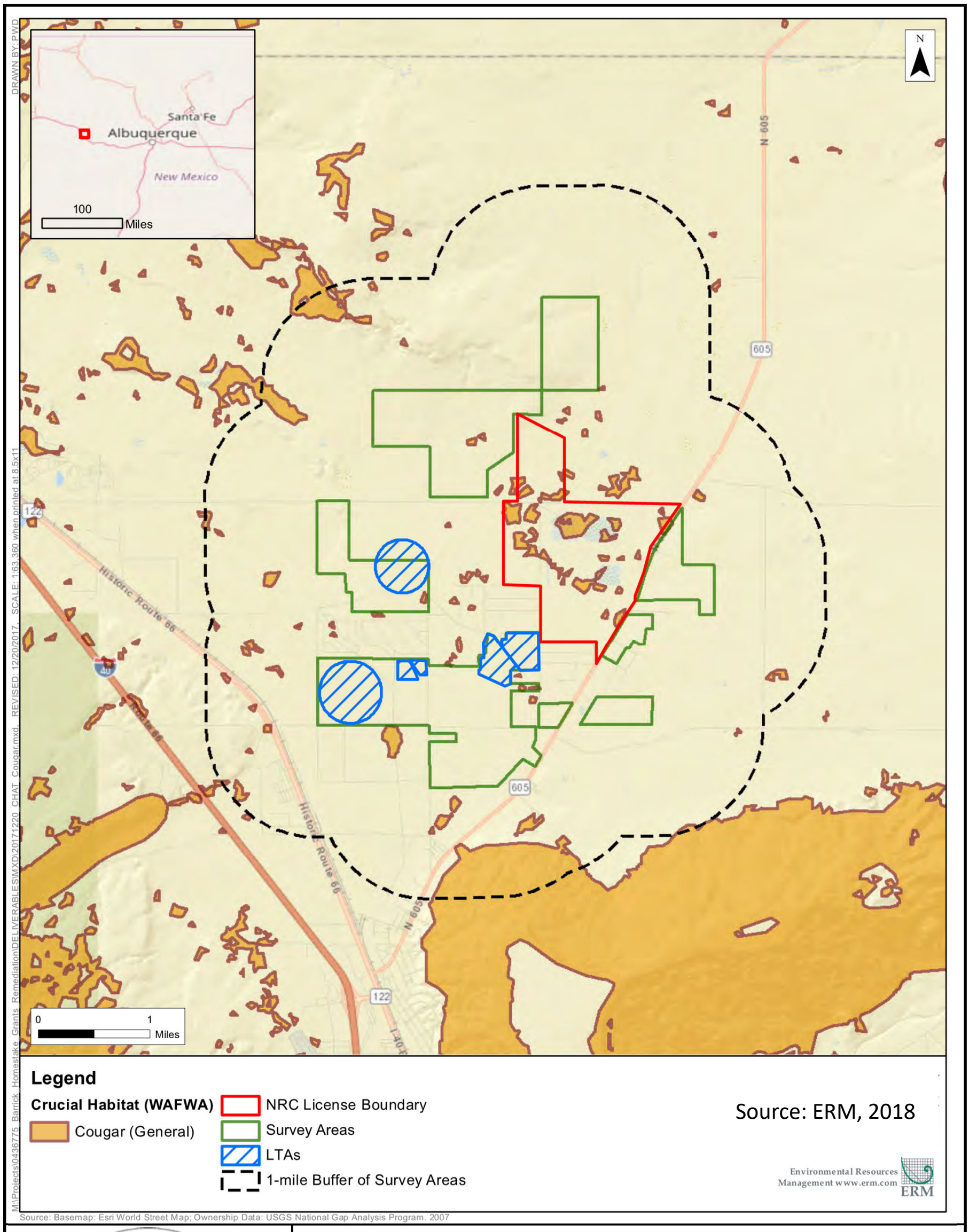

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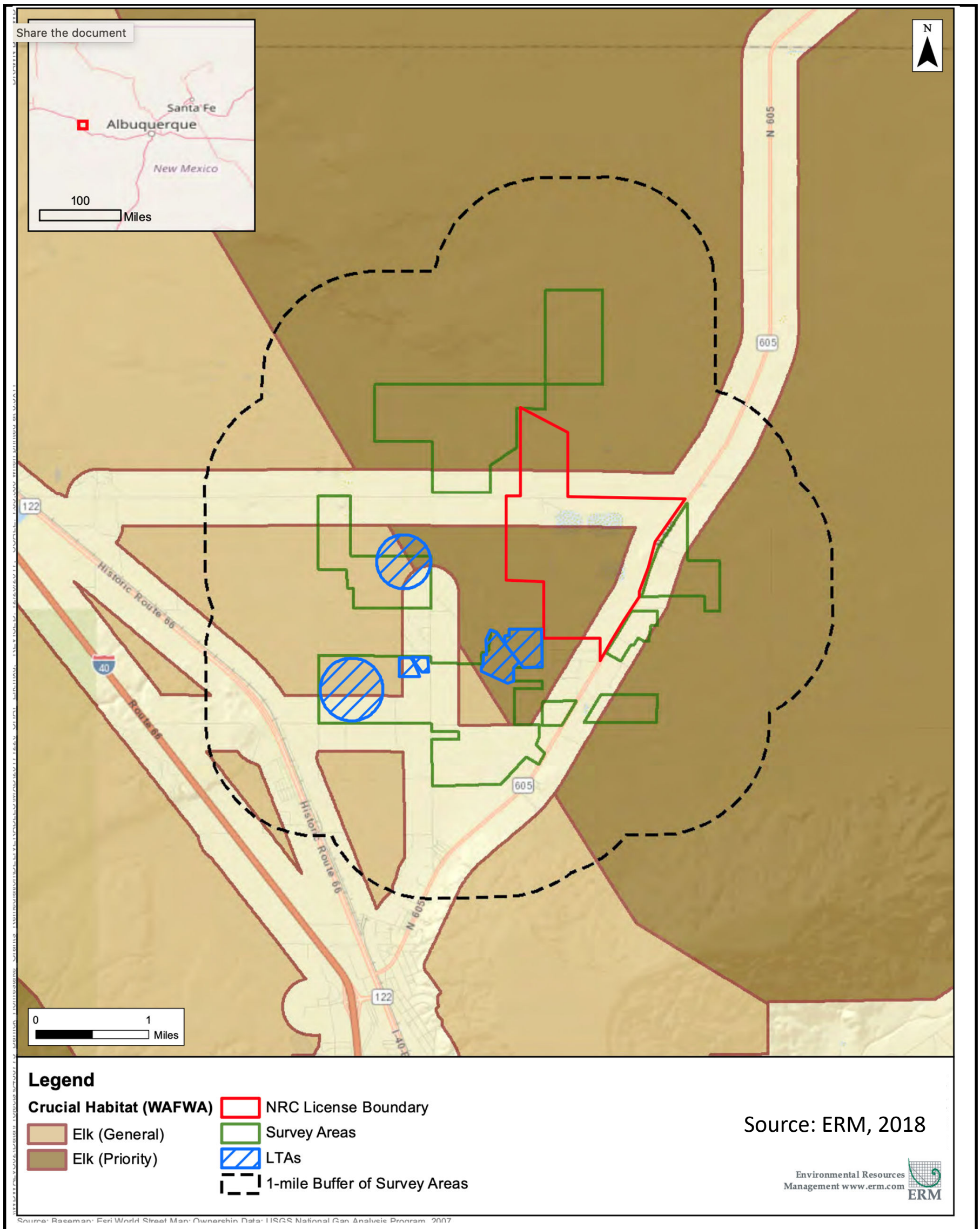
Figure 1.2-12
Crucial Cougar Habitat



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Corrective Action Program

Figure 1.2-13
Crucial Elk Habitat

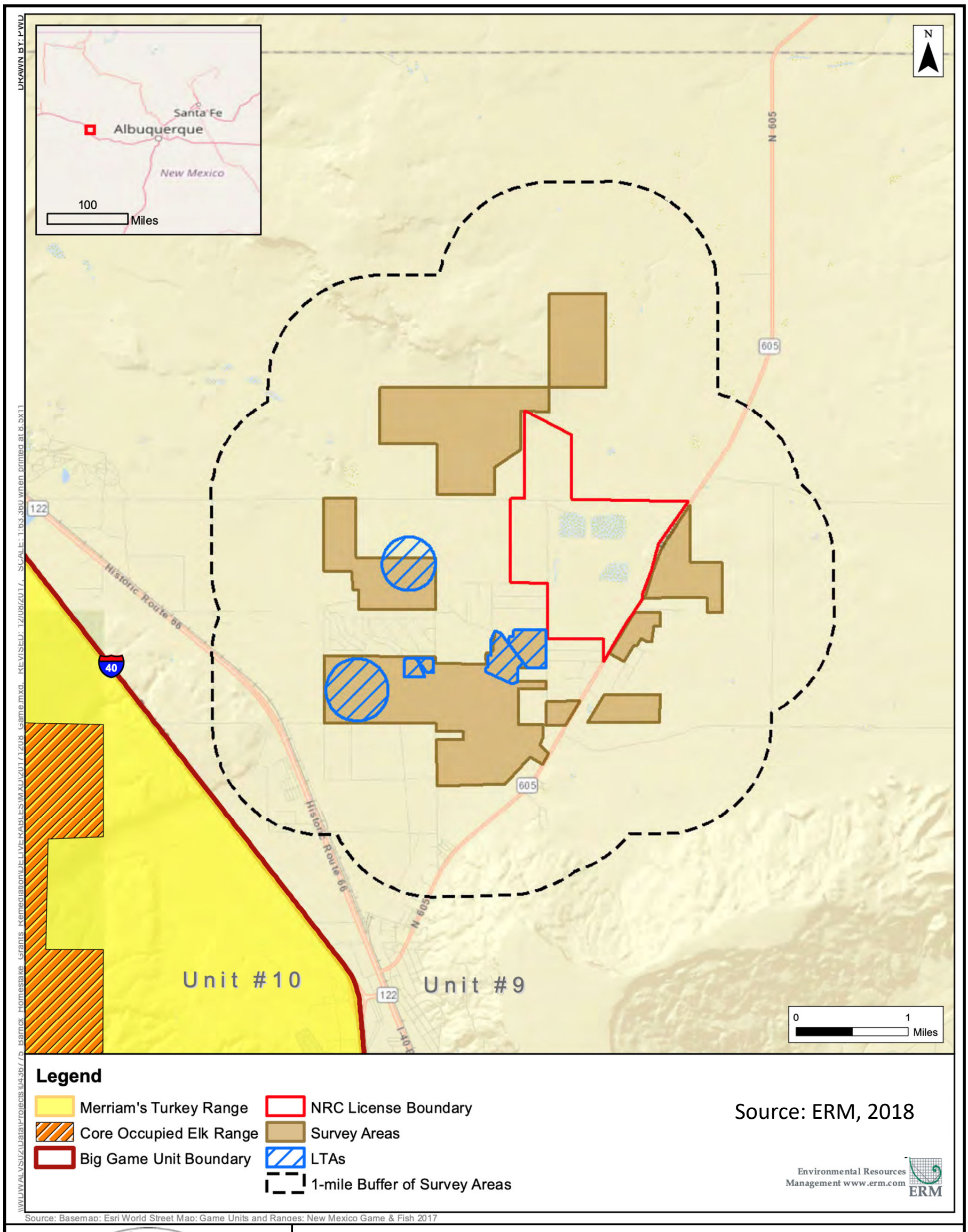

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Figure 1.2-14
Meriam's Turkey Range and Game Units

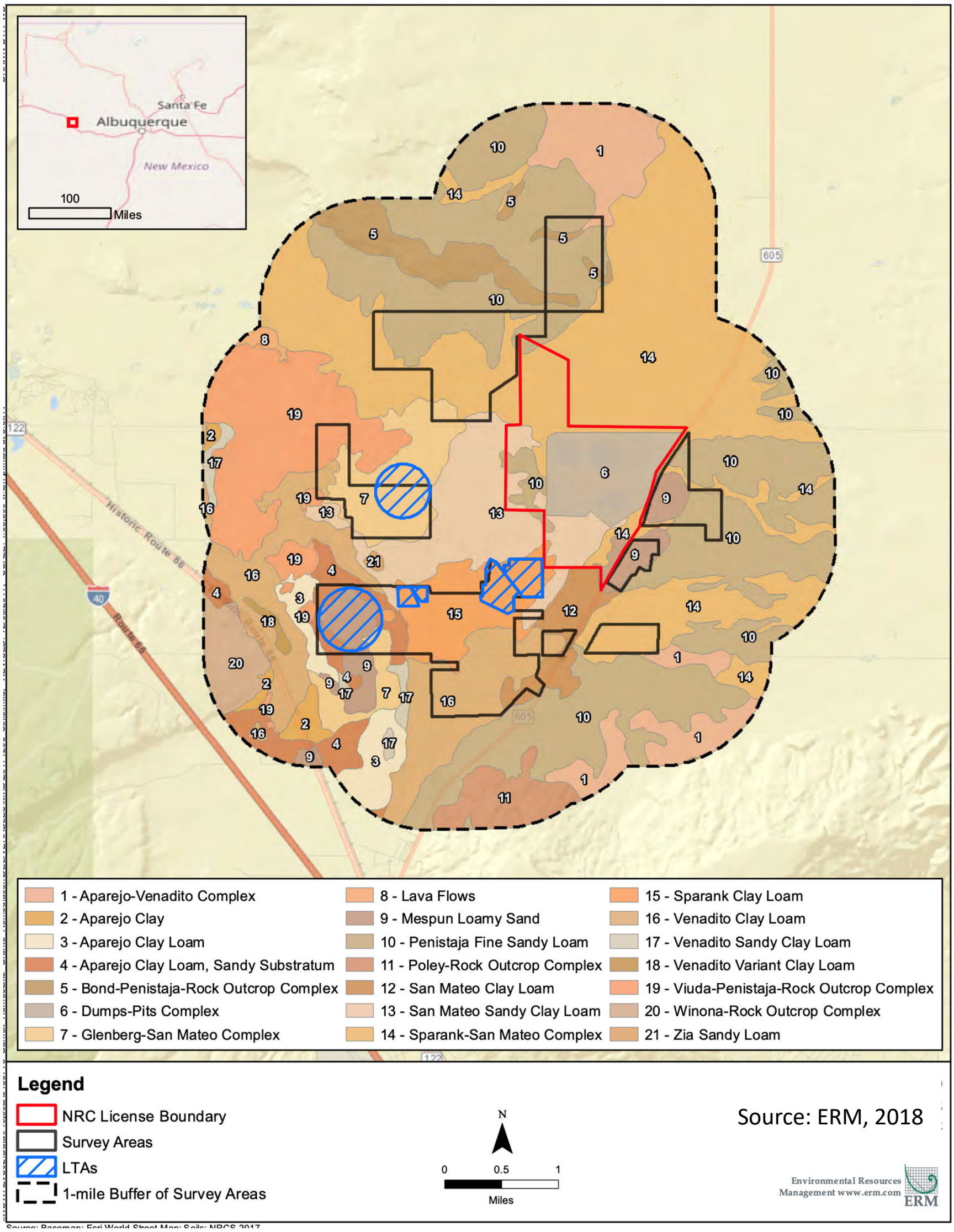

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Figure 1.2-15
NRCS Soil Map

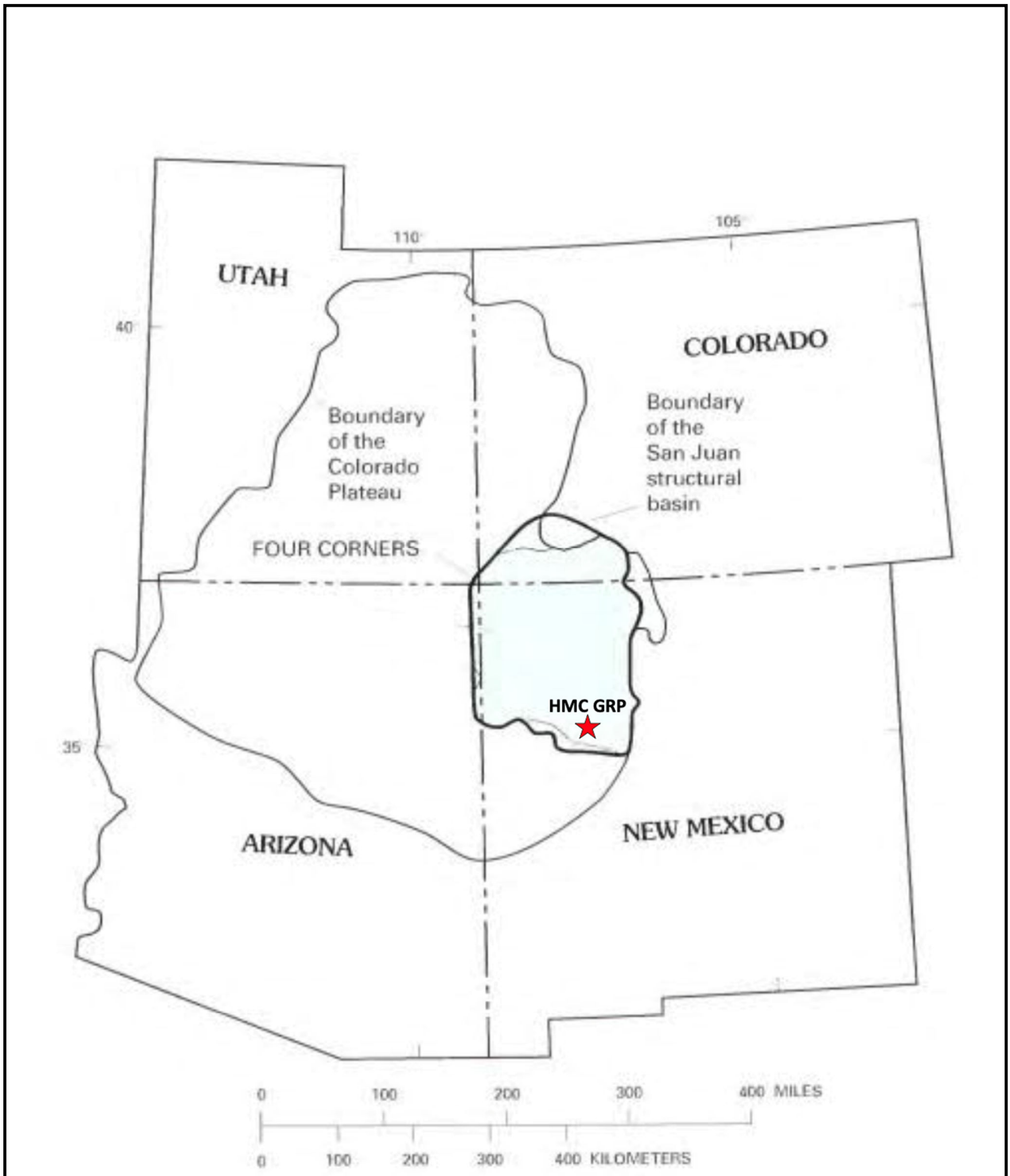

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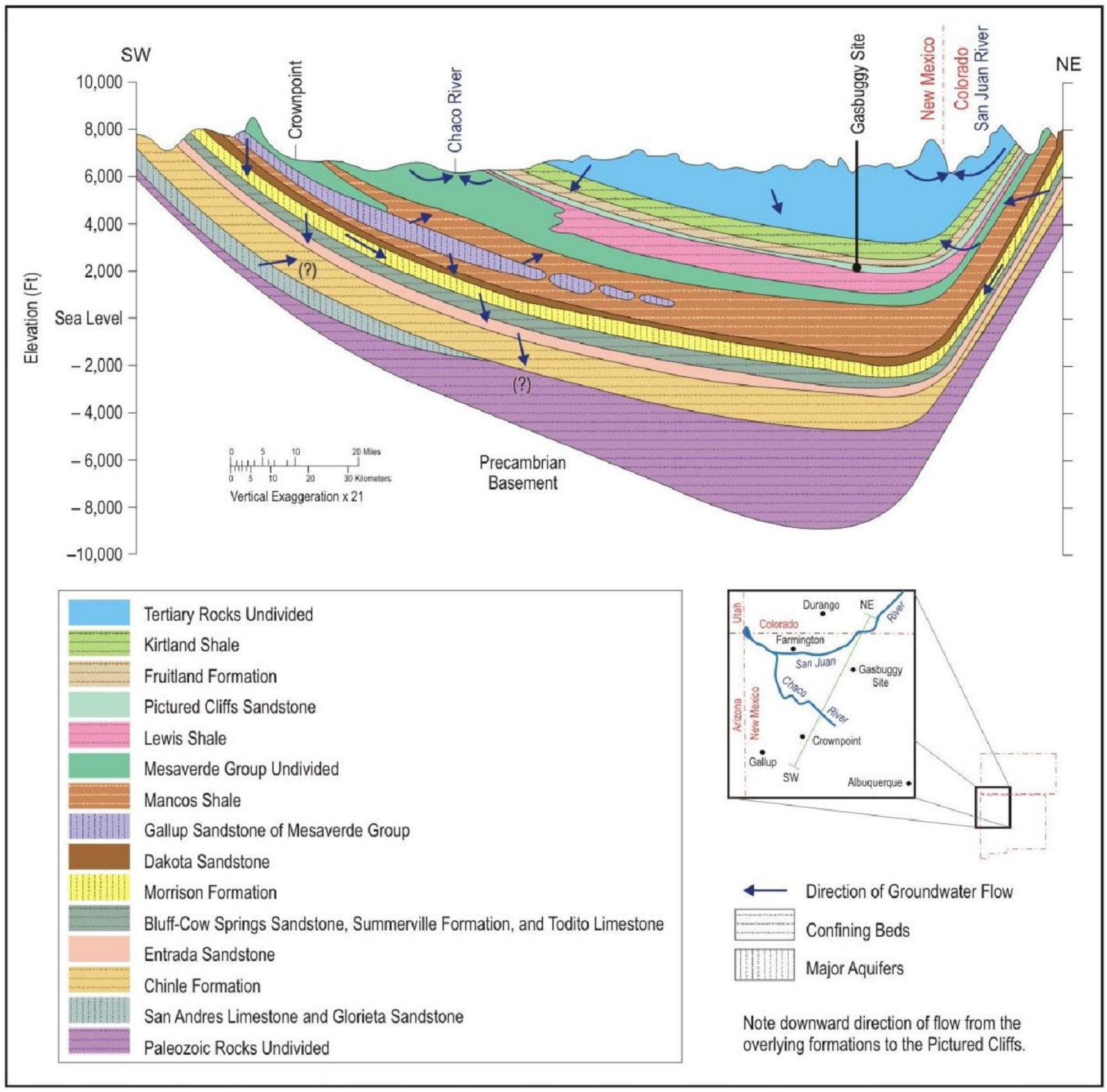
Figure 1.2-16
Colorado Plateau Physiographic Province

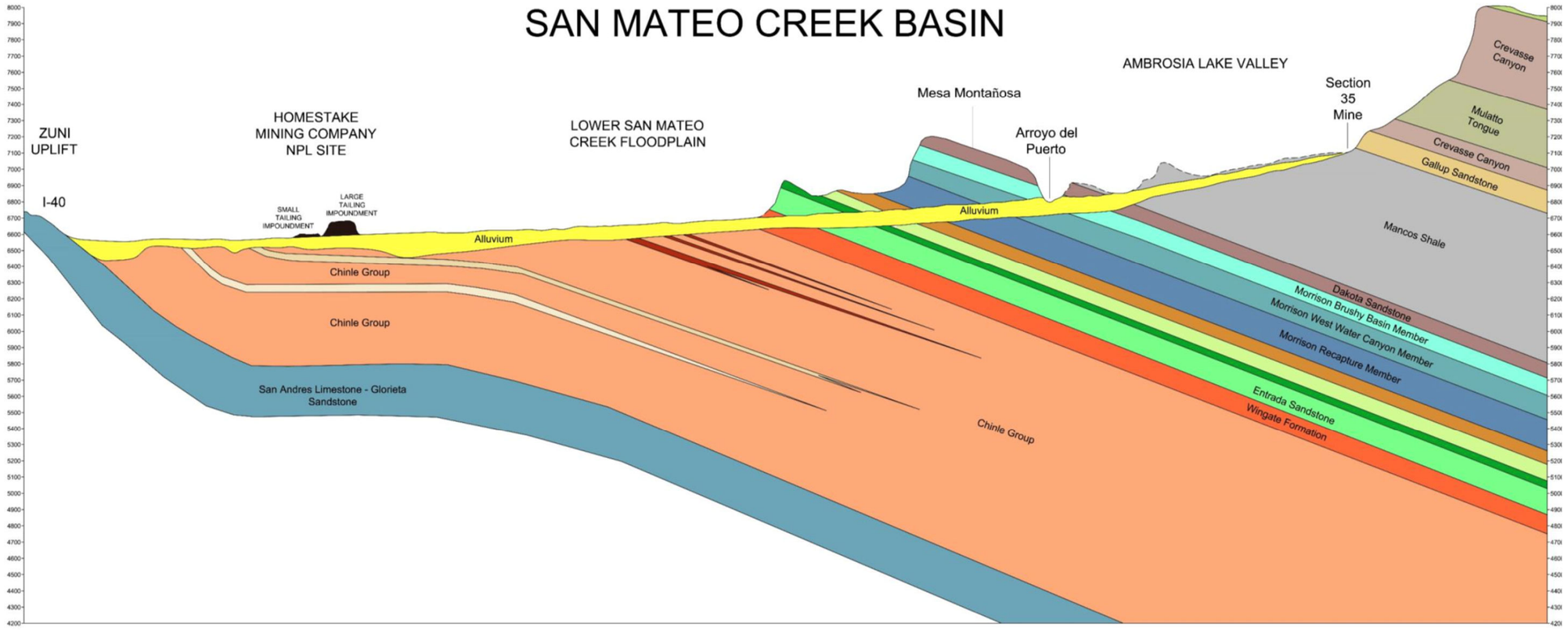


Source: DOE, 2011

Grants Reclamation Project
Corrective Action Program

Figure 1.2-17
Regional Geologic Cross Section Through the San Juan Basin

GENERALIZED GEOLOGIC CROSS-SECTION
SAN MATEO CREEK BASIN



Legend

- Alluvium/Eolian
- Point Lookout Sandstone
- Crevasse Canyon
- Mulatto Tongue
- Gallup Sandstone
- Mancos Shale
- Dakota Sandstone Formation
- Morrison Formation - Brushy Basin Member
- Morrison Formation - Westwater Canyon Member
- Morrison Formation - Recapture Member
- Bluff Sandstone
- Summerville Formation
- Todilto Limestone
- Entrada Sandstone
- Wingate Formation
- Chinle Group
- Other Chinle Sandstone
- Upper Chinle Sandstone
- Middle Chinle Sandstone
- San Andres Limestone - Glorieta Sandstone

NOTES:
1. VERTICAL EXAGGERATION = 10X
2. ELEVATIONS ARE IN FEET ABOVE MEAN SEA LEVEL.
3. SURFACE GEOLOGY IS BASED ON U.S. GEOLOGICAL SURVEY AND NEW MEXICO BUREAU OF GEOLOGY AND MINERAL RESOURCES 1967 AND 2011 GEOLOGIC MAPS OF THE DOS LOMAS QUADRANGLE, CIBOLA AND MCKINLEY COUNTIES, NEW MEXICO.
4. THIS CROSS SECTION REPRESENTS AN INTERPRETATION OF GEOLOGIC DATA AND IS SUBJECT TO CHANGE AS NEW DATA BECOME AVAILABLE.
5. THIS CROSS SECTION IS FOR ILLUSTRATION PURPOSES ONLY. IT IS DESIGNED TO AID IN THE UNDERSTANDING OF THE GENERAL GEOLOGIC FRAMEWORK OF THE STUDY AREA.
6. THE BEDROCK FORMATIONS SHOWN CROPPING OUT ABOVE THE ALLUVIUM ARE PROJECTED ONTO THE CROSS SECTION FROM THE WEST TO SHOW MESA MONTAÑOSA AND AMBROSIA LAKE VALLEY TERRAIN.

0 150 300 600
VERTICAL SCALE IN FEET
VERTICAL EXAGGERATION: 10X

0 1500 3000 6000
HORIZONTAL SCALE IN FEET

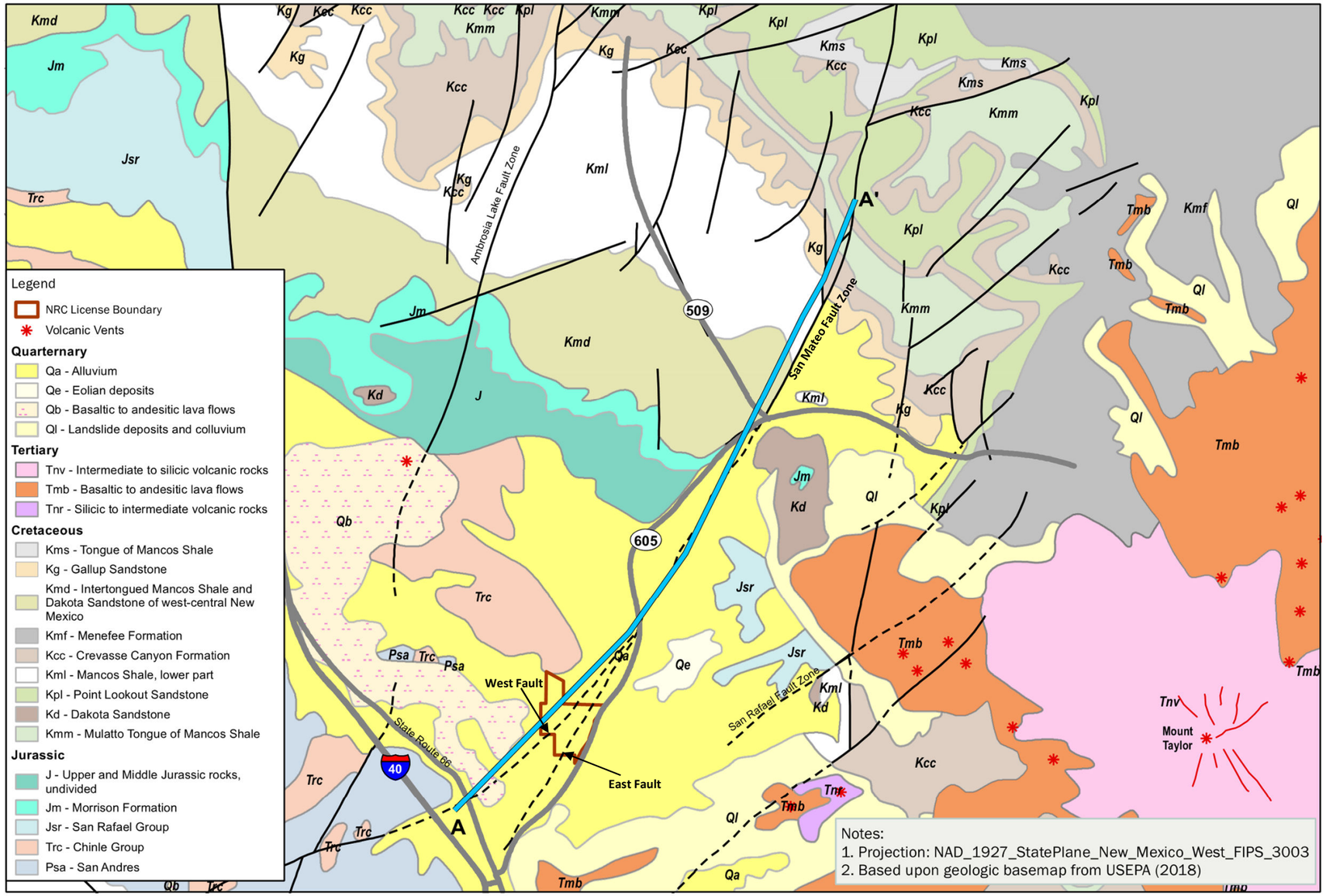
SEMS ID: NMN000606847
TDD NO: 0001/17-039

Cross Section Location shown on Figure 1.2-19

Source: Weston, 2018

Note: One of the Chinle water-bearing units beneath the GRP is missing in this figure.

Figure 1.2-18
Generalized Cross Section
Through the San Mateo Basin

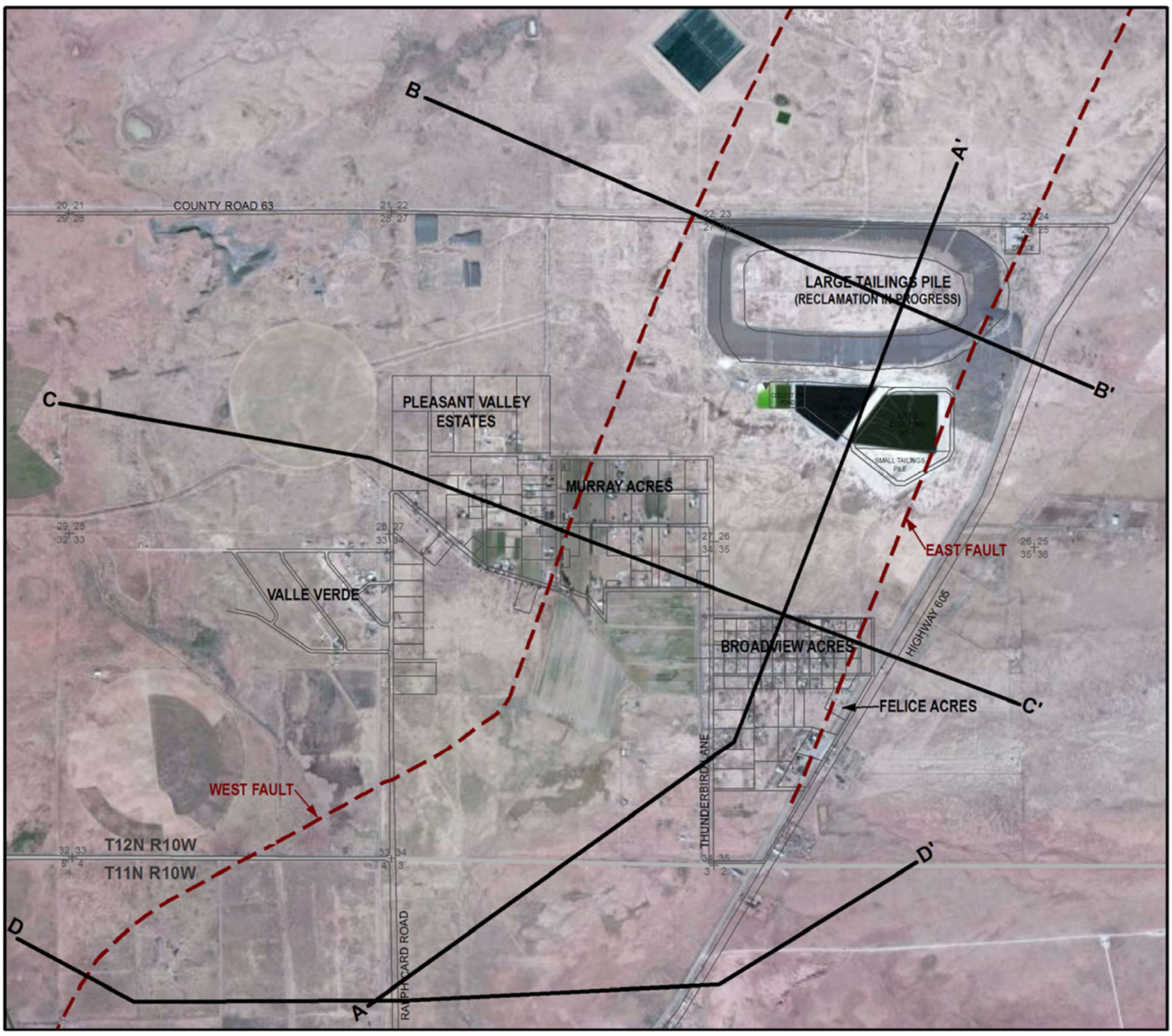


Cross Section Along Blue Line Shown in Figure 1.2-18

Grants Reclamation Project
Corrective Action Program

Source: Weston, 2018

Figure 1.2-19
Surface Geology of the
San Mateo Creek Basin



LEGEND:

Hydrogeologic Cross Section Line

Fault

N

0 1,250 2,500 Feet

Aerial: Bing Maps - © 2010 Microsoft Corporation and its data suppliers

Source: Grants Reclamation Project Updated Corrective Action Program, HMC, 2012

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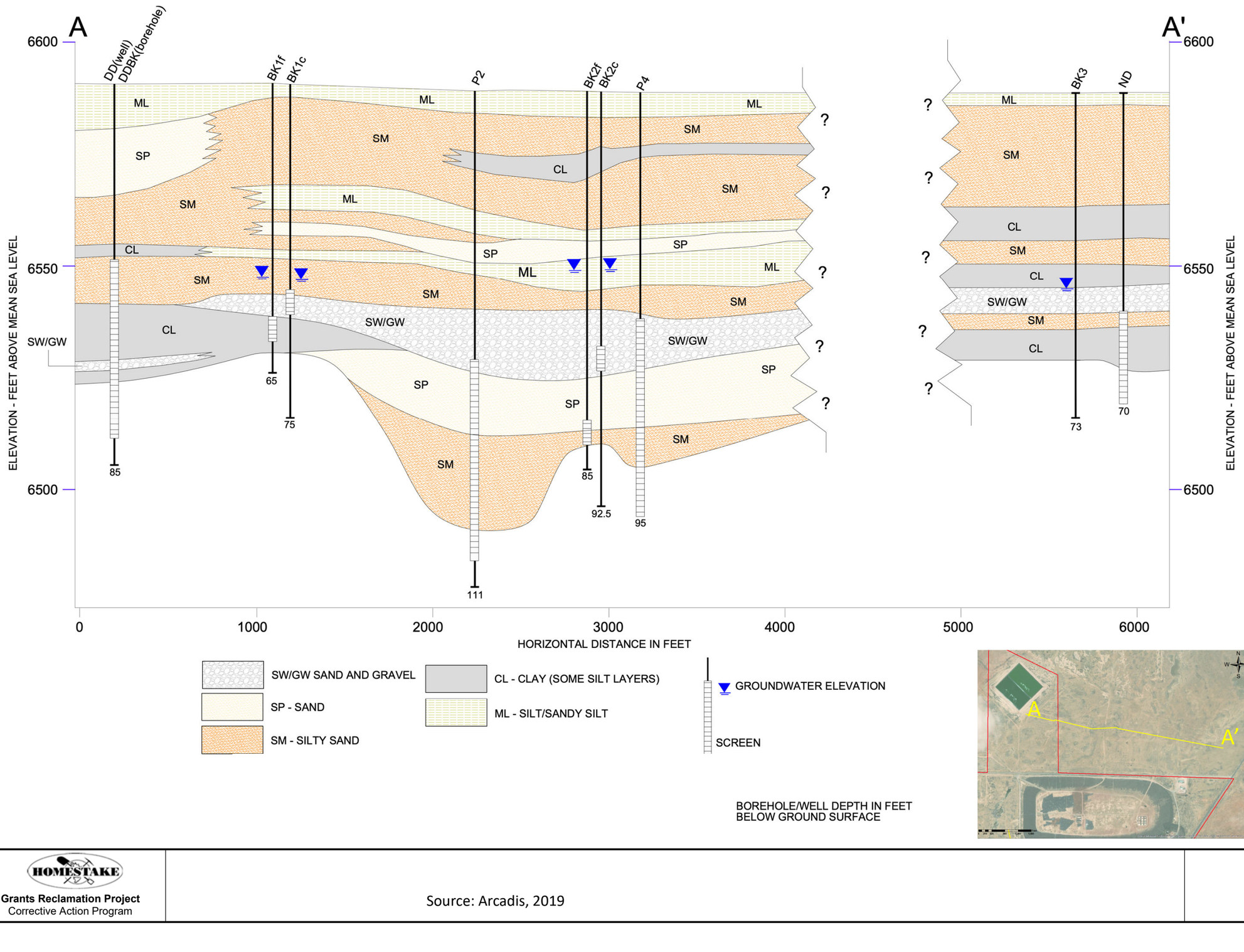
Grants Reclamation Project
Corrective Action Program

Figure 1.2-20
Faults Mapped at GRP



Grants Reclamation Project
Corrective Action Program

Source: Arcadis, 2019

Figure 1.2-21
Cross Section North of
Large Tailings Pile

NORTH
A

SOUTH
A'

IW-1D IW-1S IW-2D IW-2S IW-3D IW-3S IW-4D IW-4S IW-5D IW-5S IW-6D IW-6S IW-7D IW-7S IW-8D IW-8S IW-9D IW-9S IW-10D IW-10S IW-11D IW-11S IW-12D IW-12S IW-13D IW-13S IW-14D IW-14S IW-15D IW-15S IW-16D IW-16S IW-17D IW-17S

DEPTH (FEET BGS.)

0 -10 -20 -30 -40 -50 -60 -70 -80 -90 -100 -110 -120

0.0979 04/15/15
0.198 04/14/15
0.583 04/15/15
1.77 04/15/15
0.210 04/13/15
144 04/13/15
1.07 04/13/15
0.279 04/12/15
2.01 04/12/15
1.59 04/12/15
1.67 04/10/15
1.62 04/10/15
0.904 04/11/15
0.680 04/11/15
0.444 04/11/15

LEGEND:

- FINES (SILTS AND CLAYS) WITH NO TO SOME (10-50%) SAND GRAVEL
- SAND WITH SOME (21-50%) FINES
- FINE TO MEDIUM SAND WITH NO TO LITTLE (0-20%) FINES
- MEDIUM TO COARSE SAND WITH NO LITTLE (0-20%) FINES
- SAND WITH LITTLE TO SOME (10-50%) GRAVEL
- GRAVEL
- BEDROCK

1.07 04/13/15 — WELL SCREEN, CONCENTRATION OF URANIUM (mg/L) AND DATE SAMPLED

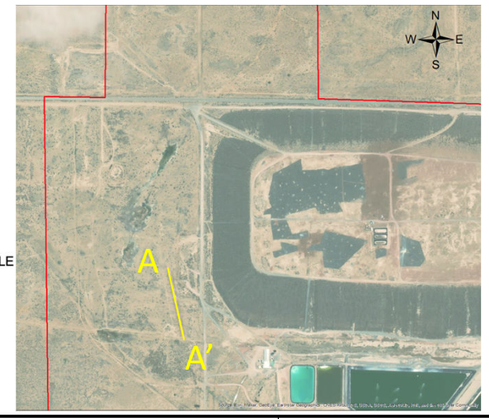
DEPTH TO WATER TABLE (FEET BGS.)

NOTES:

BGS = BELOW GROUND SURFACE
mg/L = MILLIGRAMS PER LITER

0 60' 120' GRAPHIC SCALE — HORIZONTAL SCALE

0 20' 40' GRAPHIC SCALE — VERTICAL SCALE



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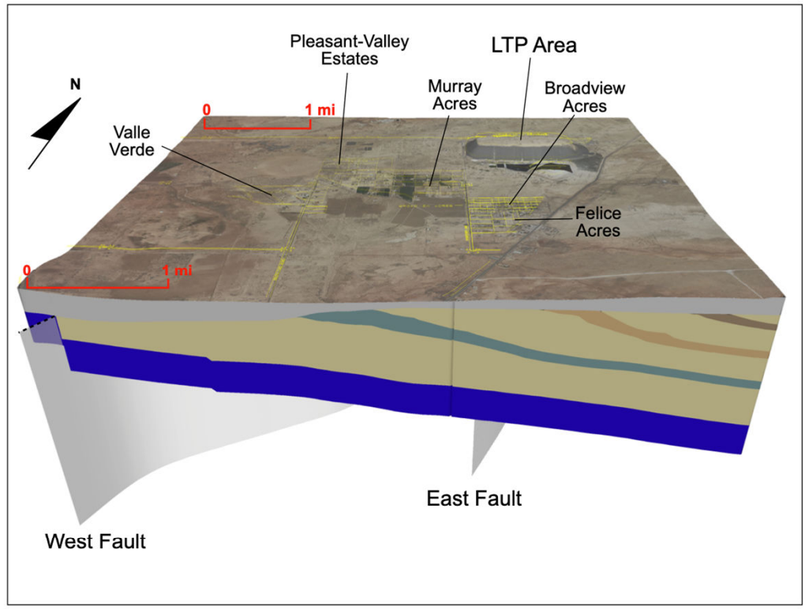
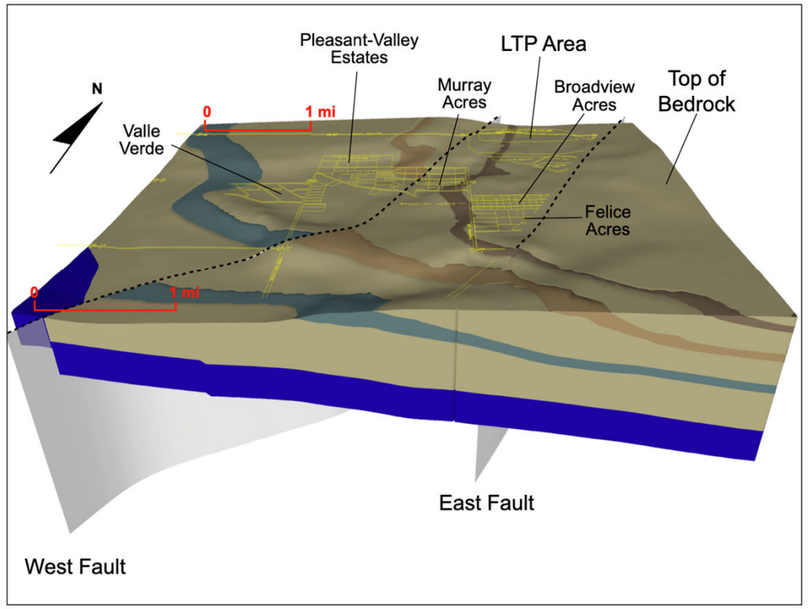
Grants Reclamation Project
Corrective Action Program

Source: Arcadis, 2016

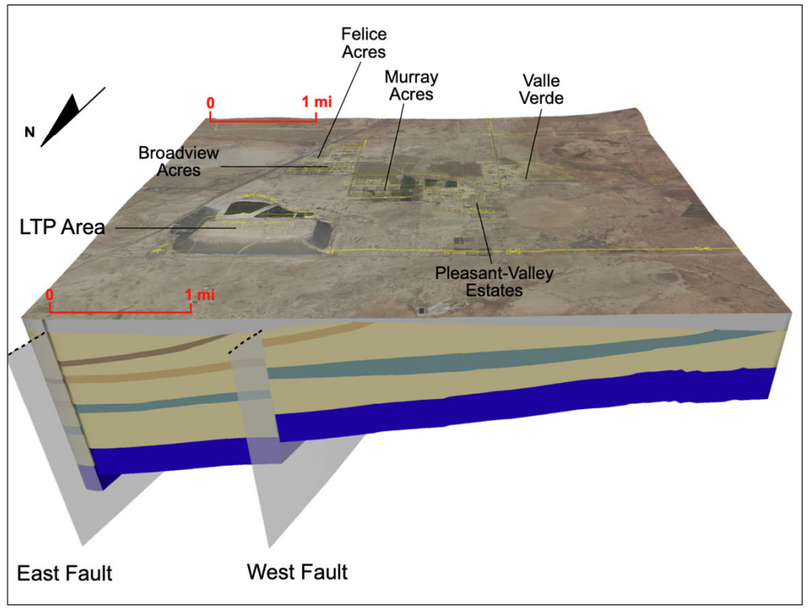
Figure 1.2-22
Cross Section West of
Large Tailings Pile



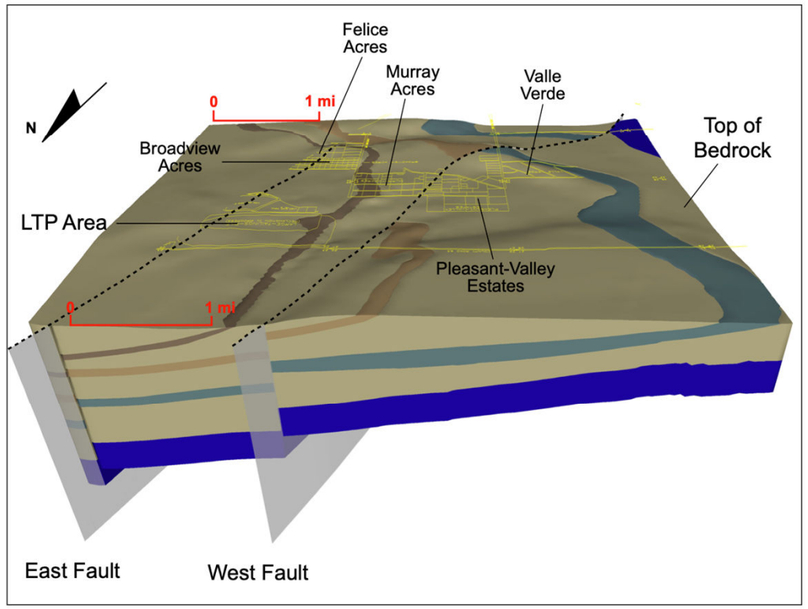
1. ALLUVIUM AND BEDROCK BLOCK MODEL – FACING NORTH



2. BEDROCK BLOCK MODEL DEPICTING CHINLE AND SAN ANDRES-GLORIETTA AQUIFER SUBCROP LOCATIONS – FACING NORTH



3. ALLUVIUM AND BEDROCK BLOCK MODEL – FACING SOUTH



4. BEDROCK BLOCK MODEL DEPICTING CHINLE AND SAN ANDRES-GLORIETTA AQUIFER SUBCROP LOCATIONS – FACING SOUTH

LEGENDS:

BEDROCK HYDROSTRATIGRAPHY

- ALLUVIUM
- CHINLE SHALE
- UPPER CHINLE AQUIFER
- CHINLE SHALE
- MIDDLE CHINLE AQUIFER
- CHINLE SHALE
- LOWER CHINLE AQUIFER
- CHINLE SHALE
- SAN ANDRES-GLORIETTA AQUIFER

NOTES:

1. 3D model output depicted at 5x vertical exaggeration.

Adopted from:
Grants Reclamation Project Updated Corrective Action Program, HMC, 2012

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Grants Reclamation Project
Corrective Action Program

Figure 1.2-23
Three-Dimensional Hydrogeology

CROSS SECTION A-A'

0 1200' 2400'

HORIZONTAL SCALE

SOUTH
A

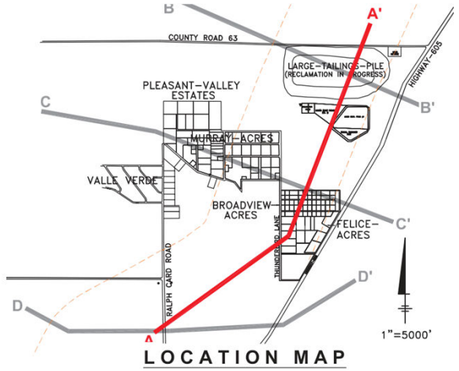
NORTH
A'

D–D'
RALPH CARD ROAD
THUNDERBIRD LANE
FELICE ACRES SUBDIVISION
C–C'
LINED EVAPORATION POND No.2
LARGE TAILINGS PILE
B–B'
COUNTY ROAD 63

GROUND
TOP OF BEDROCK
ALLUVIUM
UPPER CHINLE AQUIFER
MIDDLE CHINLE AQUIFER
LOWER CHINLE AQUIFER
SAN ANDRES–GLORIETTA AQUIFER
CHINLE SHALE

ELEVATION IN FEET

6,750
6,500
6,250
6,000
5,750
5,500



LOCATION MAP

NOTE:

1. THREE–DIMENSIONAL MODEL OUTPUT DEPICTED AT 5X VERTICAL EXAGGERATION.

LEGEND:

- LARGE TAILINGS PILE
- ALLUVIUM
- CHINLE SHALE
- UPPER CHINLE AQUIFER
- MIDDLE CHINLE AQUIFER
- LOWER CHINLE AQUIFER
- SAN ANDRES–GLORIETTA AQUIFER
- WATER TABLE

Adopted from:
Grants Reclamation Project Updated Corrective Action Program, HMC, 2012

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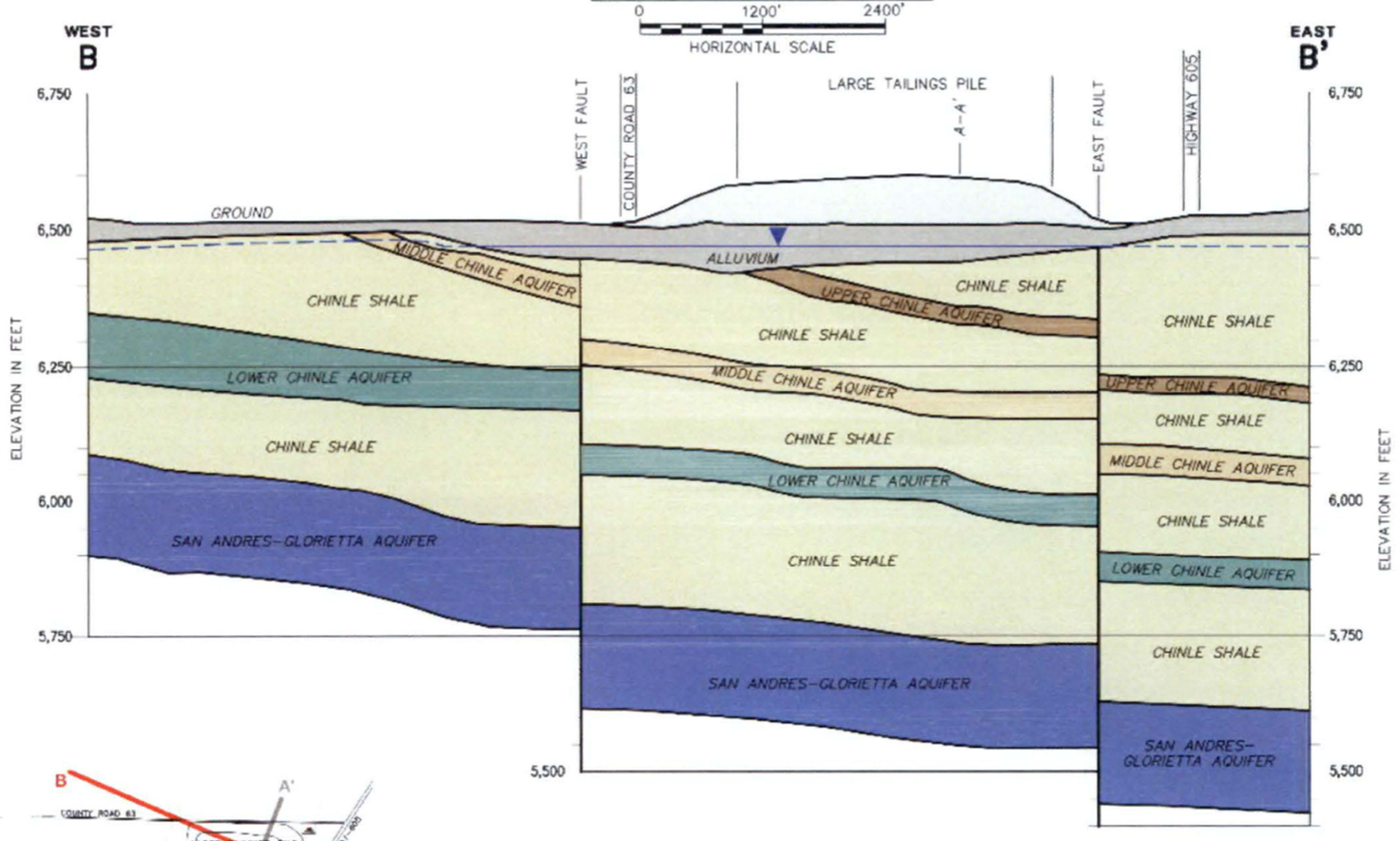
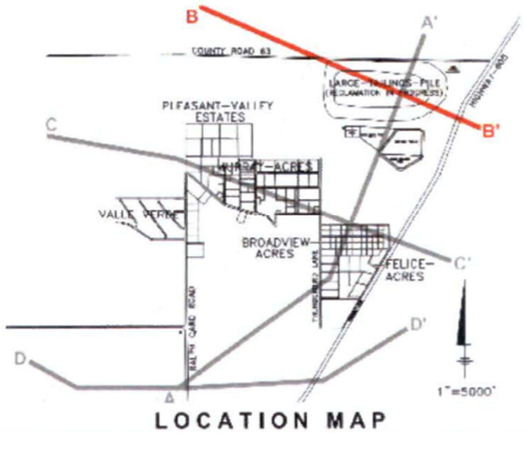
Corrective Action Program

Figure 1.2-24
Cross Section A-A'

CROSS SECTION B-B'





NOTE:

1. THREE-DIMENSIONAL MODEL OUTPUT DEPICTED AT 5X VERTICAL EXAGGERATION.

LEGEND:

- LARGE TAILINGS PILE
- ALLUVIUM
- CHINLE SHALE
- UPPER CHINLE AQUIFER
- MIDDLE CHINLE AQUIFER
- LOWER CHINLE AQUIFER
- SAN ANDRES-GLORIETTA AQUIFER
- WATER TABLE

Adapted from:
Grants Reclamation Project Updated Corrective Action Program, HMC, 2012

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Corrective Action Program

Source: HDR, 2016

Figure 1.2-25
Cross Section B-B'

CROSS SECTION C-C'

0 1200' 2400'

HORIZONTAL SCALE

WEST C

EAST C'

PLEASANT VALLEY ESTATES | WEST FAULT | MURRAY ACRES | THUNDERBIRD LANE | A-A' | BROADVIEW ACRES | EAST FAULT | HIGHWAY 605

ELEVATION IN FEET

6,750
6,500
6,250
6,000
5,750
5,500

GROUND

ALLUVIUM

BASALT

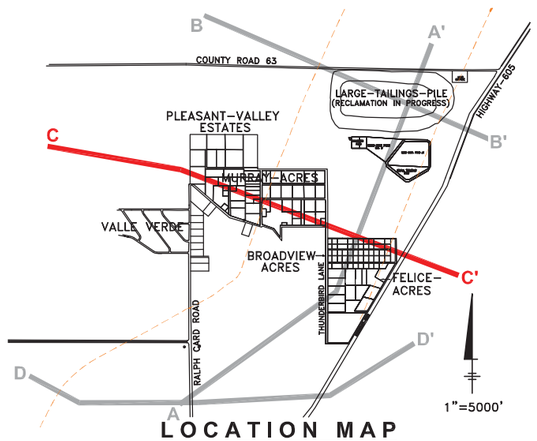
CHINLE SHALE

UPPER CHINLE AQUIFER

MIDDLE CHINLE AQUIFER

LOWER CHINLE AQUIFER

SAN ANDRES–GLORIETTA AQUIFER



LOCATION MAP

NOTES:

1. THREE–DIMENSIONAL MODEL OUTPUT DEPICTED AT 5X VERITICAL EXAGGERATION.
2. GEOLOGIC CONTACTS DASHED WHERE INFERRED.

LEGEND:

- ALLUVIUM
- BASALT
- CHINLE SHALE
- UPPER CHINLE AQUIFER
- MIDDLE CHINLE AQUIFER
- LOWER CHINLE AQUIFER
- SAN ANDRES–GLORIETTA AQUIFER
- WATER TABLE

Modified: September 4, 2015
Adopted from:
Grants Reclamation Project Updated Corrective Action Program, HMC, 2012

DATE MODIFIED: 08/31/15

MODIFIED BY: JDLoving

G:\ENVCAD\Irvine\ACTA\A000012\007C\000001\A0000120.007C_xSect C-C.pdf

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Corrective Action Program

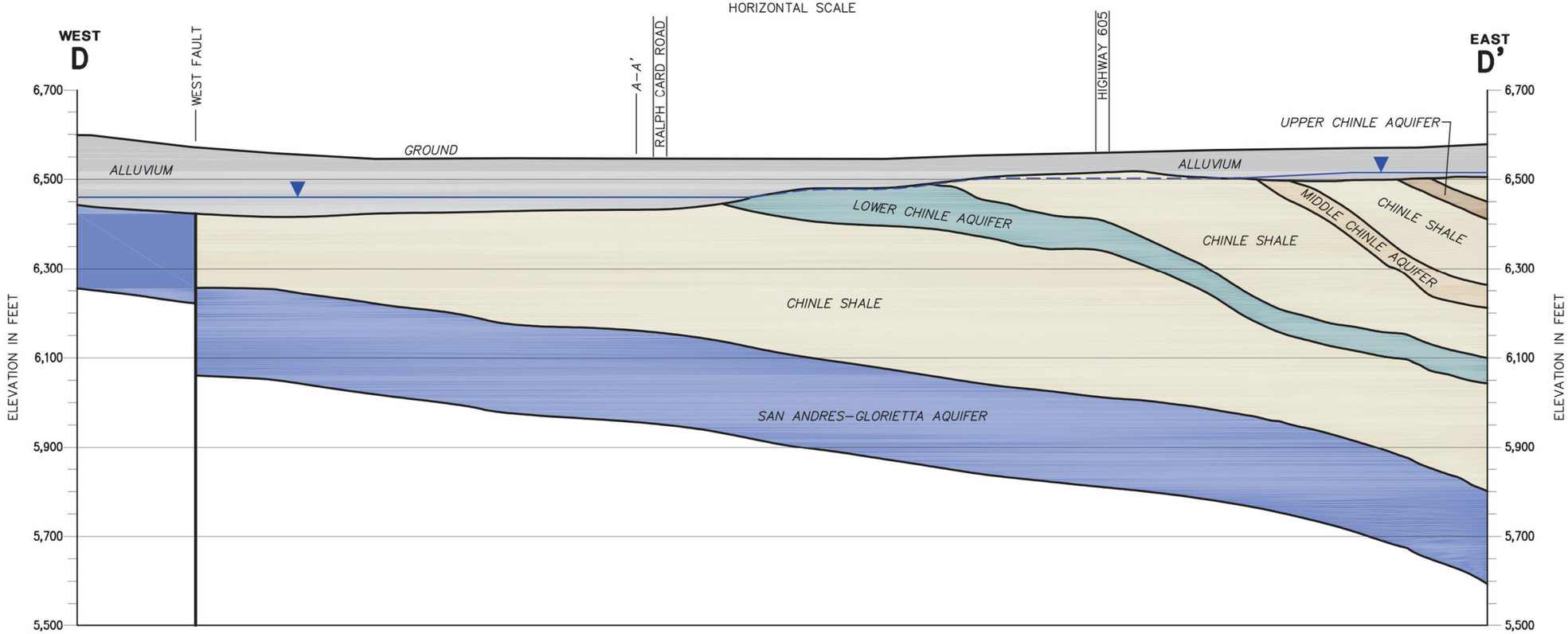
Source: HDR, 2016

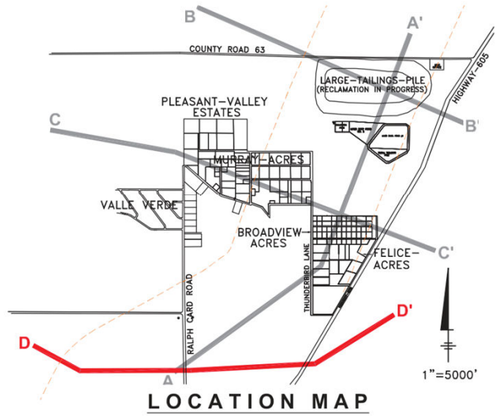
Figure 1.2-26
Cross Section C-C'

CROSS SECTION D-D'

0 1200' 2400'

HORIZONTAL SCALE





LOCATION MAP

NOTE:

1. THREE–DIMENSIONAL MODEL OUTPUT DEPICTED AT 5X VERTICAL EXAGGERATION.

LEGEND:

- LARGE TAILINGS PILE
- ALLUVIUM
- CHINLE SHALE
- UPPER CHINLE AQUIFER
- MIDDLE CHINLE AQUIFER
- LOWER CHINLE AQUIFER
- SAN ANDRES–GLORIETTA AQUIFER
- WATER TABLE

Adopted from:
Grants Reclamation Project Updated Corrective Action Program, HMC, 2012

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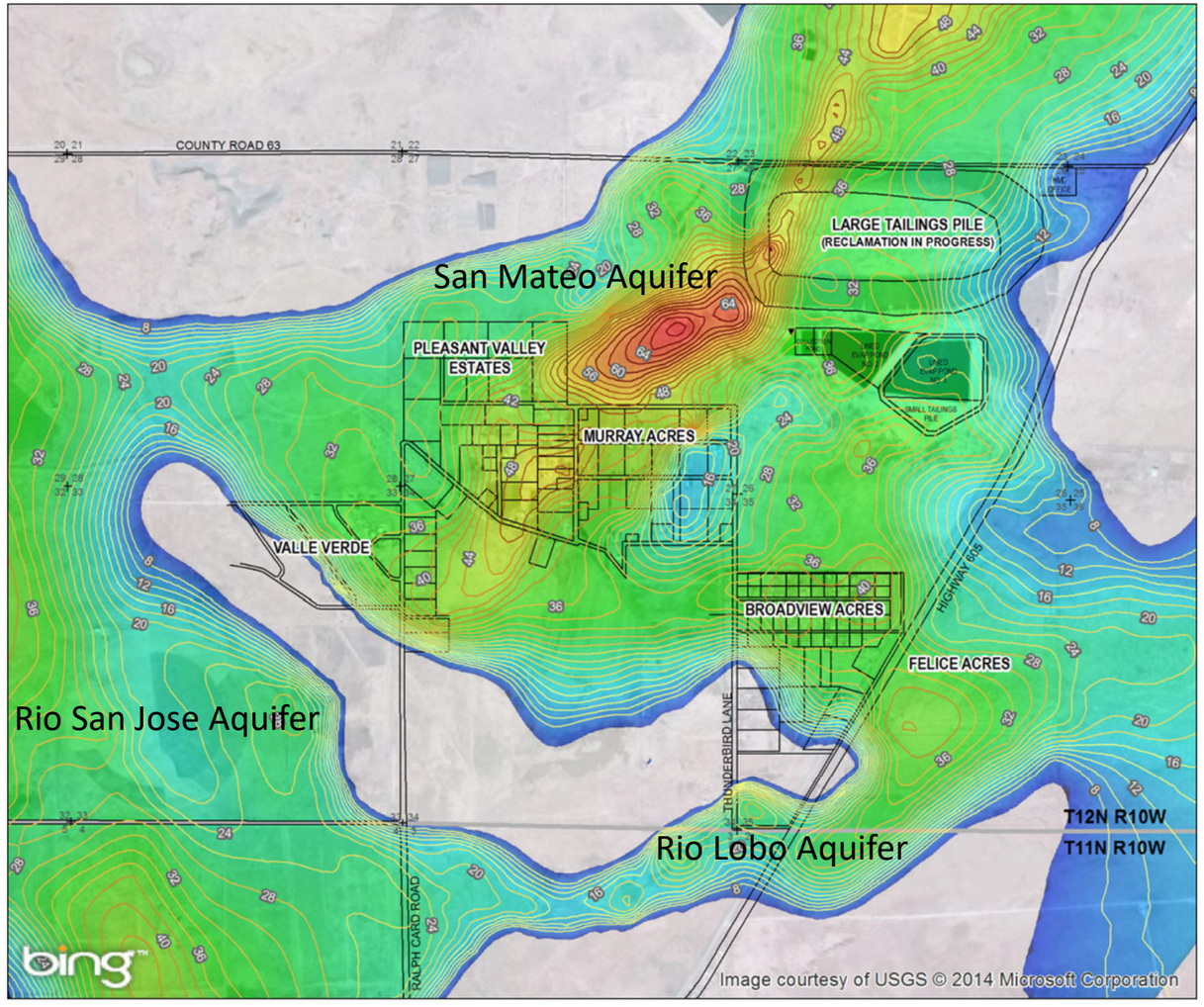
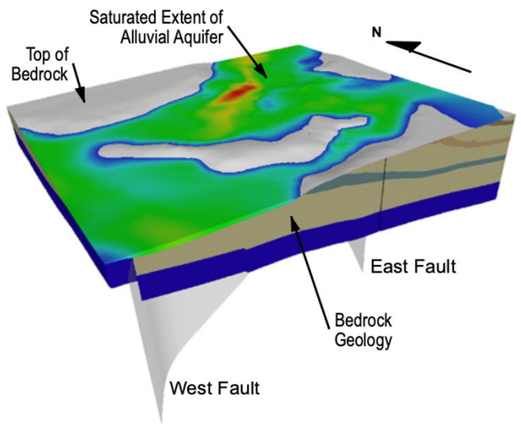
Corrective Action Program

Figure 1.2-27
Cross Section D-D'



3D BEDROCK GEOLOGY AND SATURATED EXTENT OF ALLUVIAL AQUIFER - FACING NORTHEAST



LEGENDS:

Saturated Alluvial Thickness (feet)

69
60
52
43
34
26
17
9
0

Bedrock Hydrostratigraphy

- Chinle Shale
- Upper Chinle Aquifer
- Chinle Shale
- Middle Chinle Aquifer
- Chinle Shale
- Lower Chinle Aquifer
- Chinle Shale
- San Andres-Glorietta Aquifer

Source: Grants Reclamation Project Updated Corrective Action Program, HMC, 2012

N

0 1,350 2,700 Feet

Aerial: Bing Maps - © 2010 Microsoft Corporation and its data suppliers

Thickness Contours in Feet

- 8 - 16
- 17 - 26
- 27 - 36
- 37 - 46
- 47 - 56
- 57 - 68

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Corrective Action Program

Figure 1.2-28
Saturated Extent of the Alluvial Aquifer

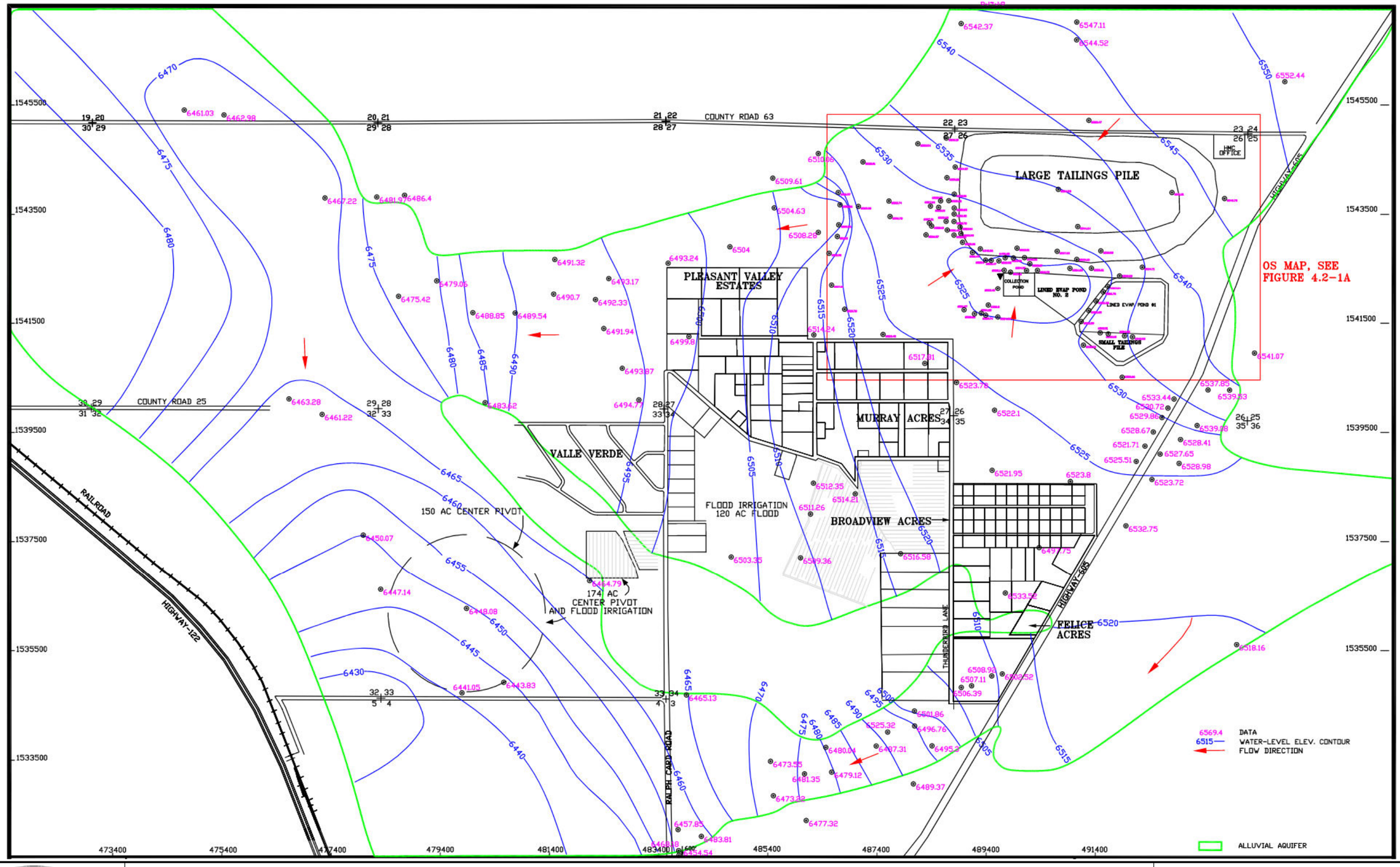

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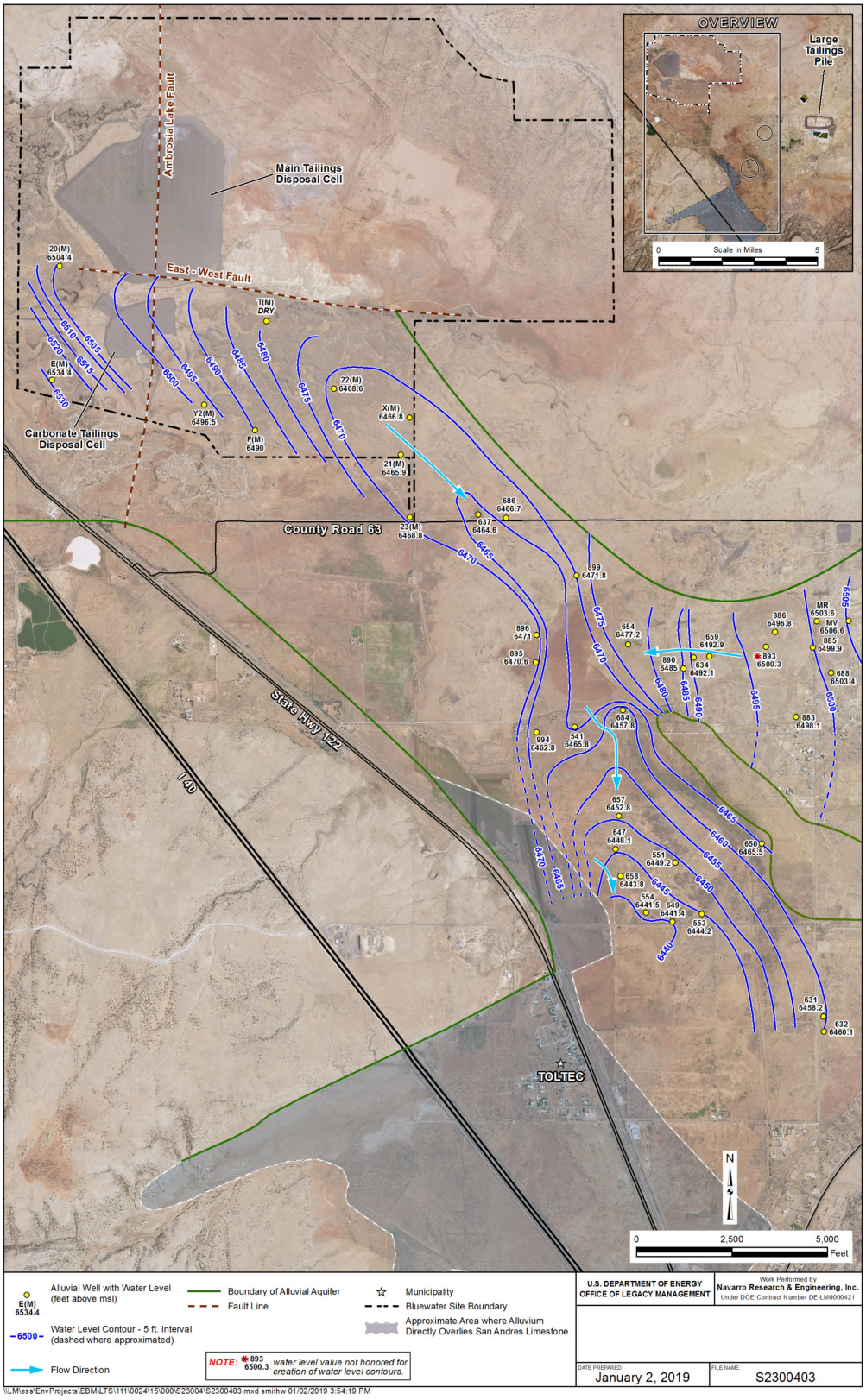
Figure 1.2-29
Groundwater Potentiometric Surface
Alluvial Aquifer, Fall 2024



Source: DOE, 2019

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Figure 1.2-30
San Jose Groundwater Elevation Contours

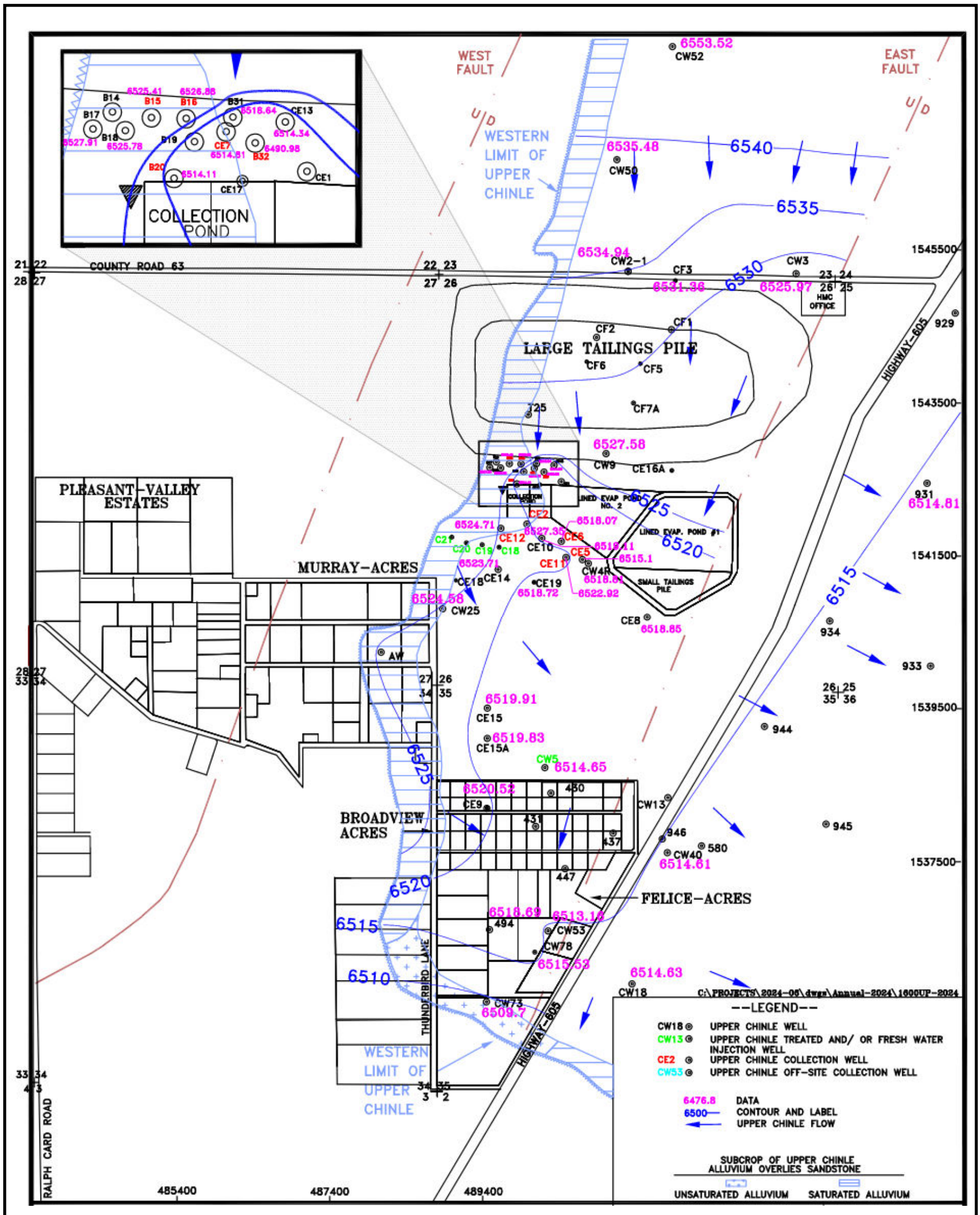

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Figure 1.2-31
Upper Chinle Groundwater Elevation
and Flow Direction, Fall 2024

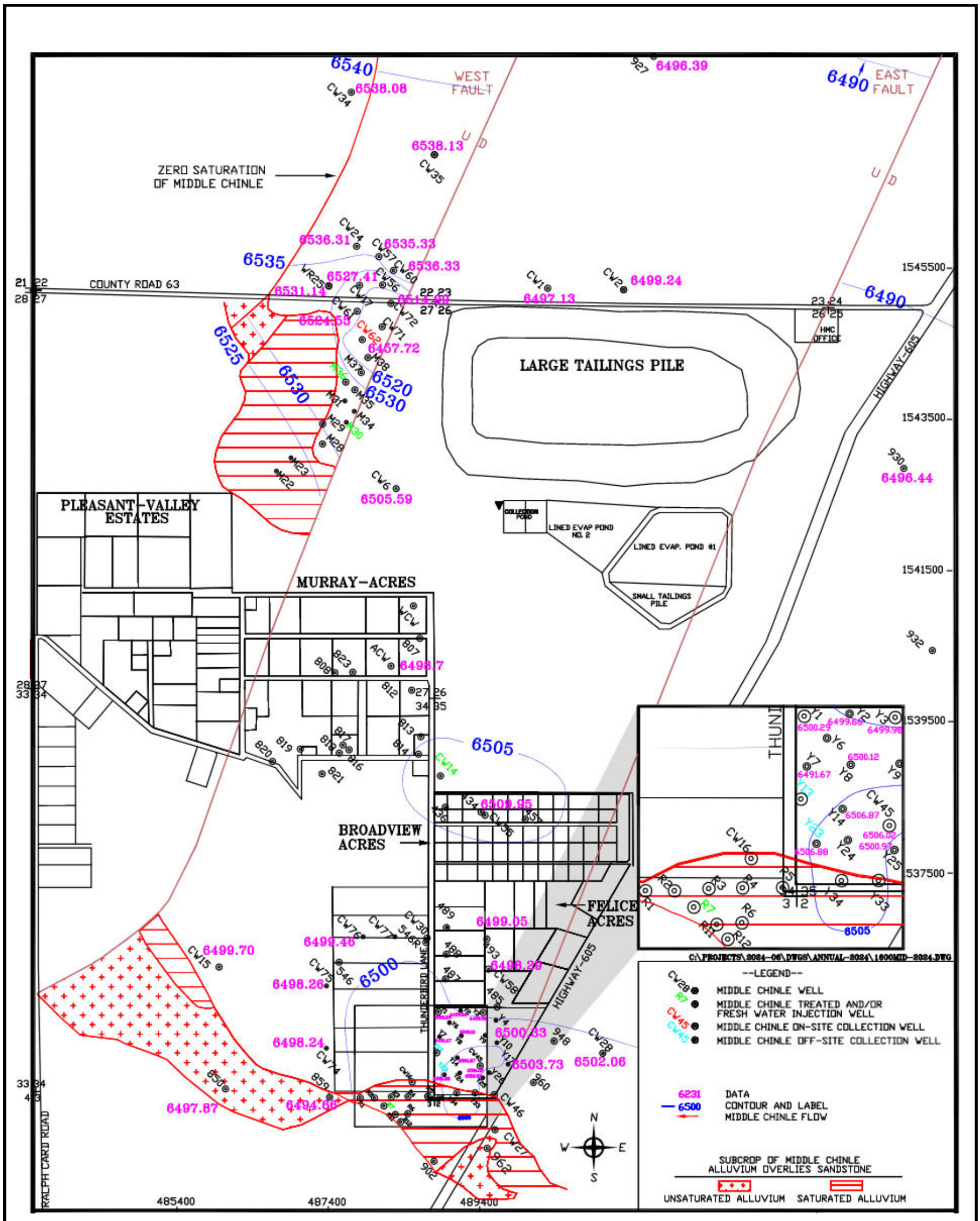

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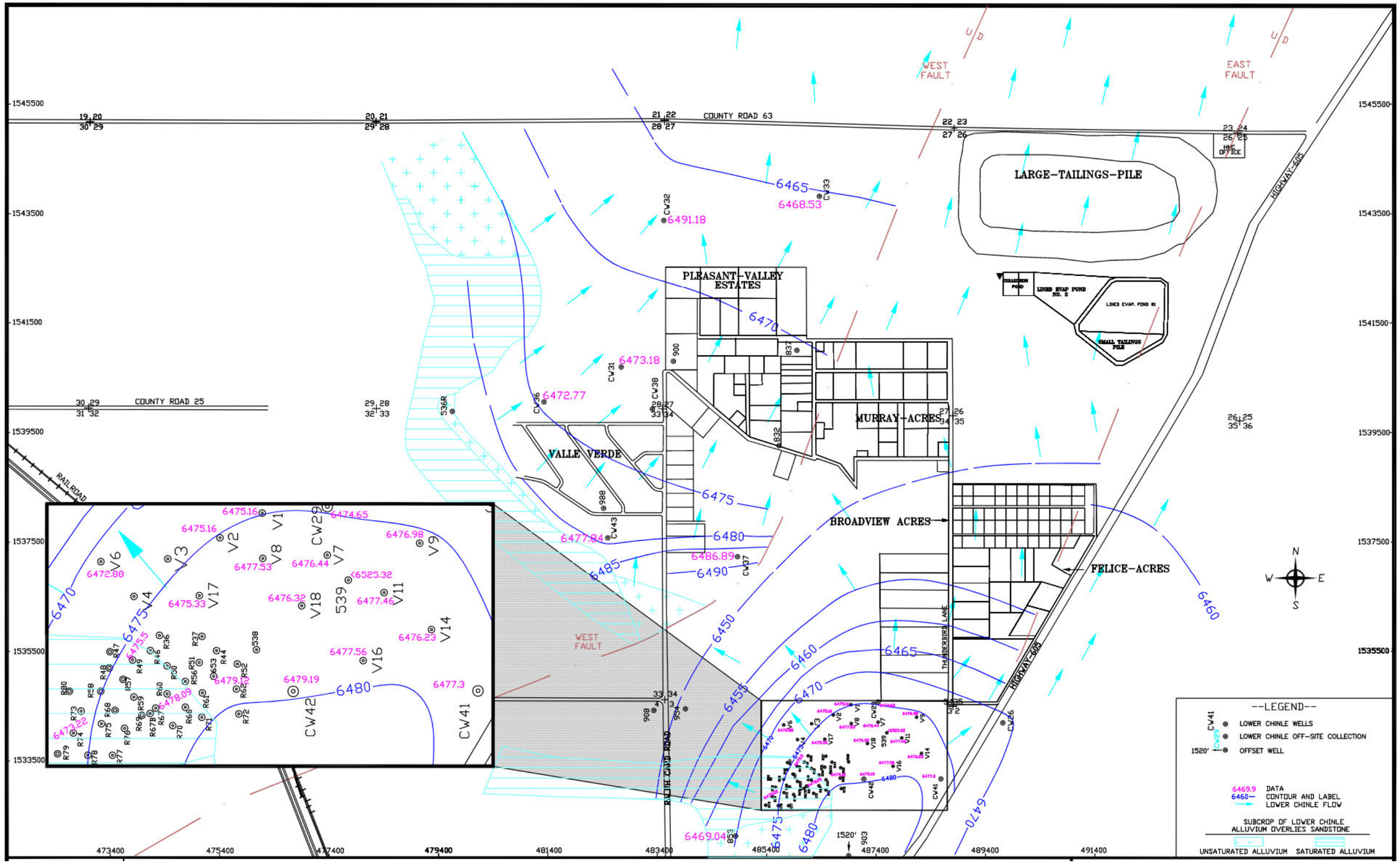
Figure 1.2-32
Middle Chinle Groundwater Elevation and Flow Direction, Fall 2024



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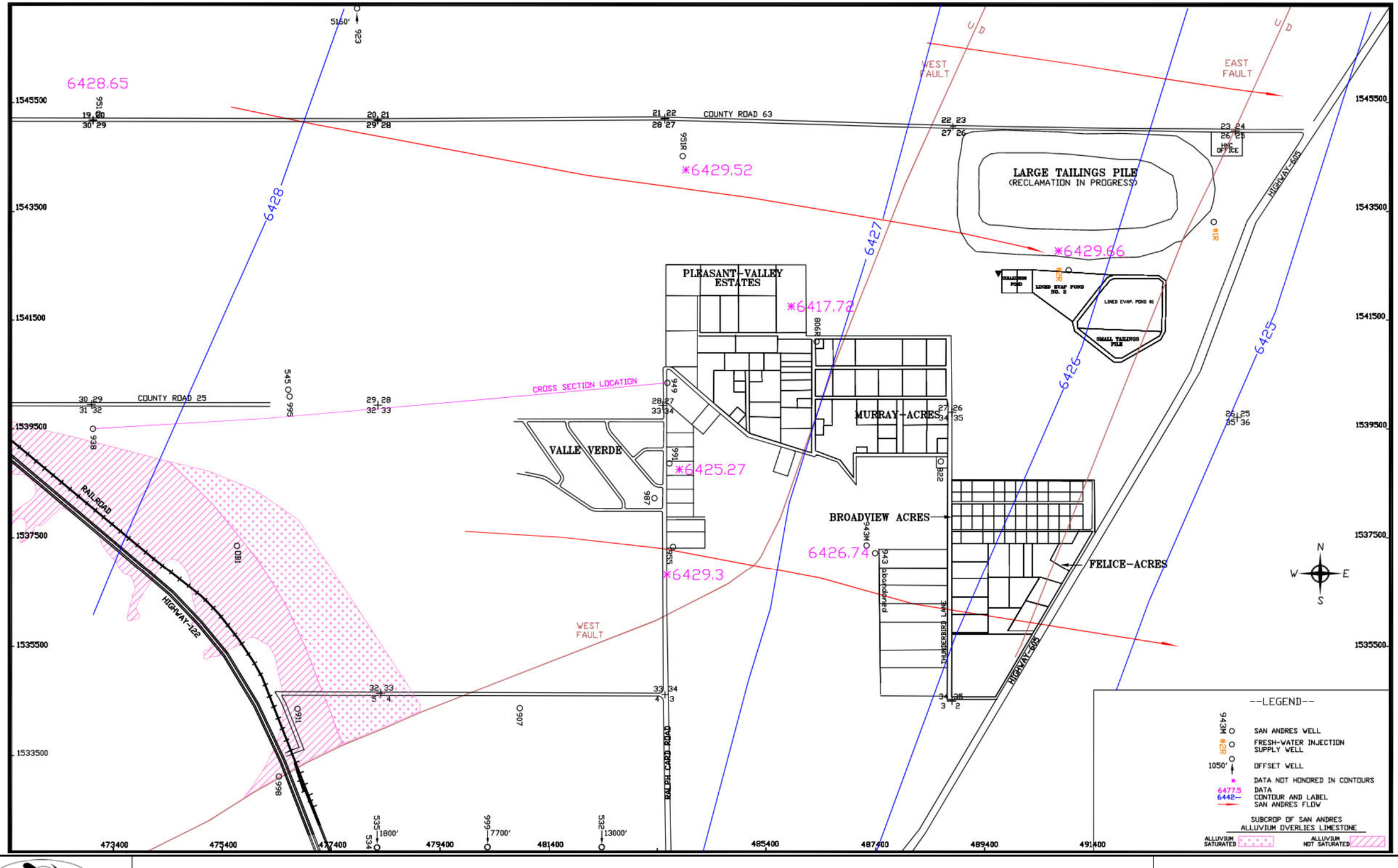
Elevation-feet above mean sea level

Figure 1.2-33
Lower Chinle Groundwater Elevation and Flow Direction, Fall 2024



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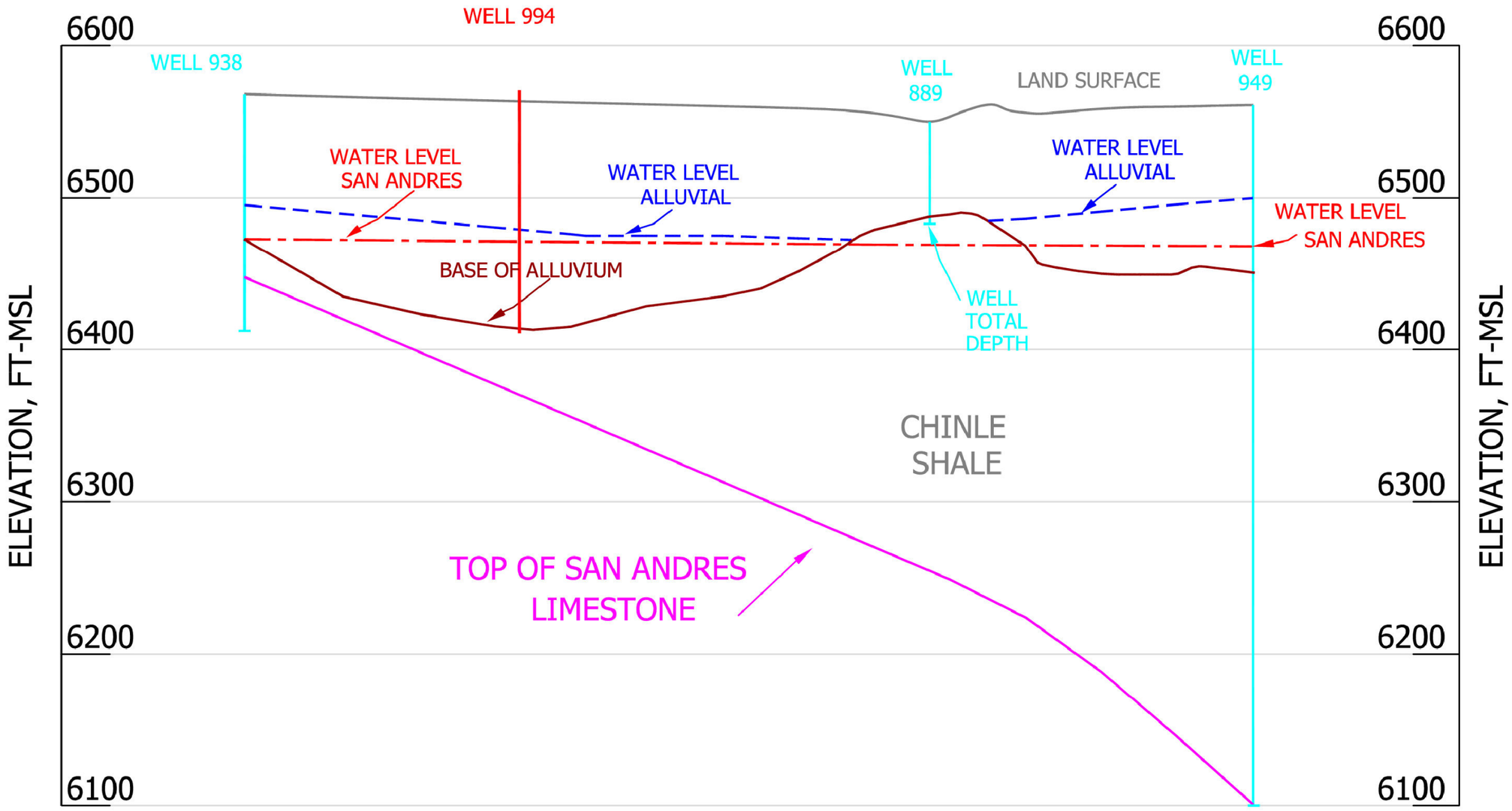
Corrective Action Program

Elevation-feet above mean sea level

Figure 1.2-34
San Andres-Glorieta Groundwater Elevation and Flow Direction, Fall 2024



NOTE: X-SECTION BASED ON LOGS FROM WELLS 938, 889, AND 949.

HOMESTAKE **Grants Reclamation Project** Corrective Action Program	Elevation-feet above mean sea level	**Figure 1.2-35** Generalized San Andres-Glorieta Cross Section

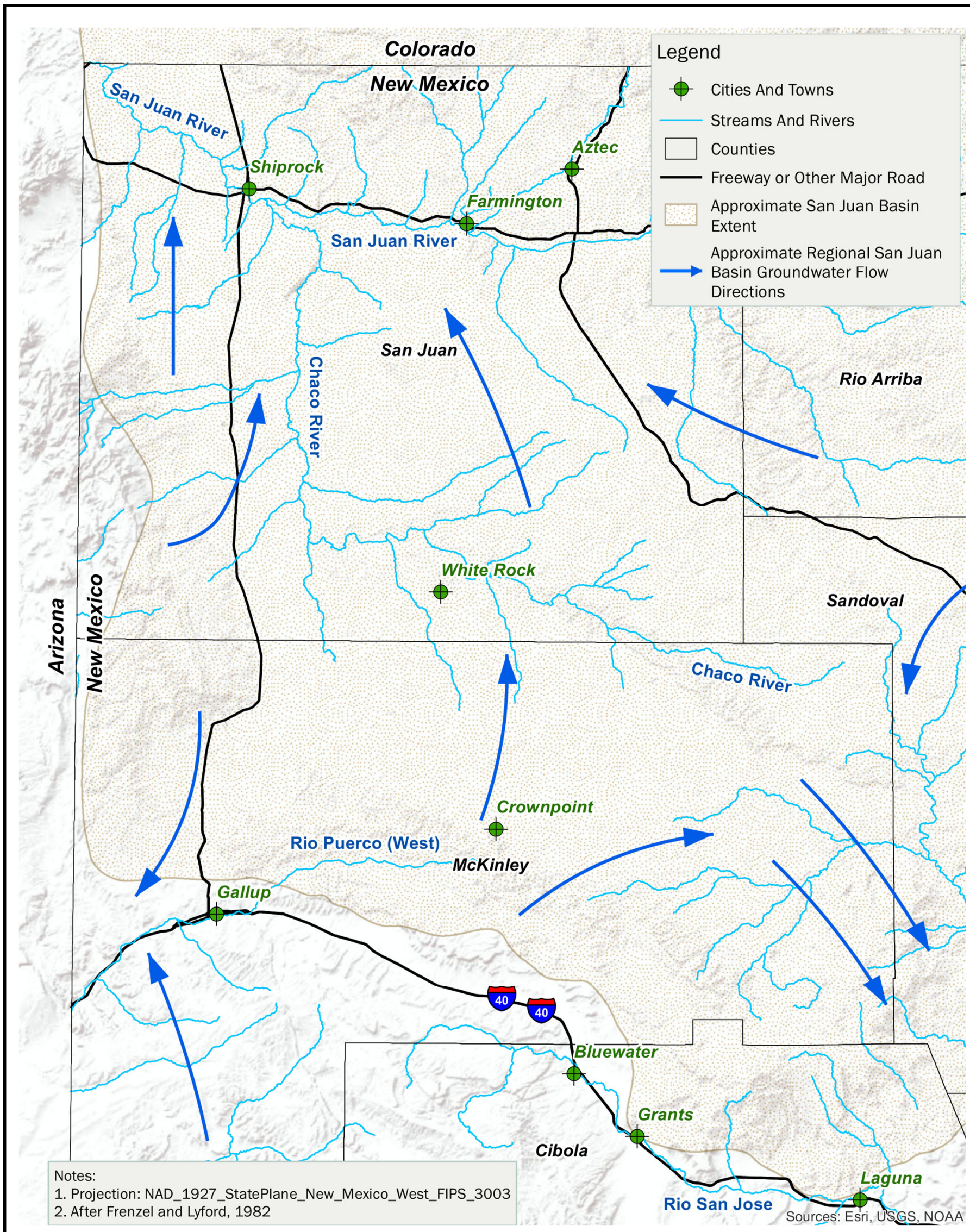


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Figure 1.2-36
Approximate Groundwater Flow Directions in Cretaceous and Jurassic Aquifers

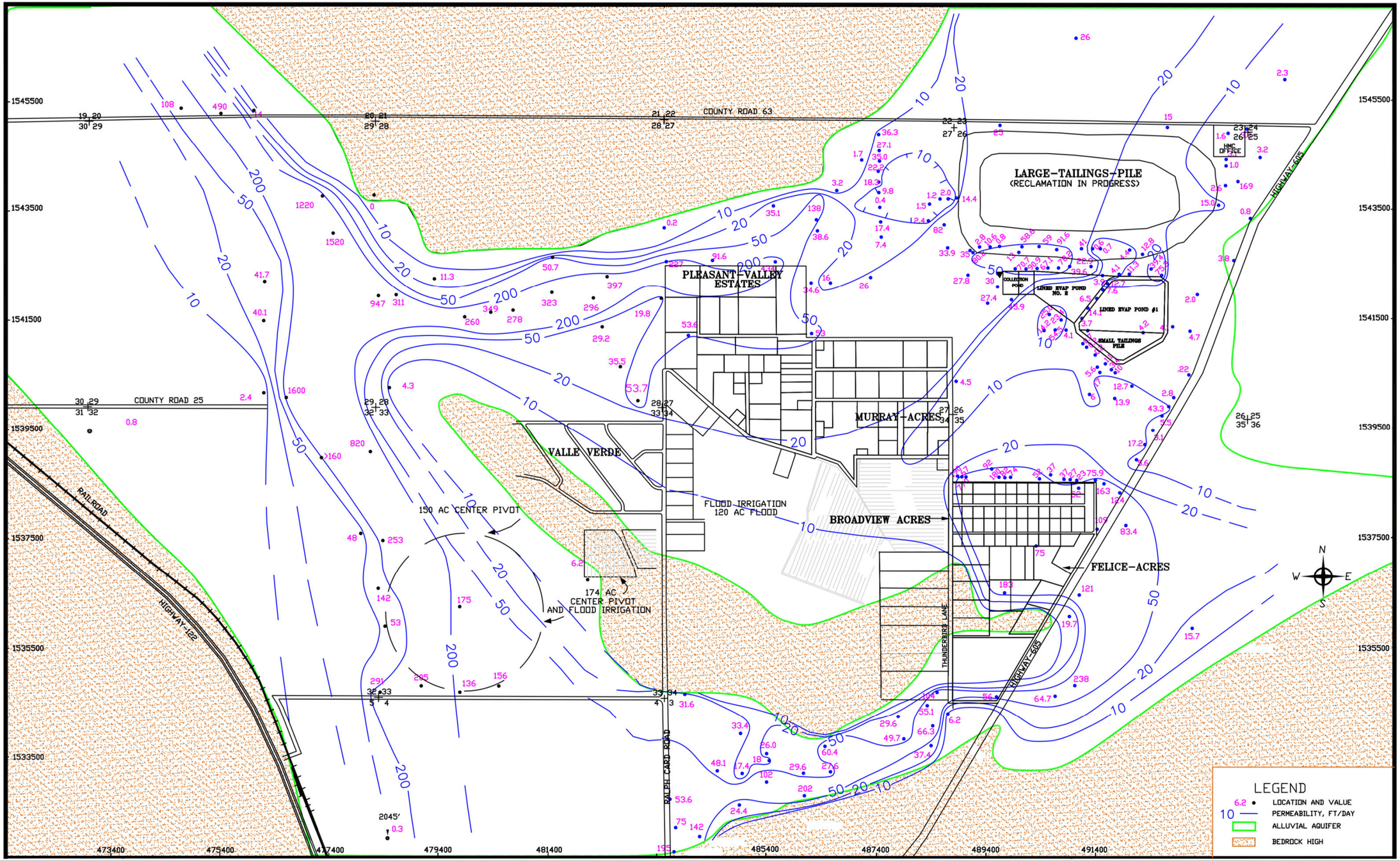

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Figure 1.2-37
Hydraulic Conductivity for the Alluvial Aquifer

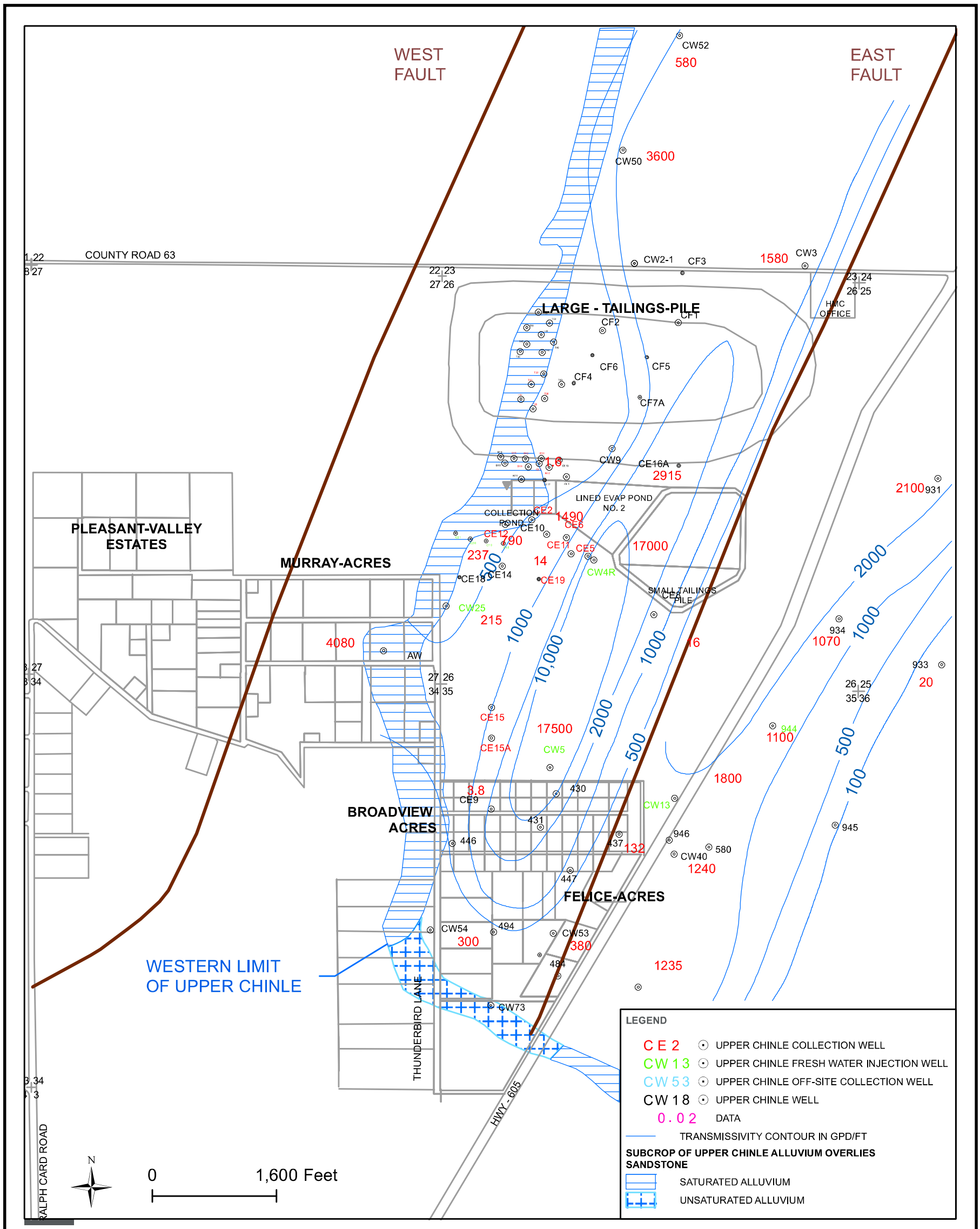

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Figure 1.2-38
Upper Chinle Transmissivity

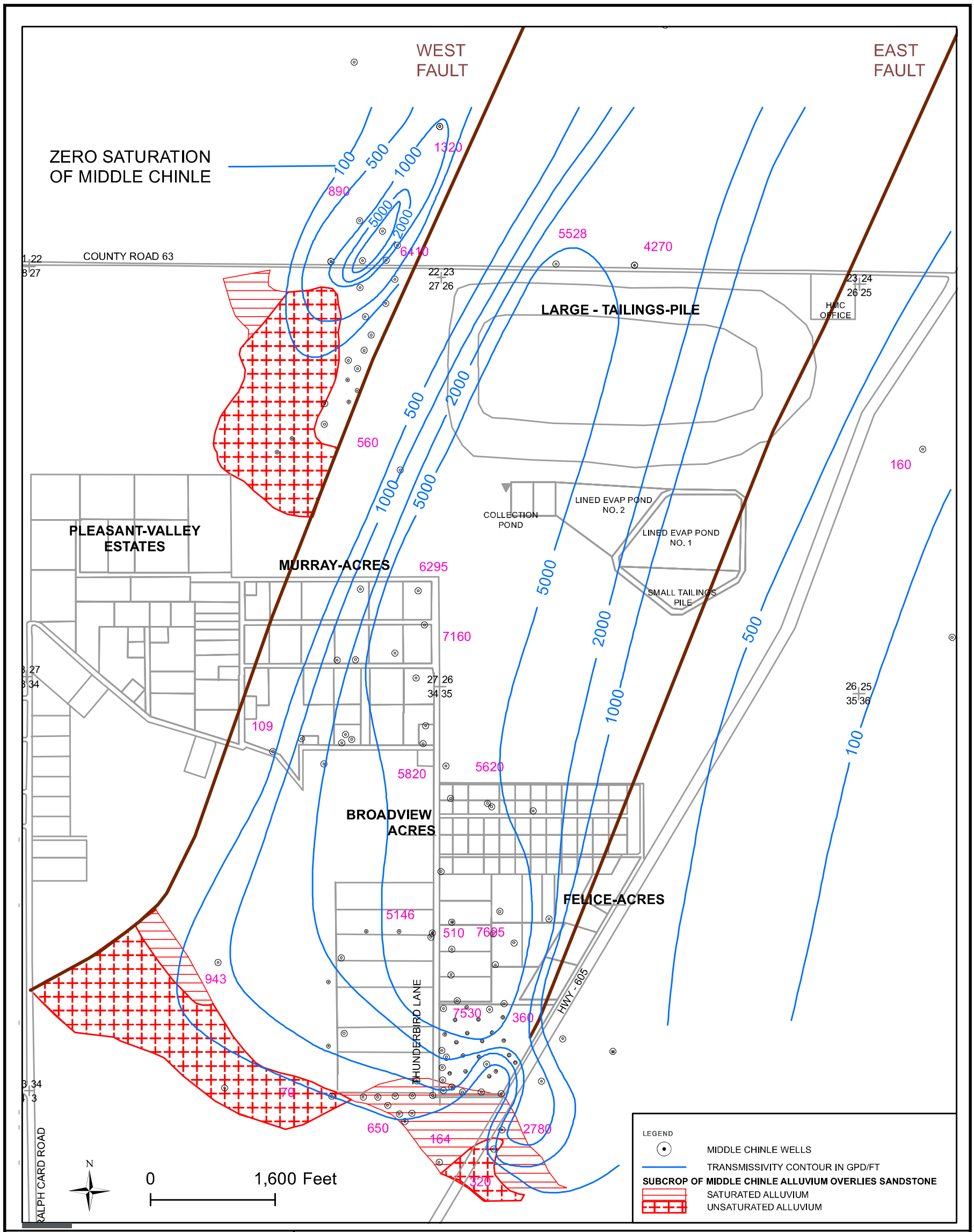

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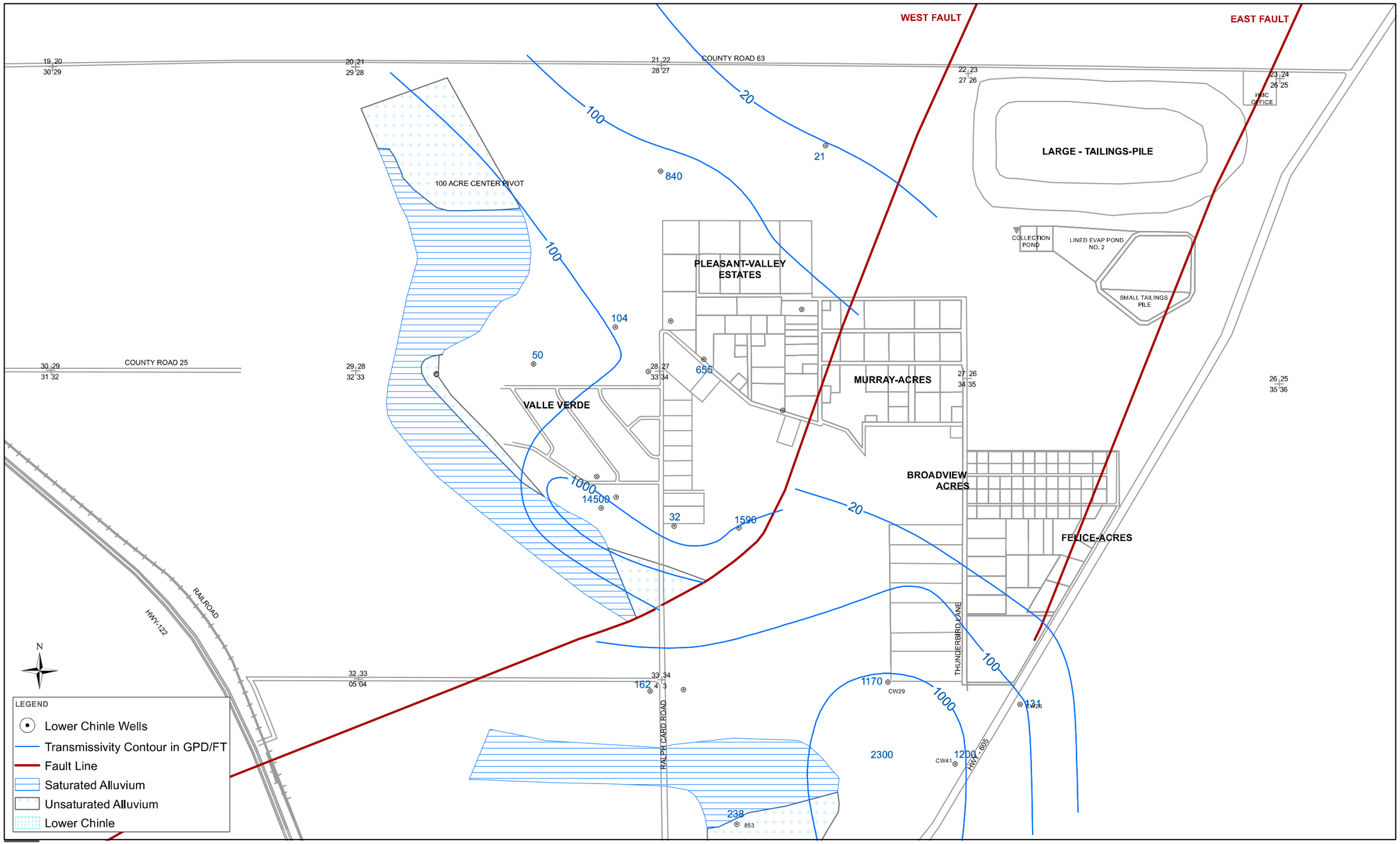
Figure 1.2-39
Middle Chinle Transmissivity



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0 1,500 Feet

Units are feet/day

Figure 1.2-40
Lower Chinle Transmissivity

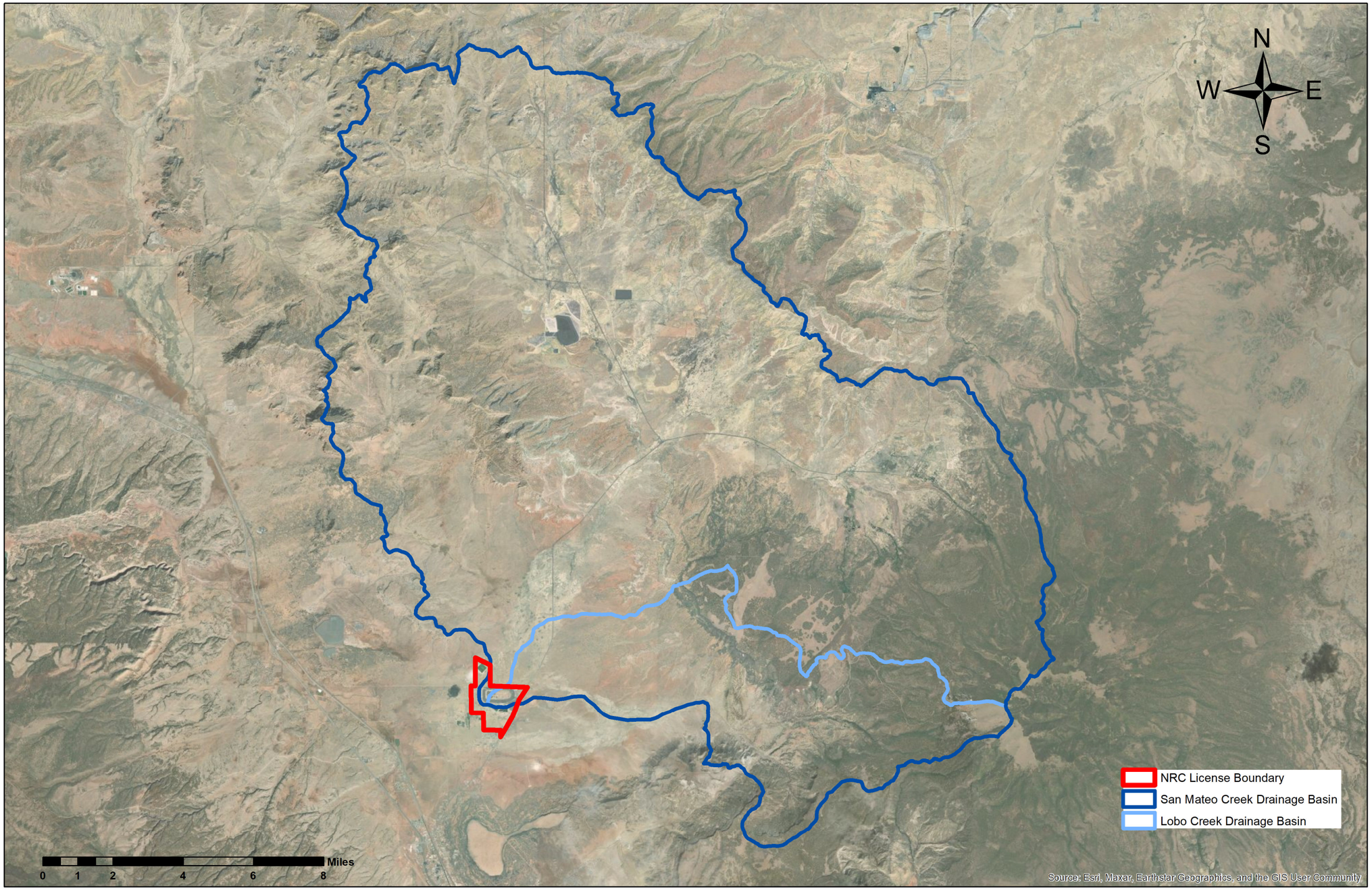

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Figure 1.2-41
Regional Surface Water
Drainage Basins

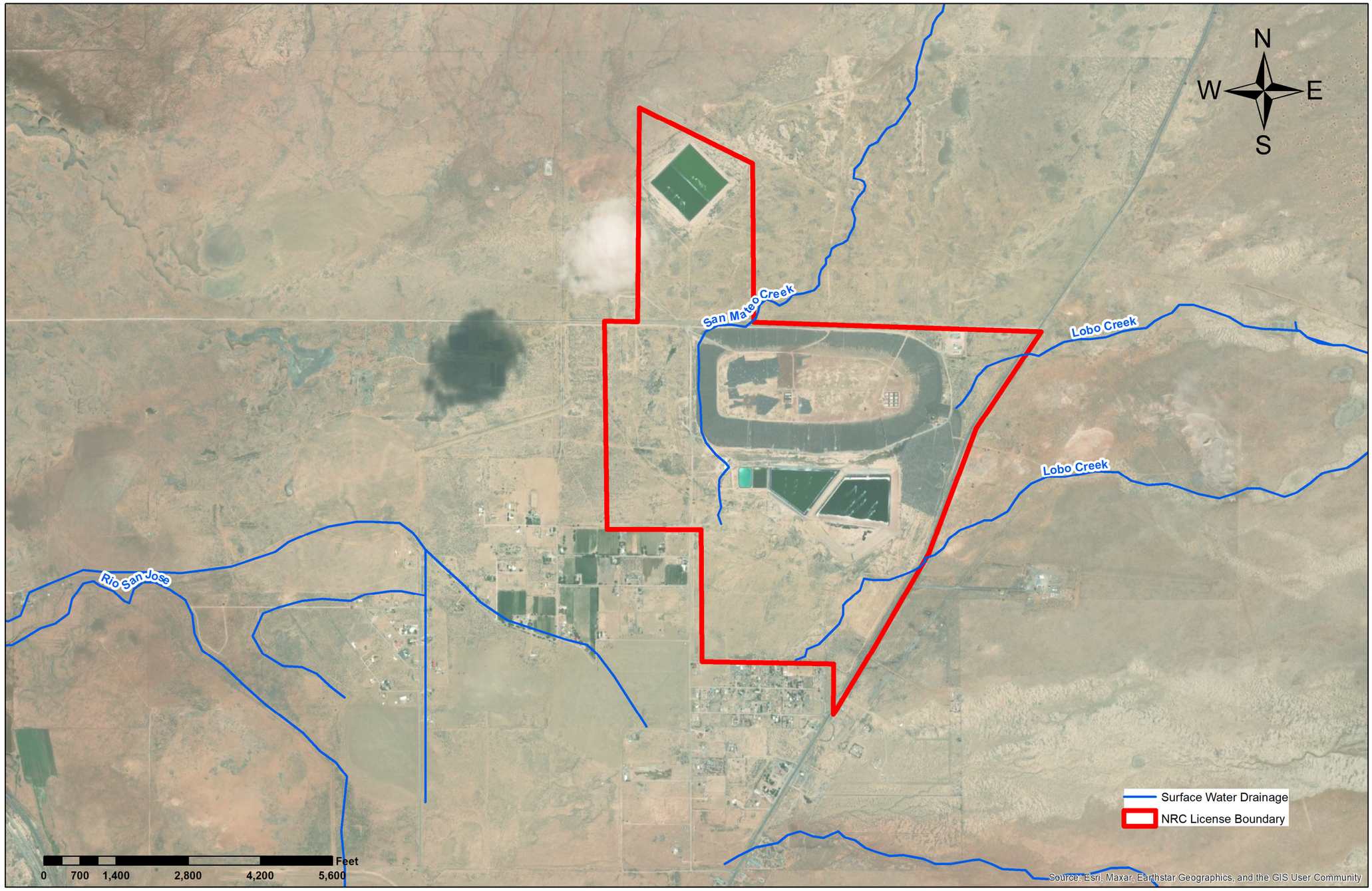

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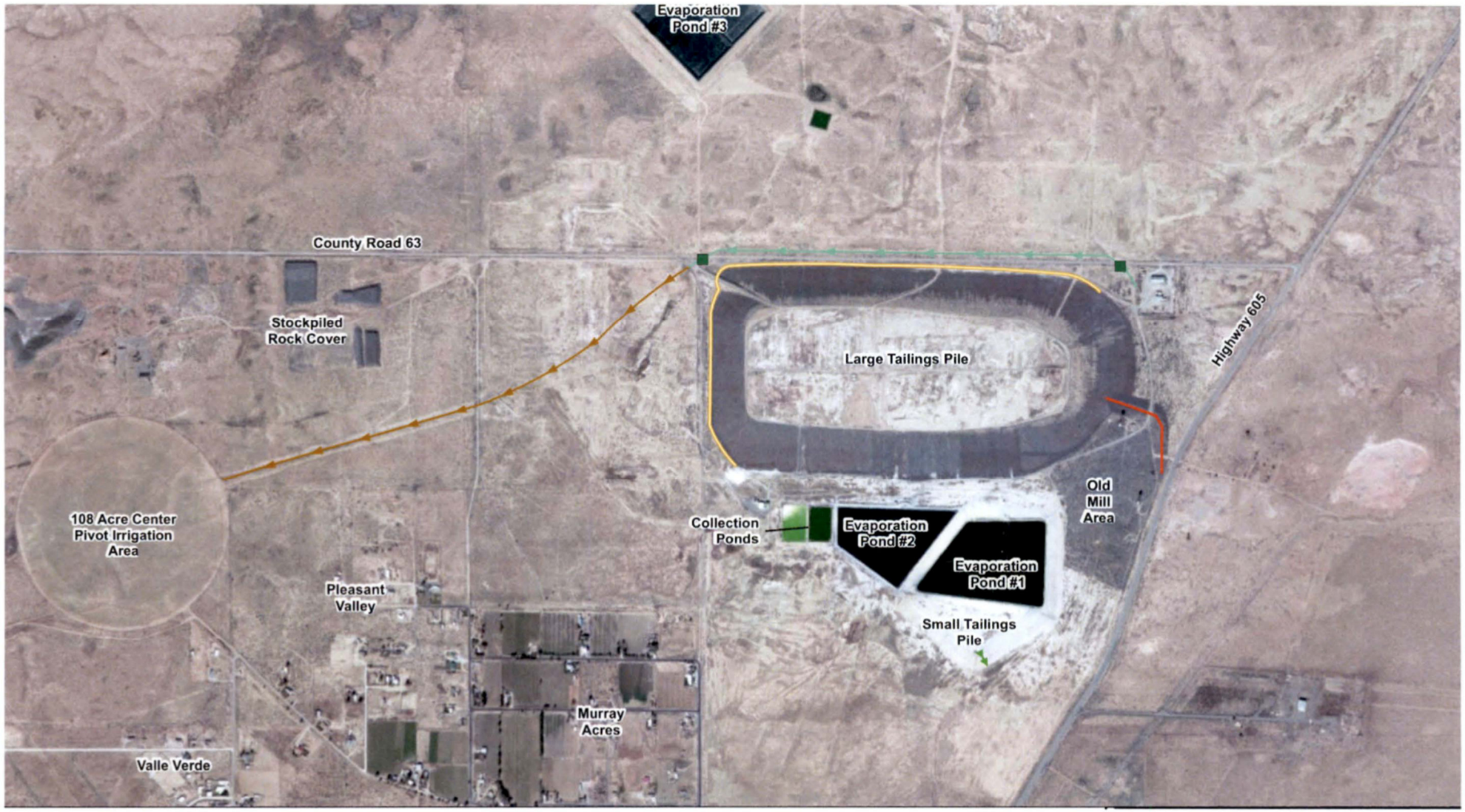
Figure 1.2-42
Surface Water Drainages



Grants Reclamation Project
Corrective Action Program

Source: HDR, 2016

Figure 1.2-43
GRP Constructed Features

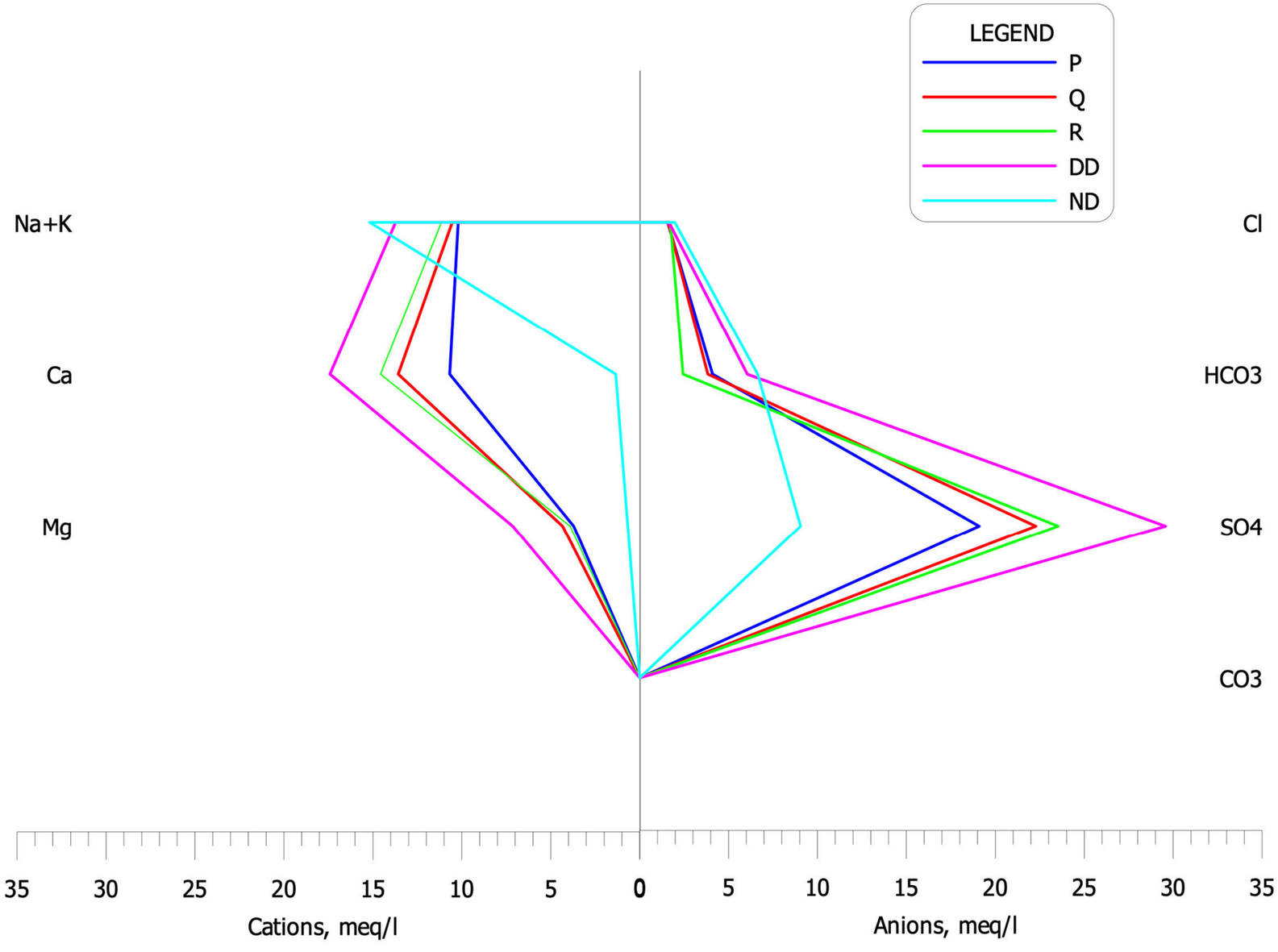


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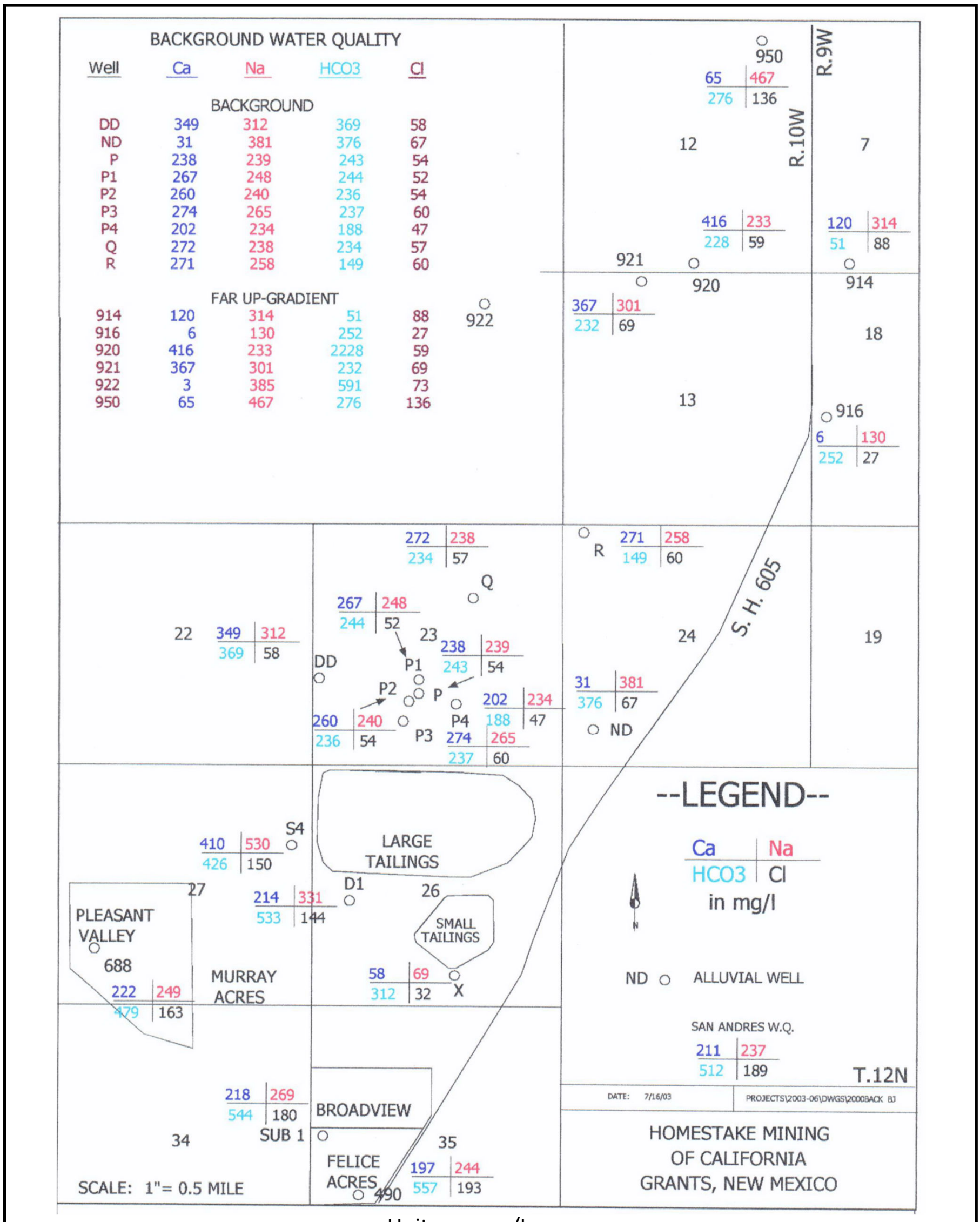
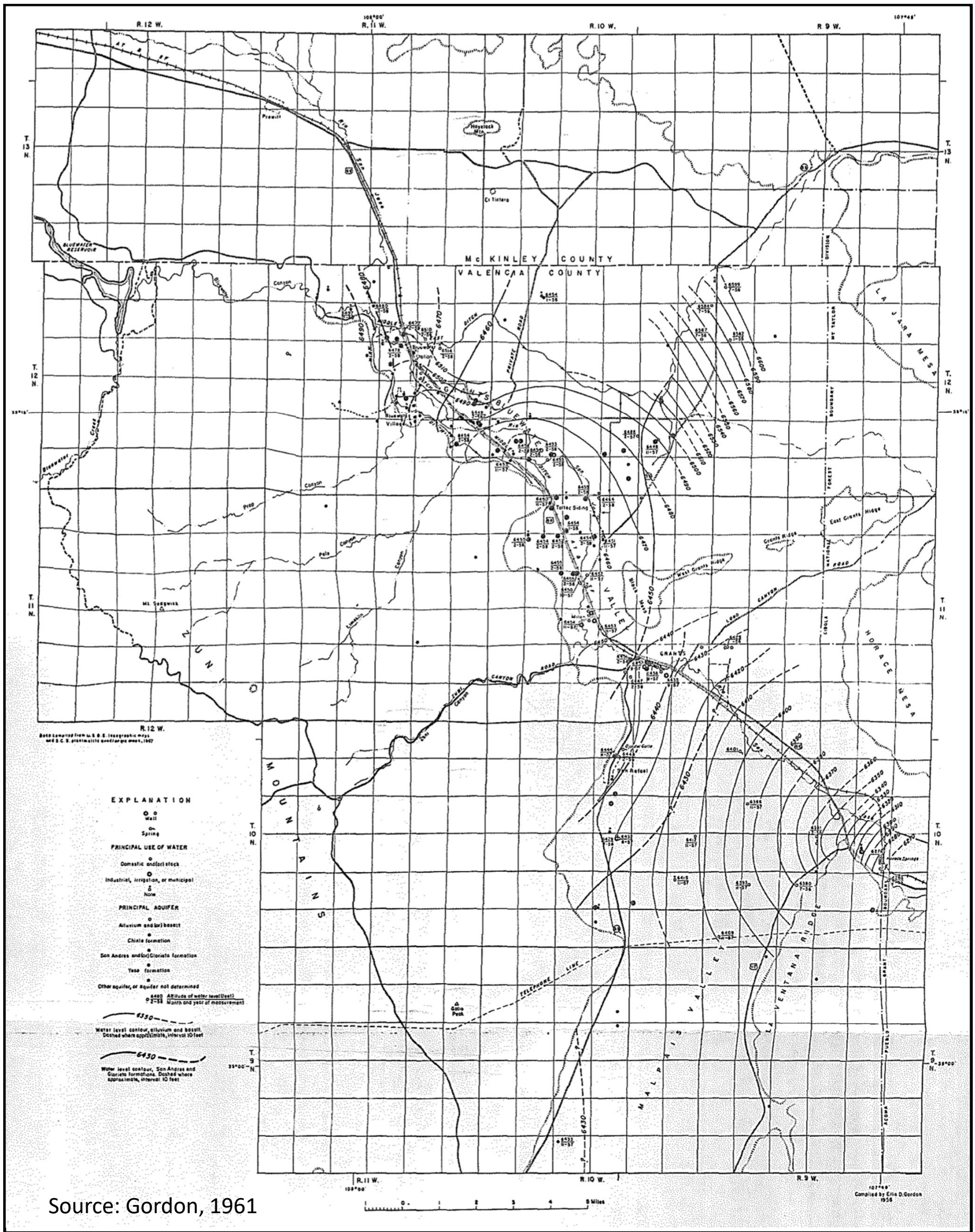
Figure 1.2-44
Stiff Diagram Comparison of Near Upgradient Alluvial Groundwater Quality



Units are mg/L

Grants Reclamation Project
Corrective Action Program

Figure 1.2-45
Major Ionic Constituent Concentration Comparisons
of Background Alluvial Wells



Source: Gordon, 1961

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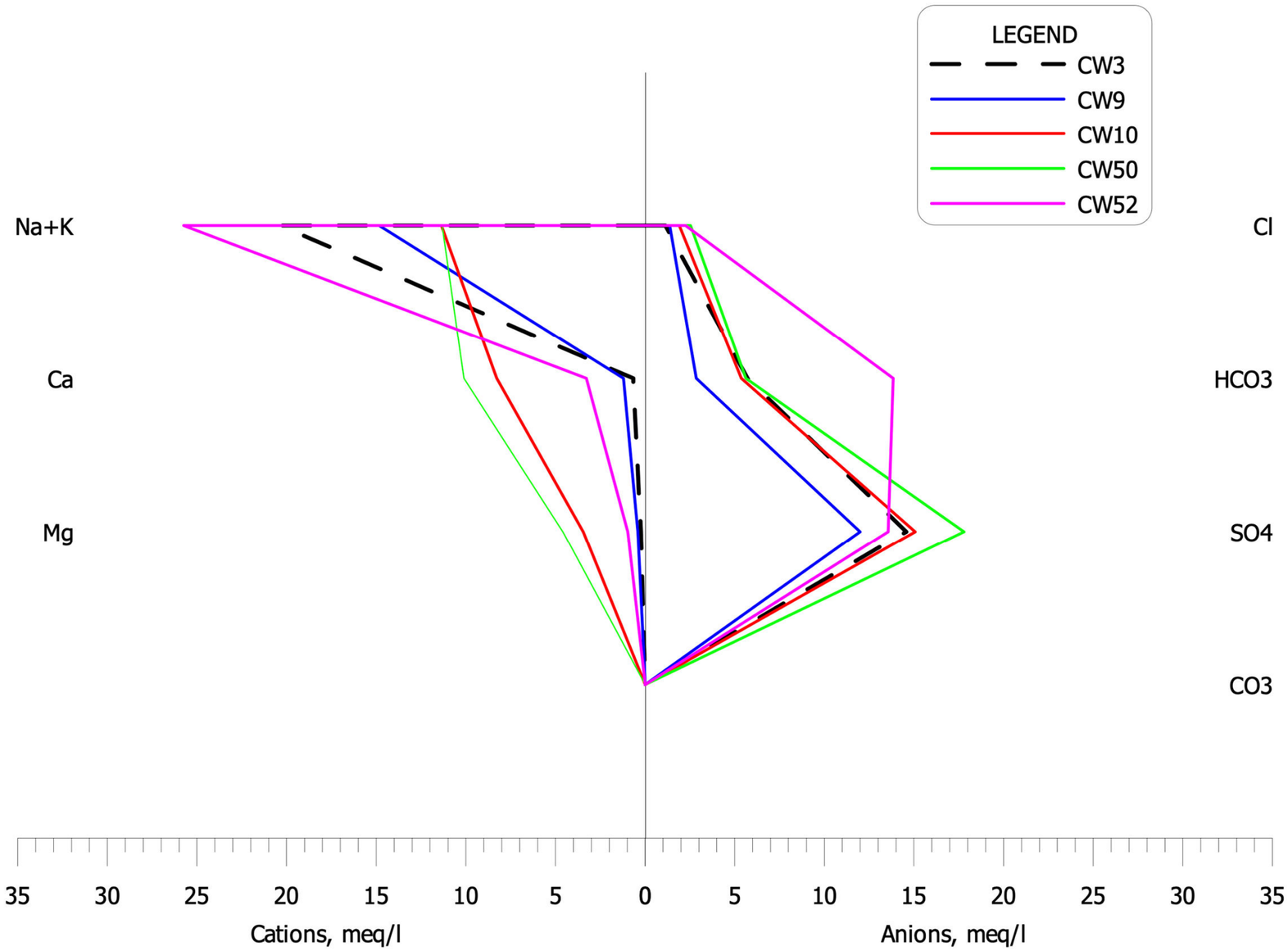
Figure 1.2-46
Regional Chinle Wells



Grants Reclamation Project
Corrective Action Program

Figure 1.2-47
Stiff Diagram Comparison of Upper Chinle Groundwater Quality in the North Wells

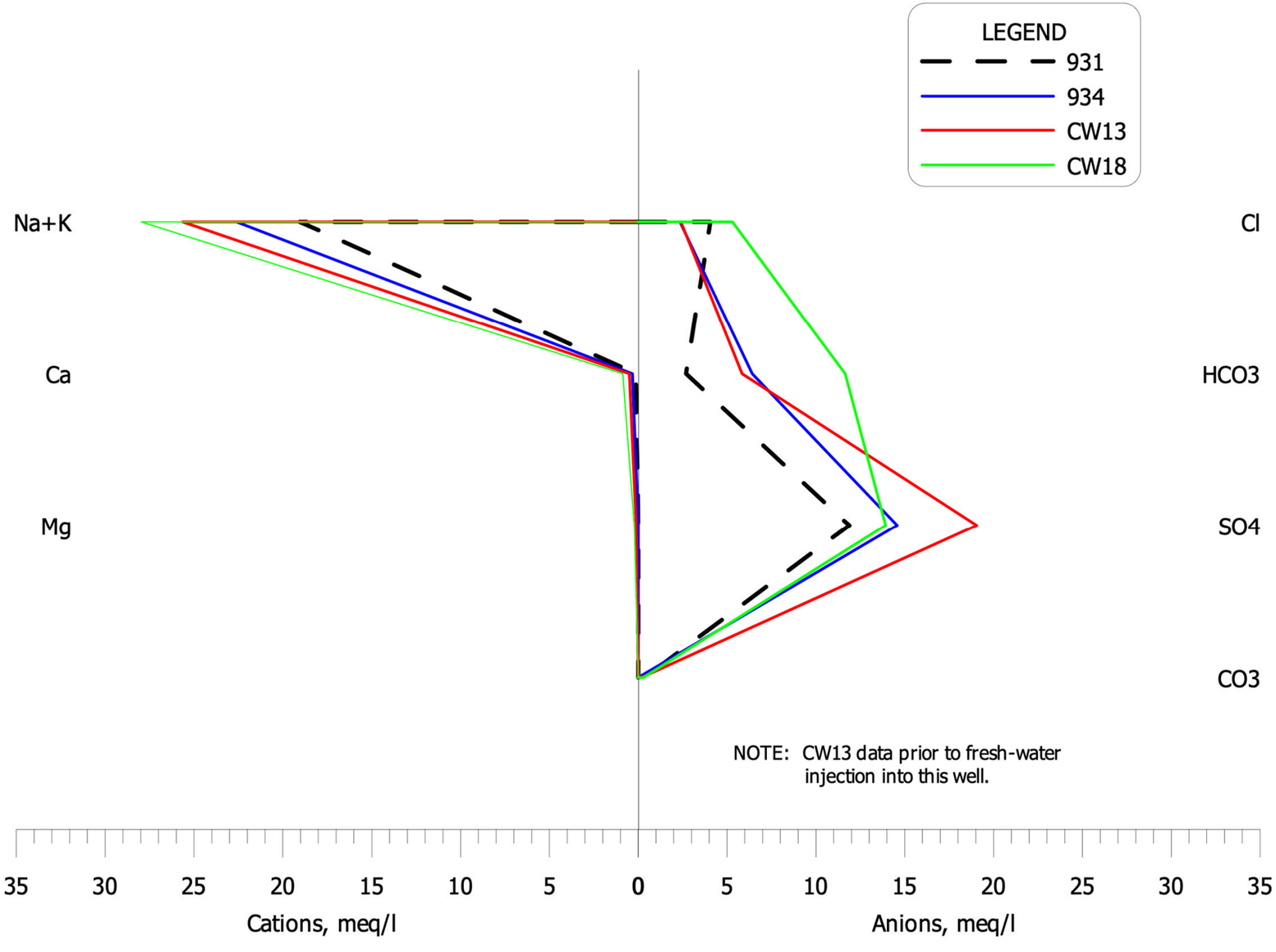


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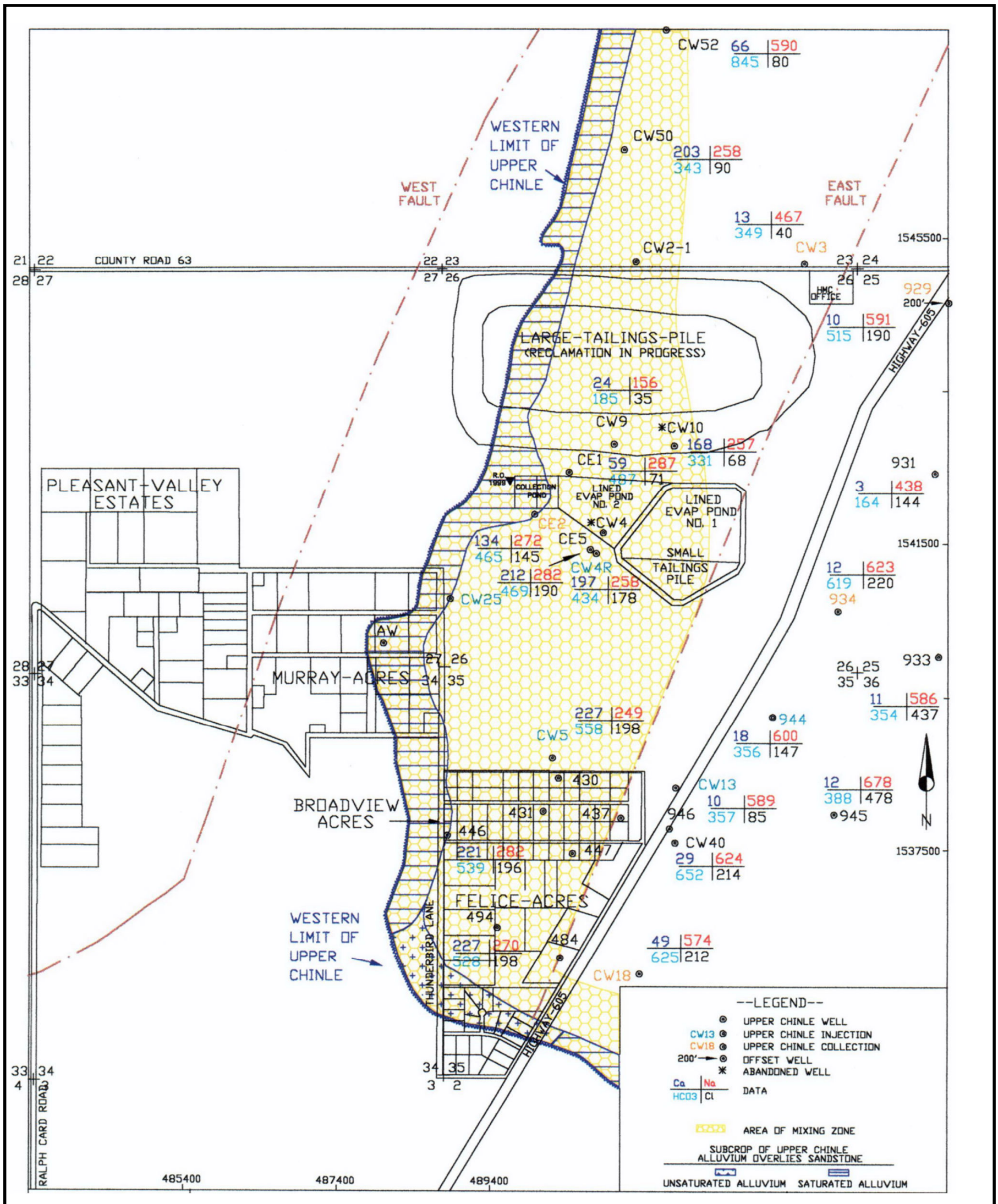
Figure 1.2-48
Stiff Diagram Comparison of Upper Chinle Groundwater Quality in the East Wells



Units are mg/L

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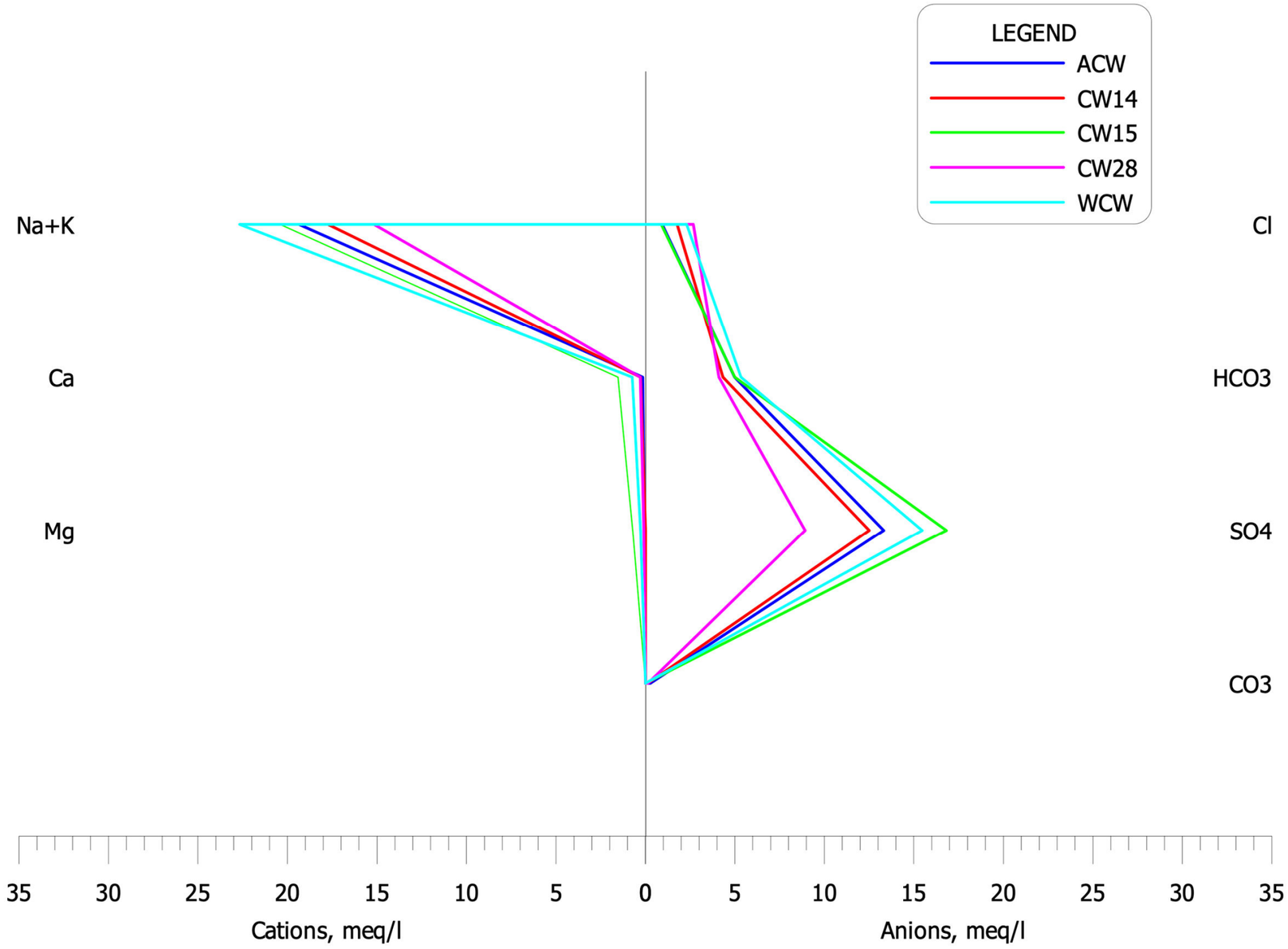
Figure 1.2-49
Major Ionic Constituent Concentration Comparisons of the Upper Chinle Wells



Grants Reclamation Project
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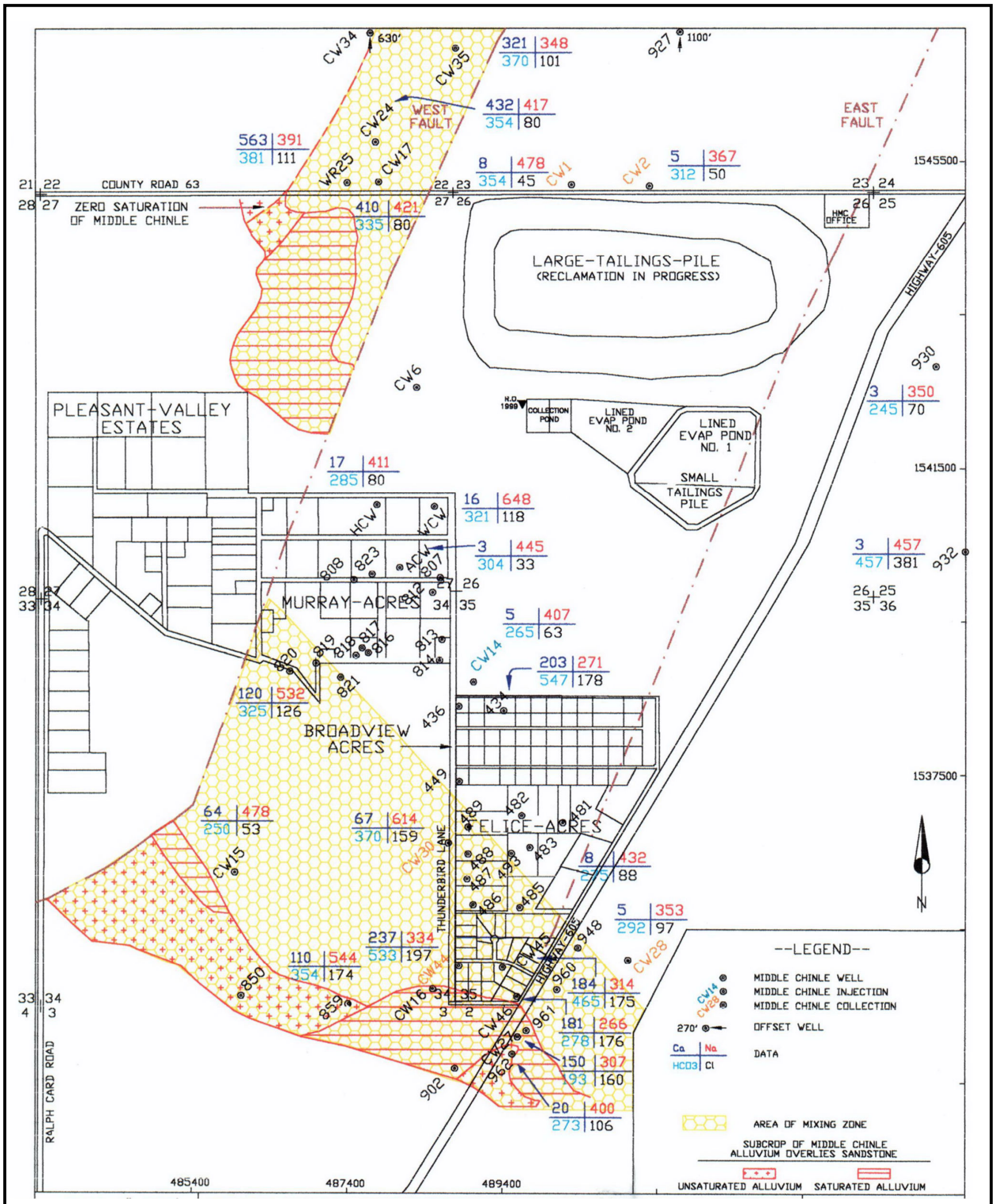
Figure 1.2-50
Stiff Diagram Comparison of Middle Chinle Groundwater Quality in the South Wells



Units are mg/L

Grants Reclamation Project
Corrective Action Program

Figure 1.2-51
Major Ionic Constituent Concentration Comparisons of the Middle Chinle Wells

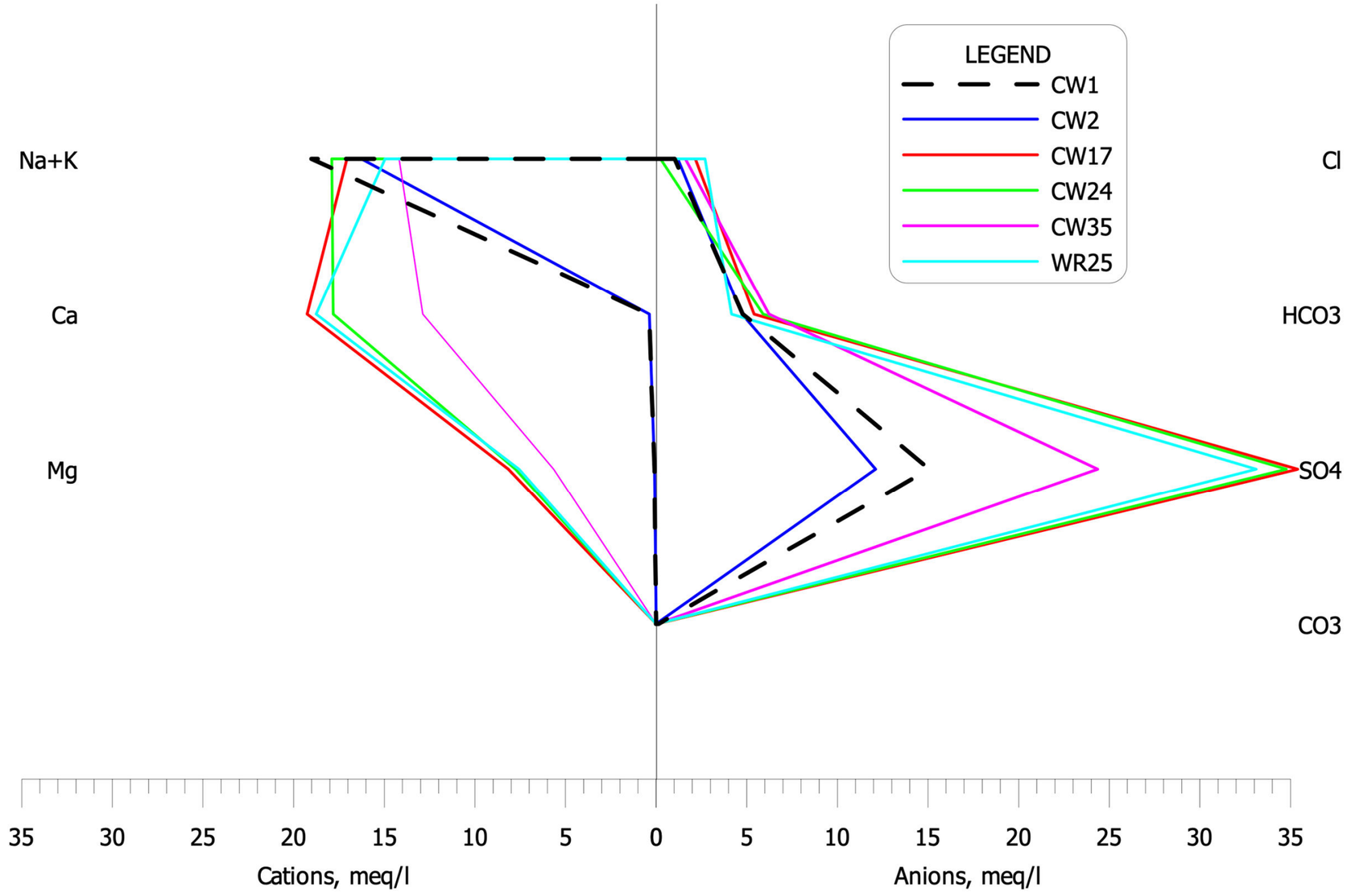


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Figure 1.2-52
Stiff Diagram Comparison of Middle Chinle Groundwater Quality in the North Wells

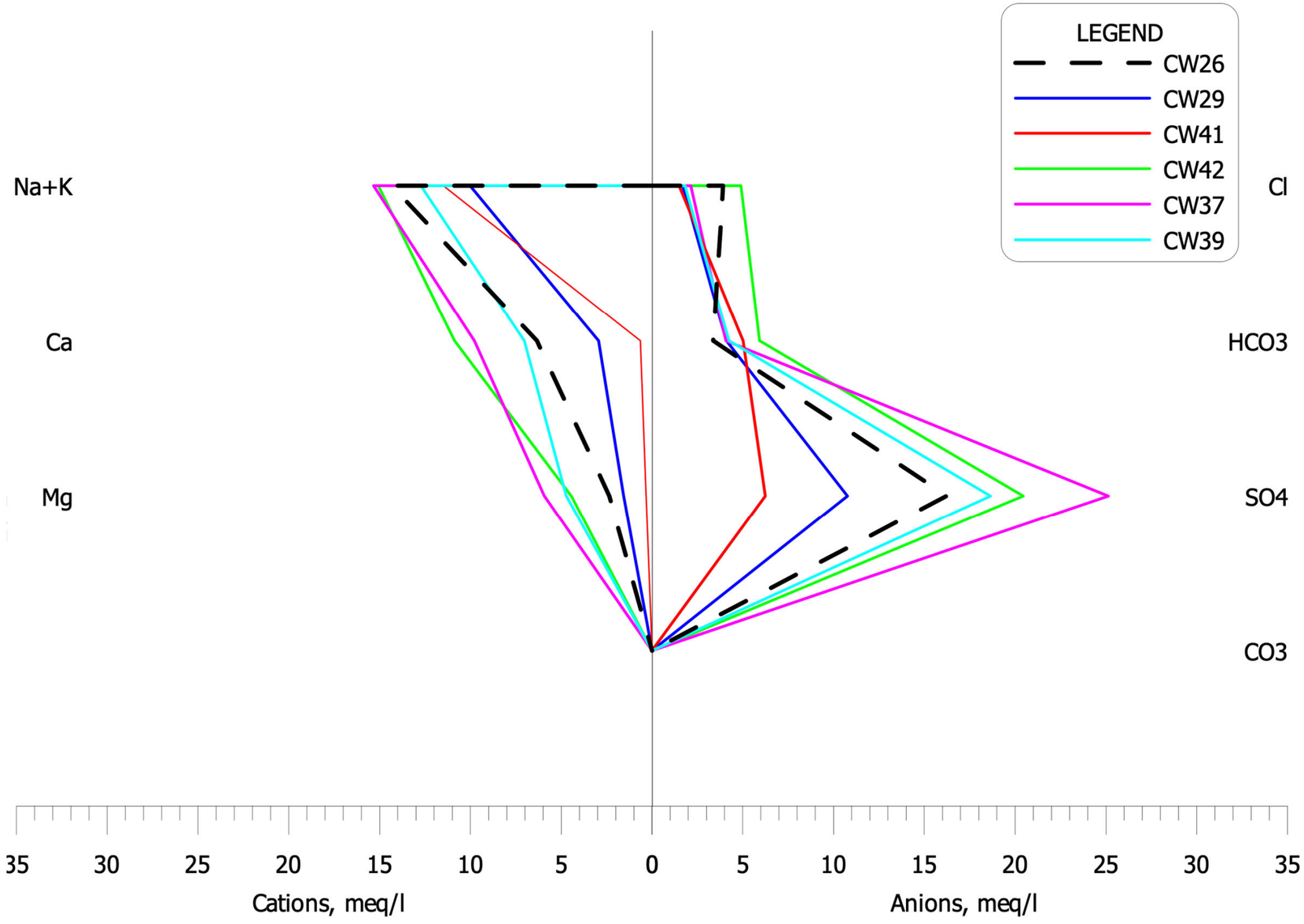

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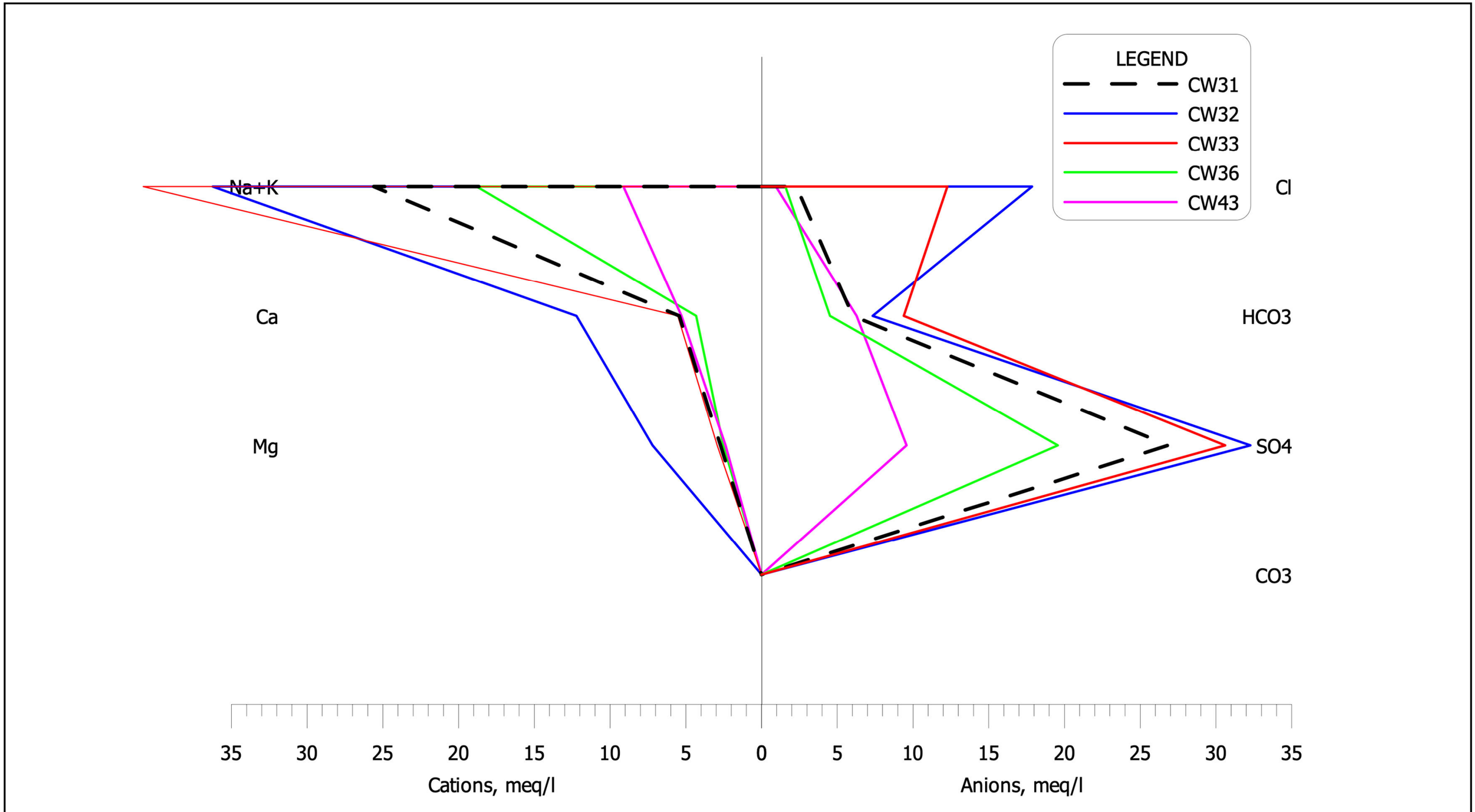
Figure 1.2-53
Stiff Diagram Comparison of Lower Chinle Groundwater Quality in the South Wells



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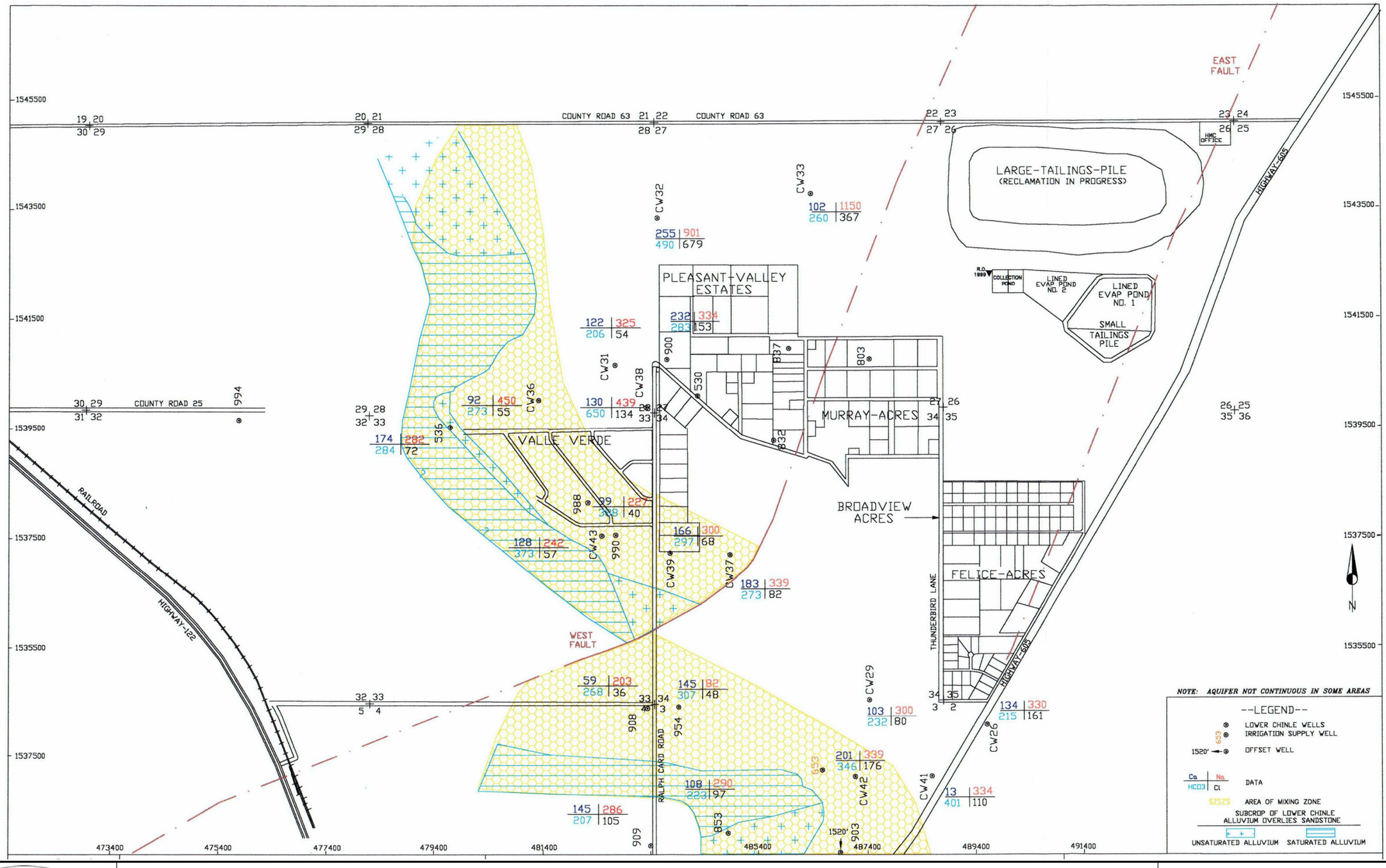
Corrective Action Program

Figure 1.2-54
Stiff Diagram Comparison of Lower Chinle Groundwater Quality in the North Wells



Grants Reclamation Project
Corrective Action Program

Units are mg/L

Figure 1.2-55
Major Ionic Constituent Concentration Comparisons of the Lower Chinle Wells

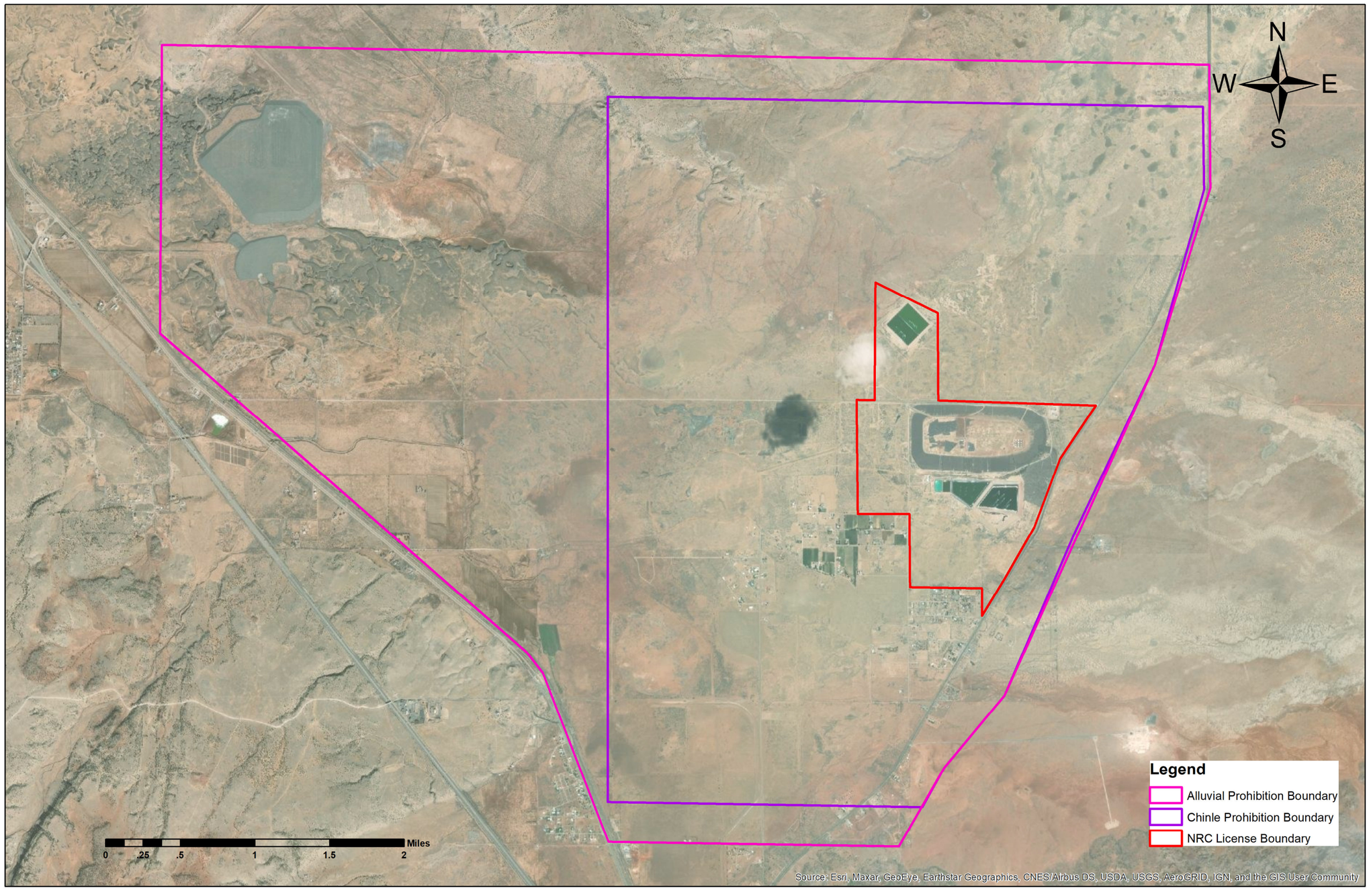


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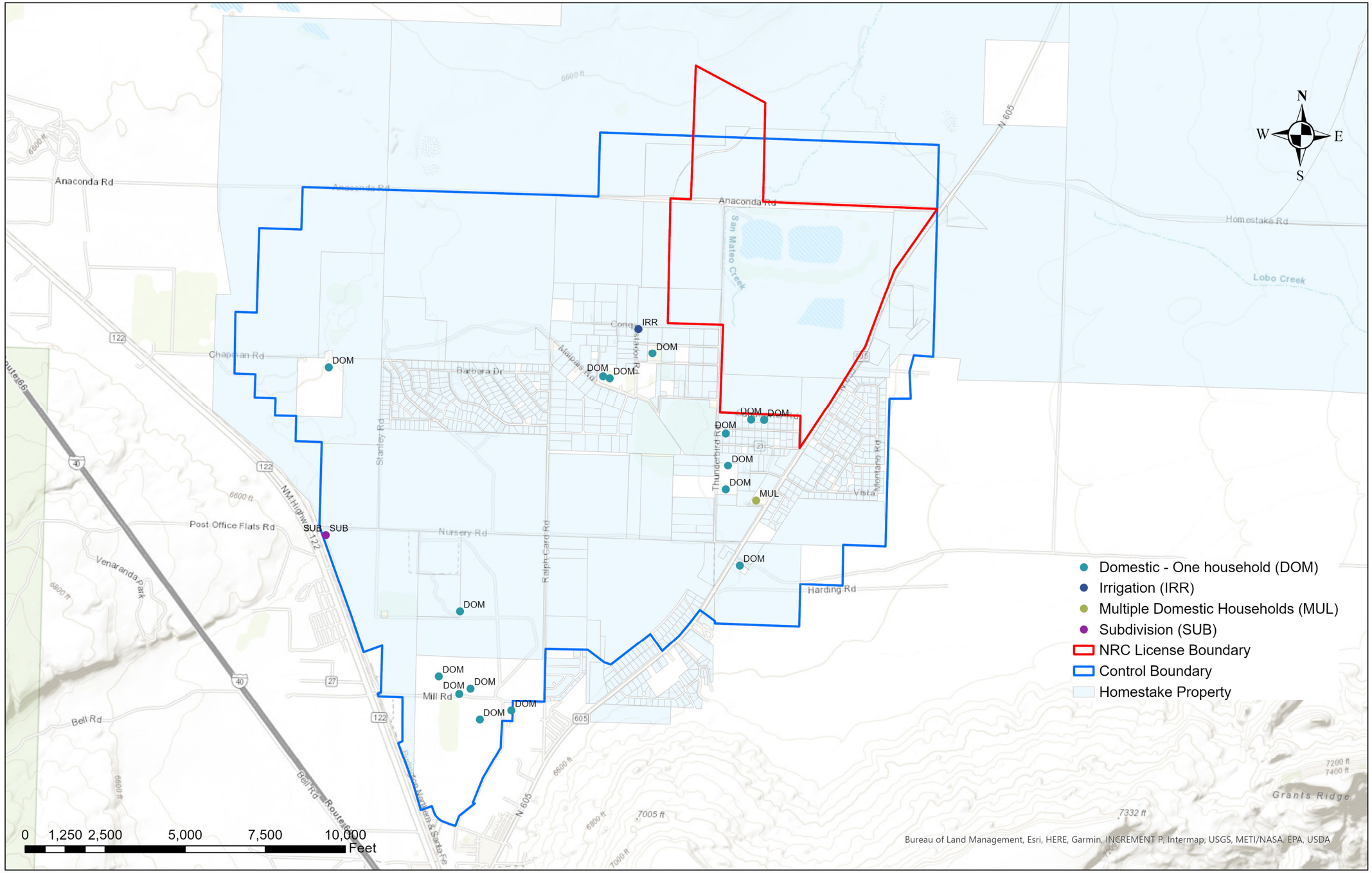
Figure 1.2-56
Groundwater Prohibition Boundaries



Grants Reclamation Project
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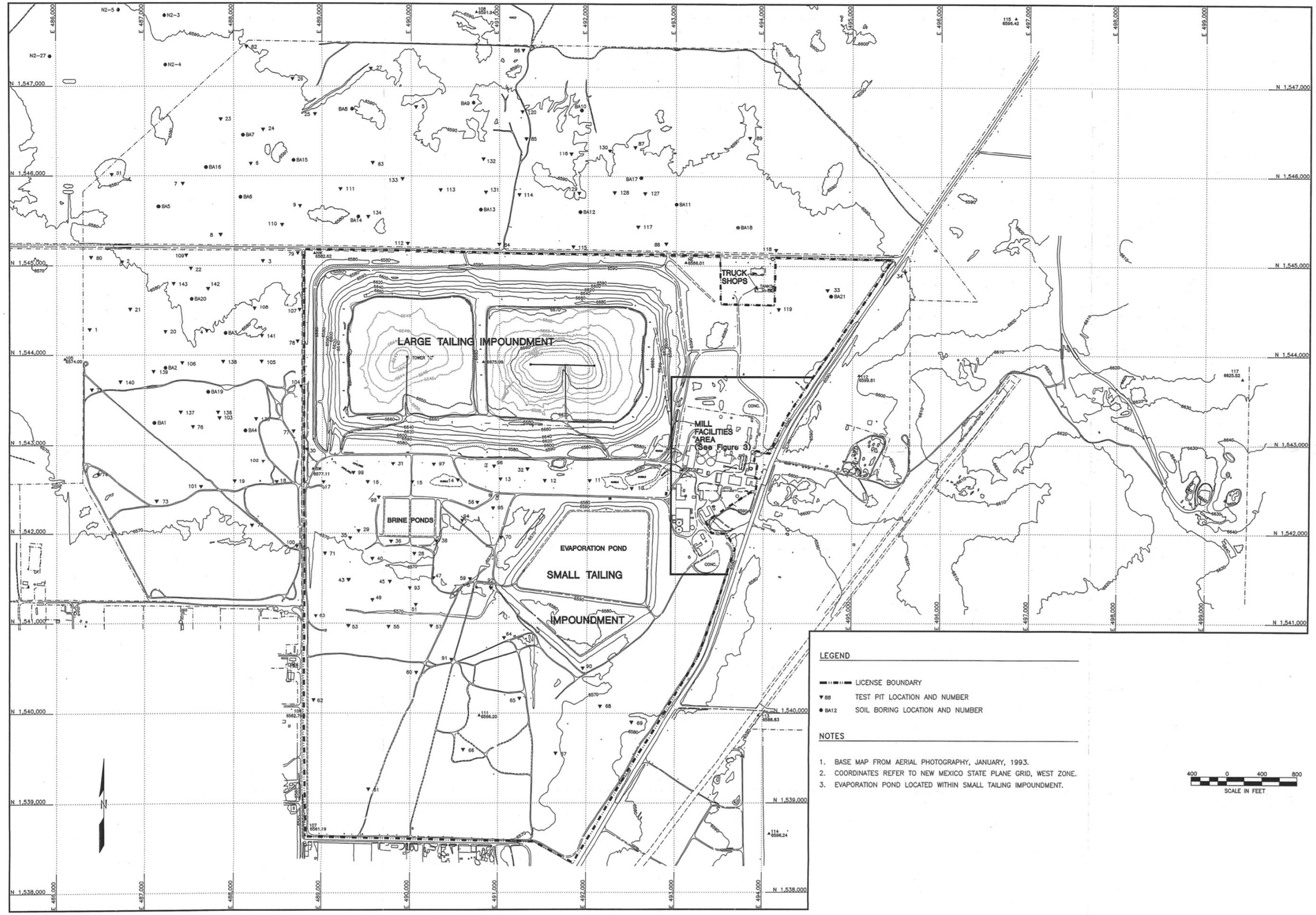
Figure 1.2-57
Private Well Permits Near GRP



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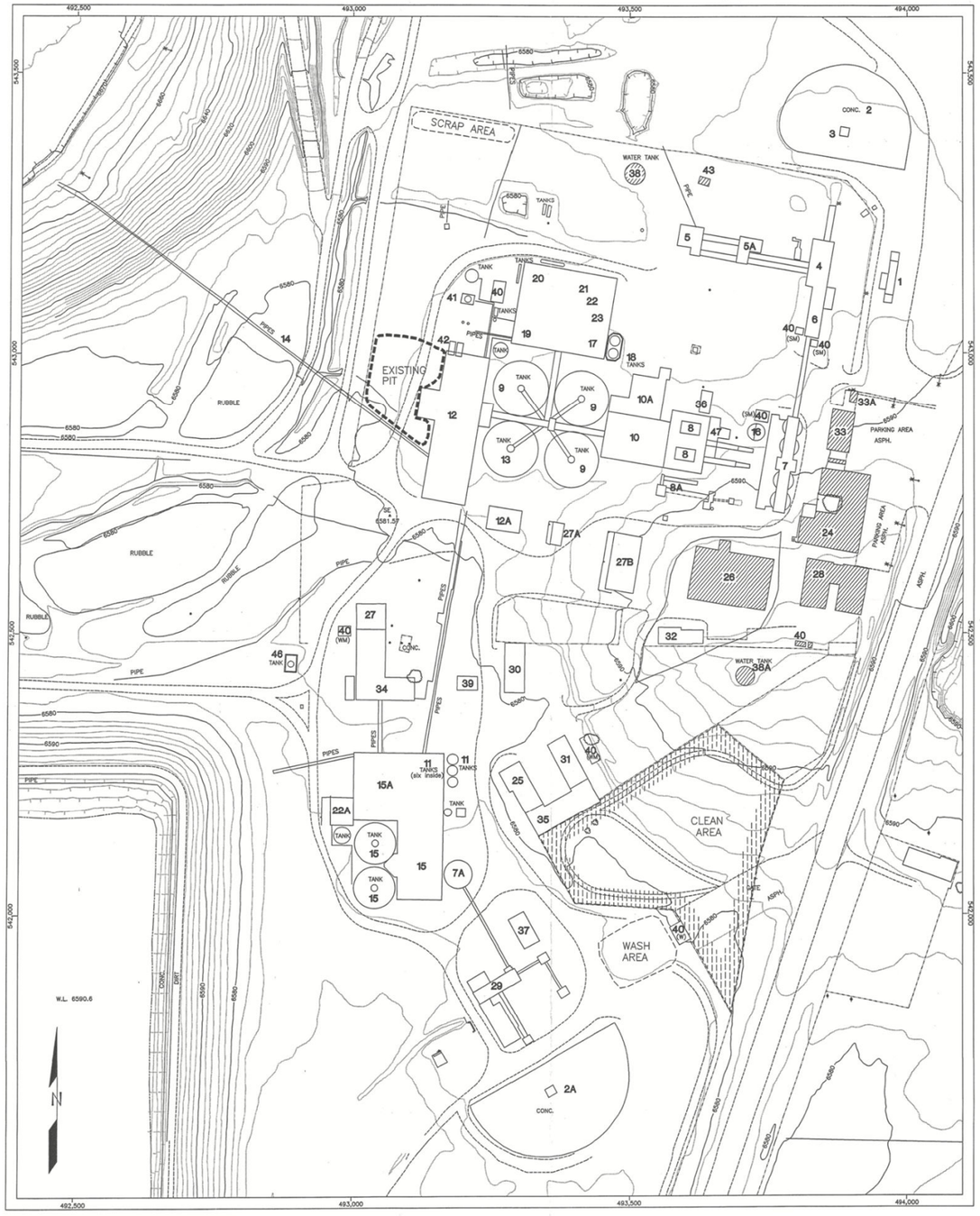
Grants Reclamation Project
Corrective Action Program

Source: AK Geoconsult et al, 1993

Figure 1.2-58
Site Plan Before Reclamation

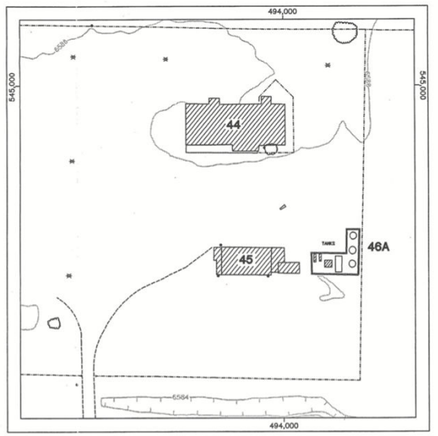


MILL FACILITIES

- **ORE RECEIVING SECTION**
  1. ORE RECEIVING SCALE (WM)
  2. ORE STORAGE PAD (C)
  2A. ORE STORAGE PAD (C)
- **CRUSHING AND SAMPLING SECTION**
  3. GRIZZLY (S)
  4. CRUSHER (SM)
  5. ROTARY DRYER (SM)
  5A. BELT TRANSFER BUILDING (SM)
  6. RECIPROCATING SAMPLERS (SM)
- **FINE ORE STORAGE SECTION**
  7. FINE ORE BINS (RC)
  7A. FINE ORE BIN (CS)
- **GRINDING SECTION**
  8. BALL MILLS (SM)
  8A. ROASTER (S)
  9. THICKENER TANKS (WS)
- **URANIUM LEACHING SECTION**
  10. PRESSURE LEACHING AUTOCLAVES (SM)
  10A. MIXING TANKS (SM)
  11. ATMOSPHERIC LEACHING PACHUCA TANKS
  12. FILTERS (SFM)
  12A. VACUUM PUMPS (SM)
  13. SOLUTION STORAGE TANK (WS)
  14. TAILINGS SLURRY PIPELINE (S)
  15. TAILINGS POND ION EXCHANGE (SM, CWS)
  15A. ION EXCHANGE PRECIPITATION UNIT (SM)
- **PRECIPITATION SECTION**
  16. PREGNANT SOLUTION TANK (CWS)
  17. PRECIPITATION TANKS (CS)
  18. PRECIPITATION TANKS (CS)
  19. PRECIPITATE THICKENER TANKS (S)
- **VANADIUM REMOVAL SECTION**
  20. ROASTING FURNACE (S)
- **PACKING–STORAGE AND SHIPPING SECTION (SM)**
  21. YELLOWCAKE DRYING FURNACE (S)
  22. YELLOWCAKE PACKAGING (SM)
  22A. YELLOWCAKE PACKAGING (SM)
  23. YELLOWCAKE DRUM STORAGE AND LOADOUT
- **MISCELLANEOUS STRUCTURES**
  24. ADMINISTRATIVE BUILDING (CB)
  25. GARAGE (PCW)
  26. SHOP (SM)
  27. WAREHOUSE (SM)
  27A. OIL STORAGE (SM)
  27B. MAIN WAREHOUSE (SM)
  28. LABORATORY (CB)
  29. SAMPLING PLANT (SM)
  30. ELECTRIC SHOP (PCW)
  31. INSTRUMENT SHOP (PCW)
  32. CARPENTER SHOP (WM)
  33. CHANGE HOUSE (CB)
  33A. GUARD SHACK (SM)
  34. POWER HOUSE (SM)
  35. ENVIRONMENTAL LAB. (PCW)
  36. COMPRESSOR HOUSE (SM)
  37. ELECTRICAL STORAGE (PCW)
  38. WATER TANK (S)
  38A. WATER TANK (S)
  39. TRAINING BUILDING (WM)
  40. STORAGE UNIT (SEE INDIVIDUAL UNITS ON PLAN)
  41. COOLING TOWER (CS)
  42. BOILERS (S)
  43. WELL
  44. TRUCK SHOP (SM)
  45. TRUCK STORAGE (SM)
  46. FUEL TANK (S)
  46A. FUEL TANKS (S)
  47. ELECTRIC VAULT (RC)

0 150 300 Feet

MILL AREA



TRUCK SHOP AREA

LEGEND

- STRUCTURES TO BE LEFT IN PLACE
- FENCE
- CLEAN AREA FOR PRE–RELEASE STORAGE OF SALVAGE

(SM)	STEEL FRAME, METAL SIDING/ROOF
(WM)	WOOD FRAME, METAL SIDING/ROOF
(C)	CONCRETE
(RC)	REINFORCED CONCRETE
(CWS)	CONCRETE PEDESTAL, WOOD BEAMS, STEEL TANK
(WS)	WOOD PILINGS AND BEAMS, STEEL TANK
(CS)	CONCRETE PEDESTAL, STEEL TANK
(S)	ALL STEEL
(SFM)	STEEL FRAME, FIBERGLASS AND METAL SIDING
(PCW)	PRE–CAST CONCRETE WALLS, WOOD FRAME ROOF
(W)	WOOD STRUCTURE
(CB)	CEMENT BLOCK WALLS, WOOD FRAME ROOF

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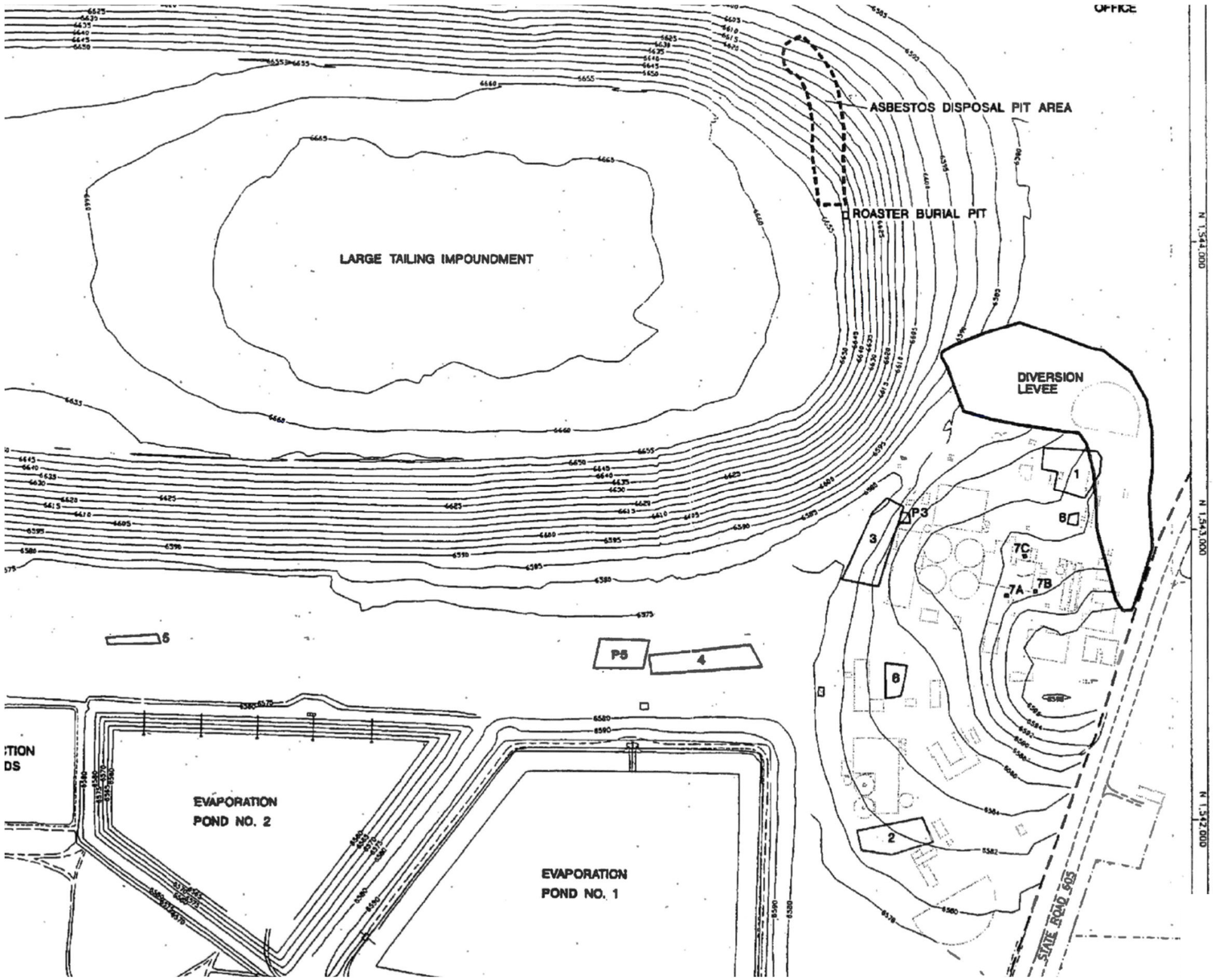
Source: AK Geoconsult and Jenkins, 1993

Figure 1.2-59
Plan of Former Mill Facilities



LEGEND

6590 — ELEVATION IN FEET ABOVE MSL

– – – – BOUNDARY OF LICENSED AREA

8 DEBRIS DISPOSAL PIT

MILL AREA CONTOURS FROM LAND SURVEY OF 12/95

Source: HMC 1996

Source: HMC Reclamation and Decommissioning Documents

N

0 300 600 Feet

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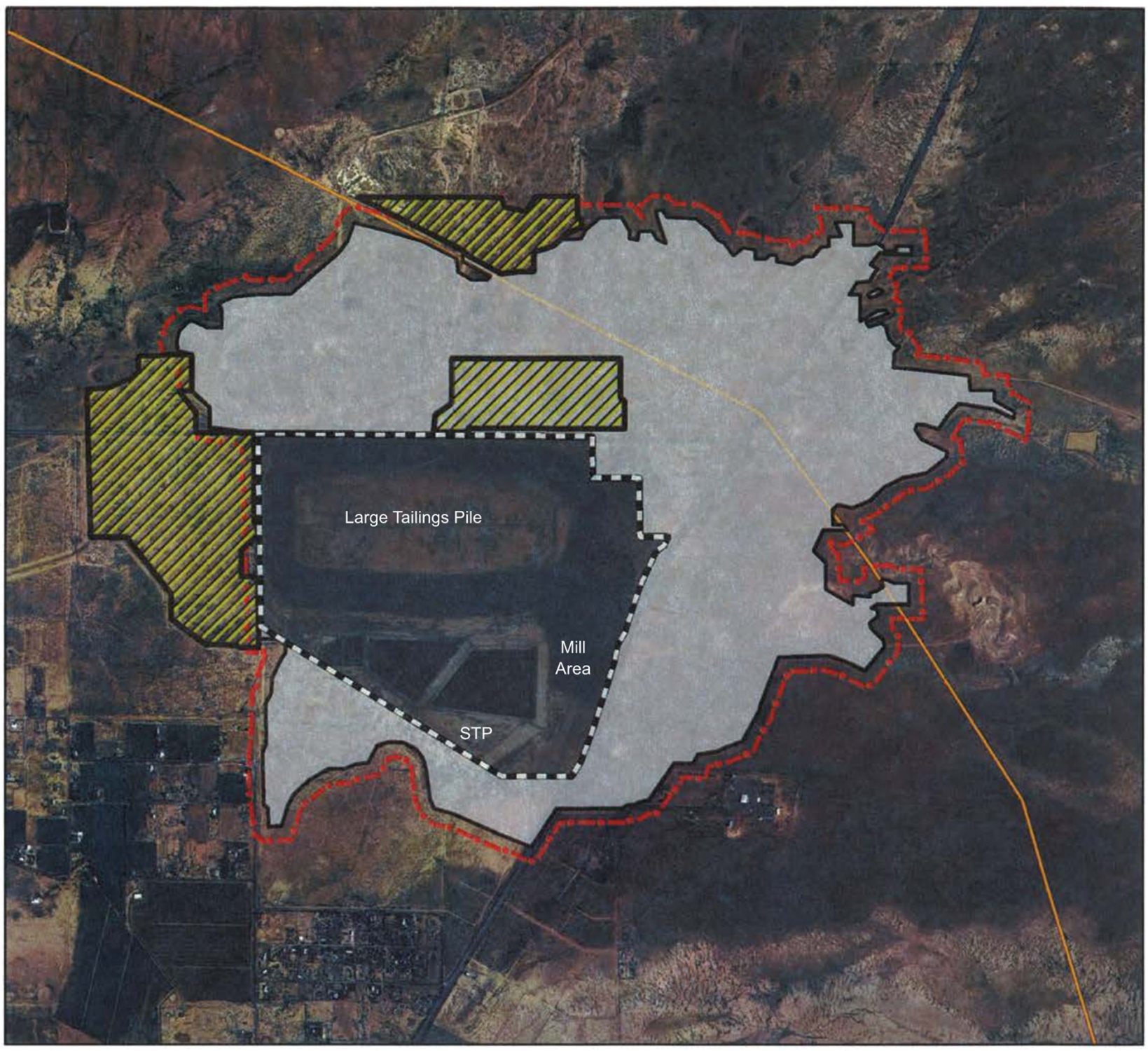
Corrective Action Program

Source: AK Geoconsult and Jenkins, 1993

Figure 1.2-60
1995 Decommissioning As-Built Overview Map



Soil Excavation and Cleanup Verification Zones

- Inner Zone Area
- Outer Zone Area
- Borrow Area Activities
- Scraped Area Boundary Offset
- Transwestern Pipeline

STP = Small Tailings Pile

The Inner and Outer Zones Used for Soil Verification

N

0 2,500 5,000 Feet

Prepared by:
Anderson Engineering Co. , Inc.
10/20/1995 FIG 3-2.DWG

Source: ERG 1995

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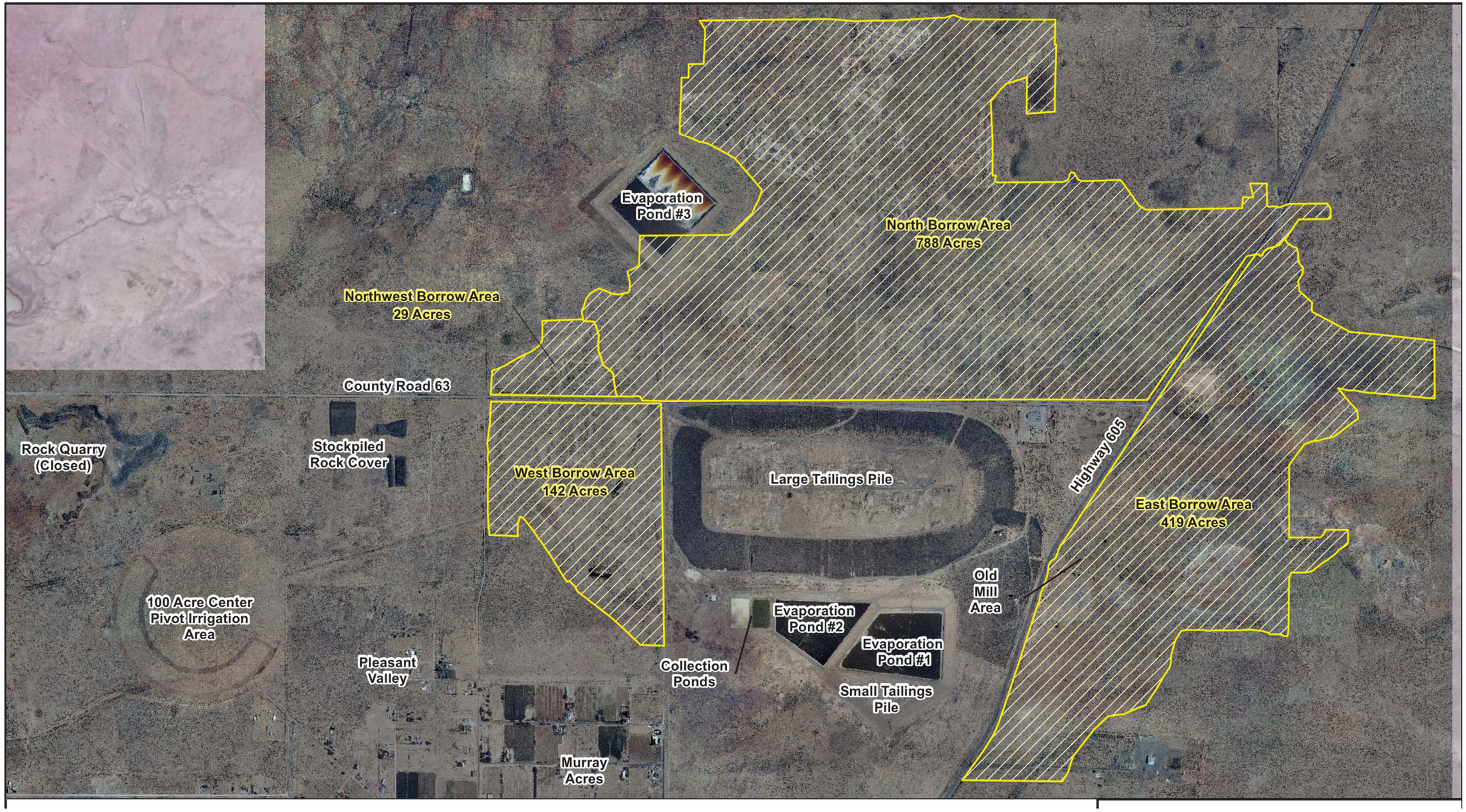
Figure 1.2-61
Soil Excavation and Cleanup
Verification Zones



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LEGEND:

Borrow Areas

Aerial Source:
Bing Maps Hybrid (photo updated in November 2010; serviced by ESRI ArcGIS Online), overlaid with 2011 High Resolution Aerials from HMC.

N

0 650 1,300 Feet

Figure 1.2-62
Primary Borrow Areas

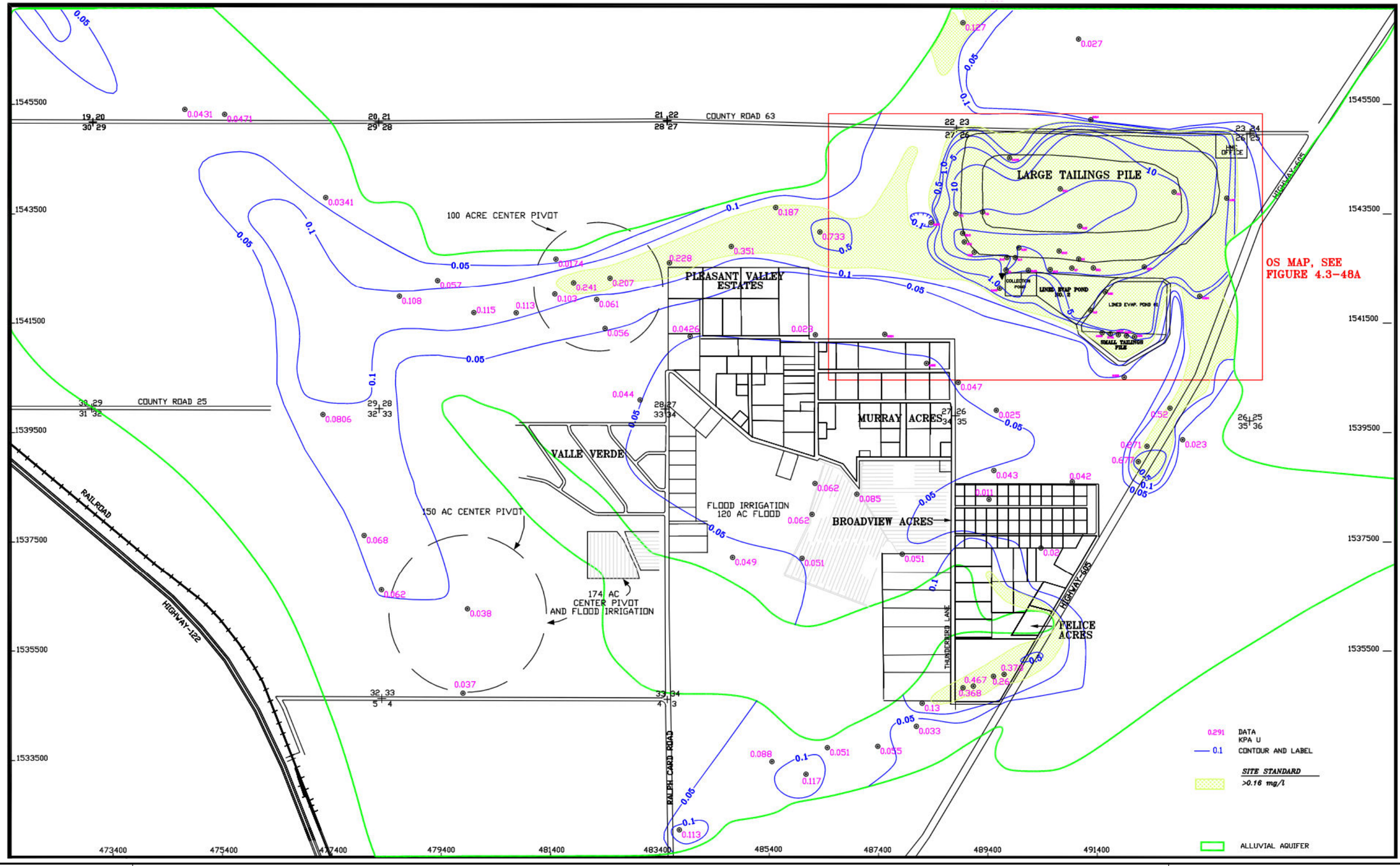

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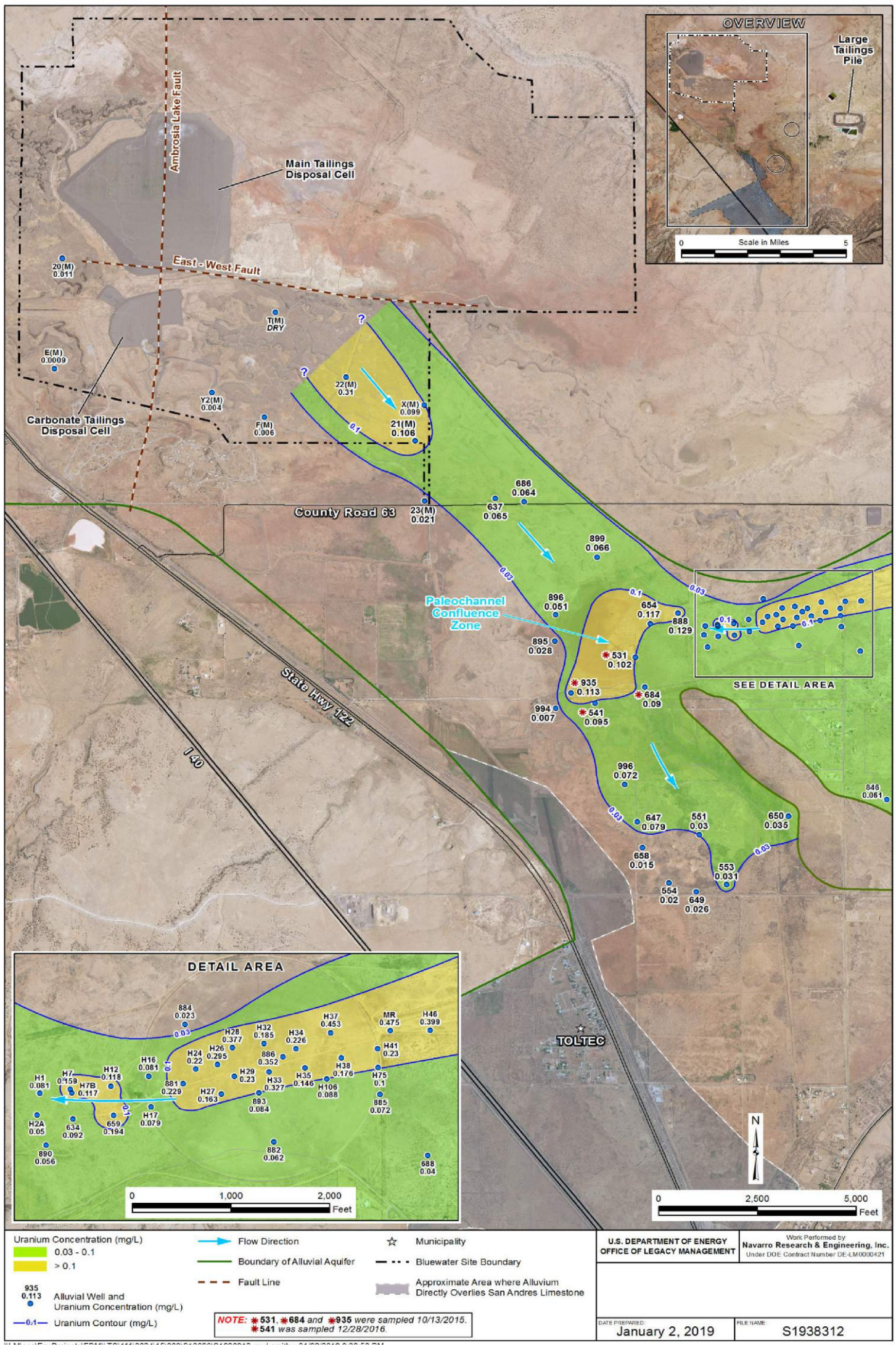
Figure 1.3-1
Alluvial Groundwater
Uranium Concentrations, 2024



Source: DOE, 2019

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Figure 1.3-2
Rio San Jose Groundwater
Uranium Concentrations

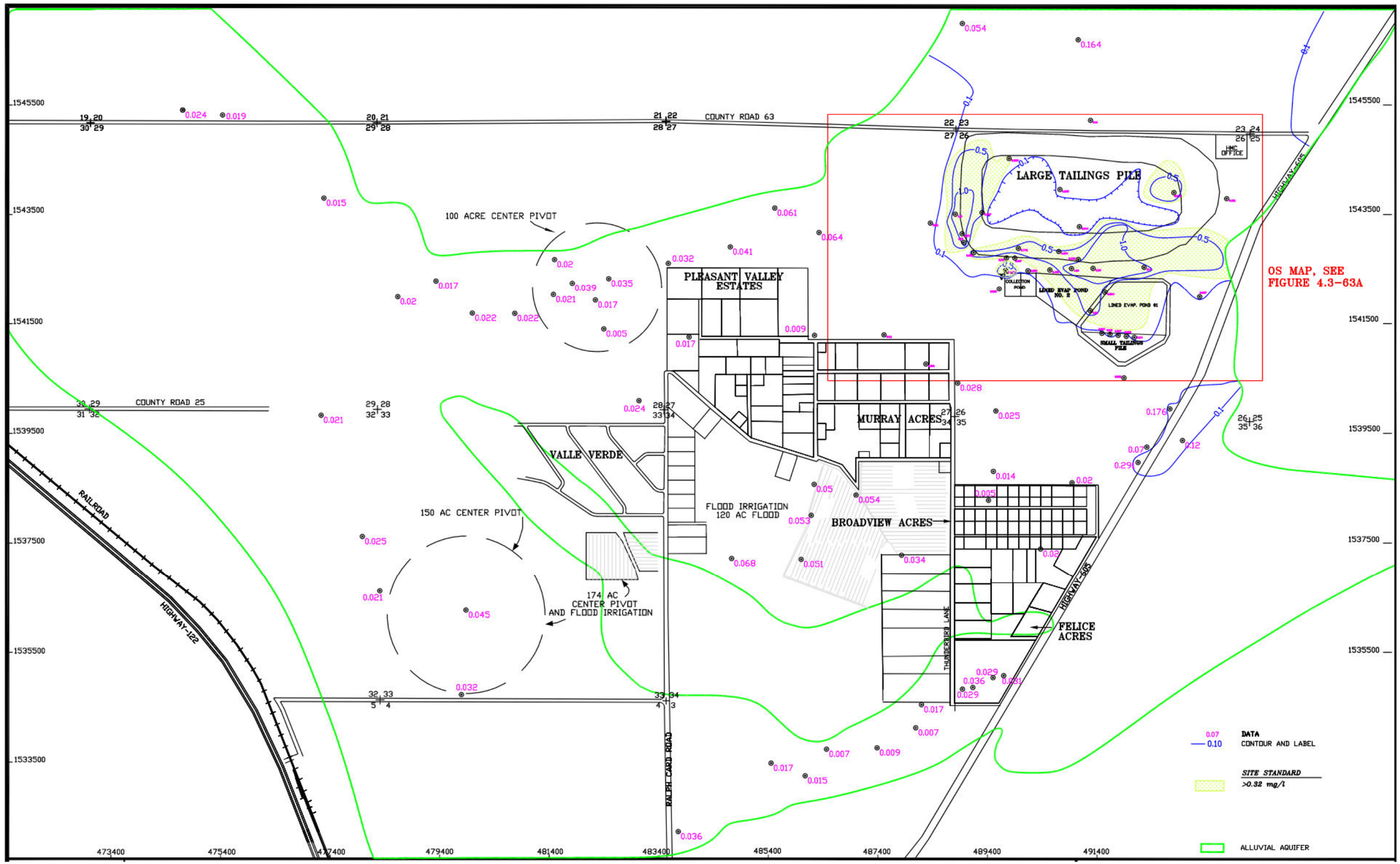

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Figure 1.3-3
Alluvial Groundwater
Selenium Concentrations, 2024

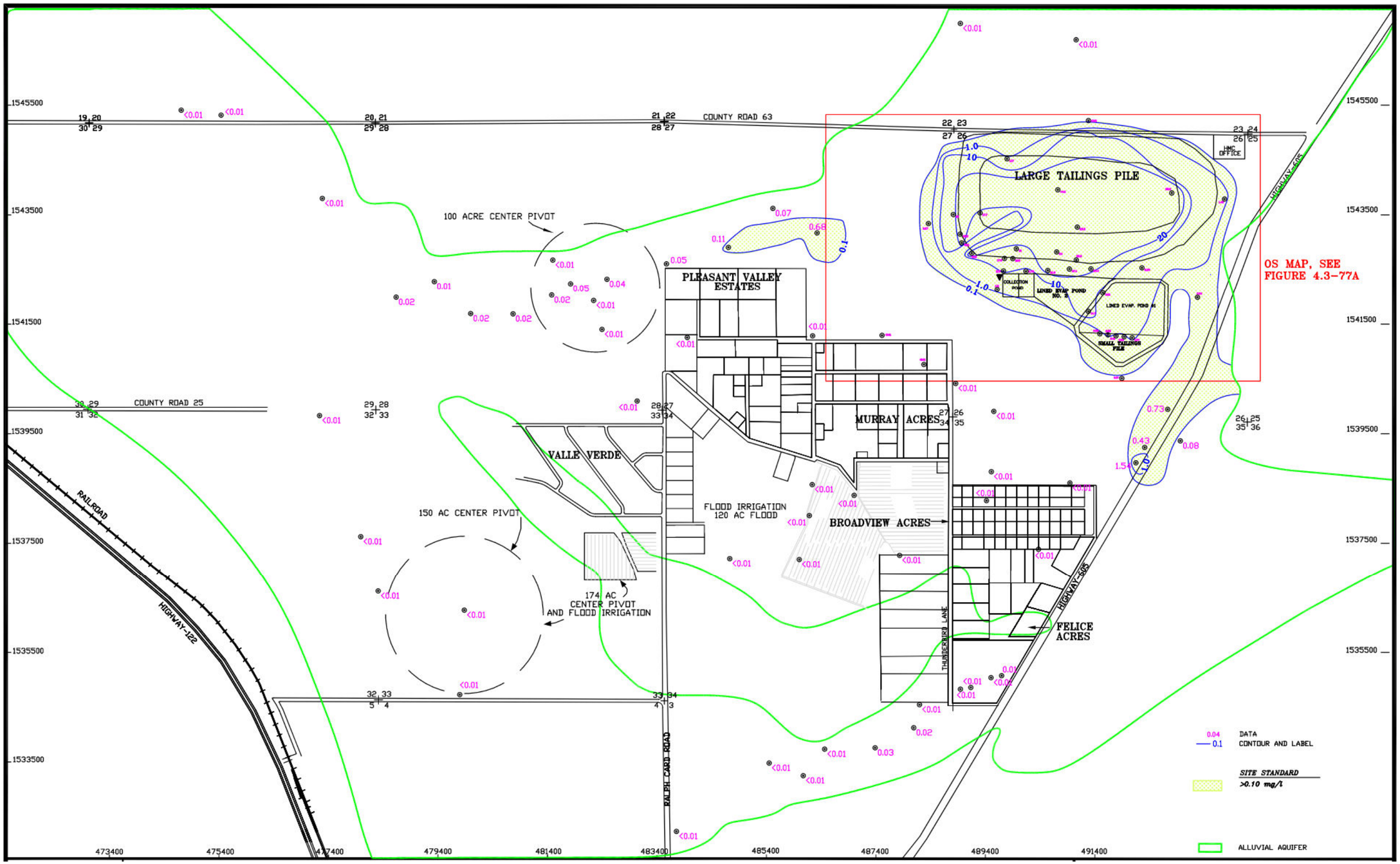

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Figure 1.3-4
Alluvial Groundwater
Molybdenum Concentrations, 2024

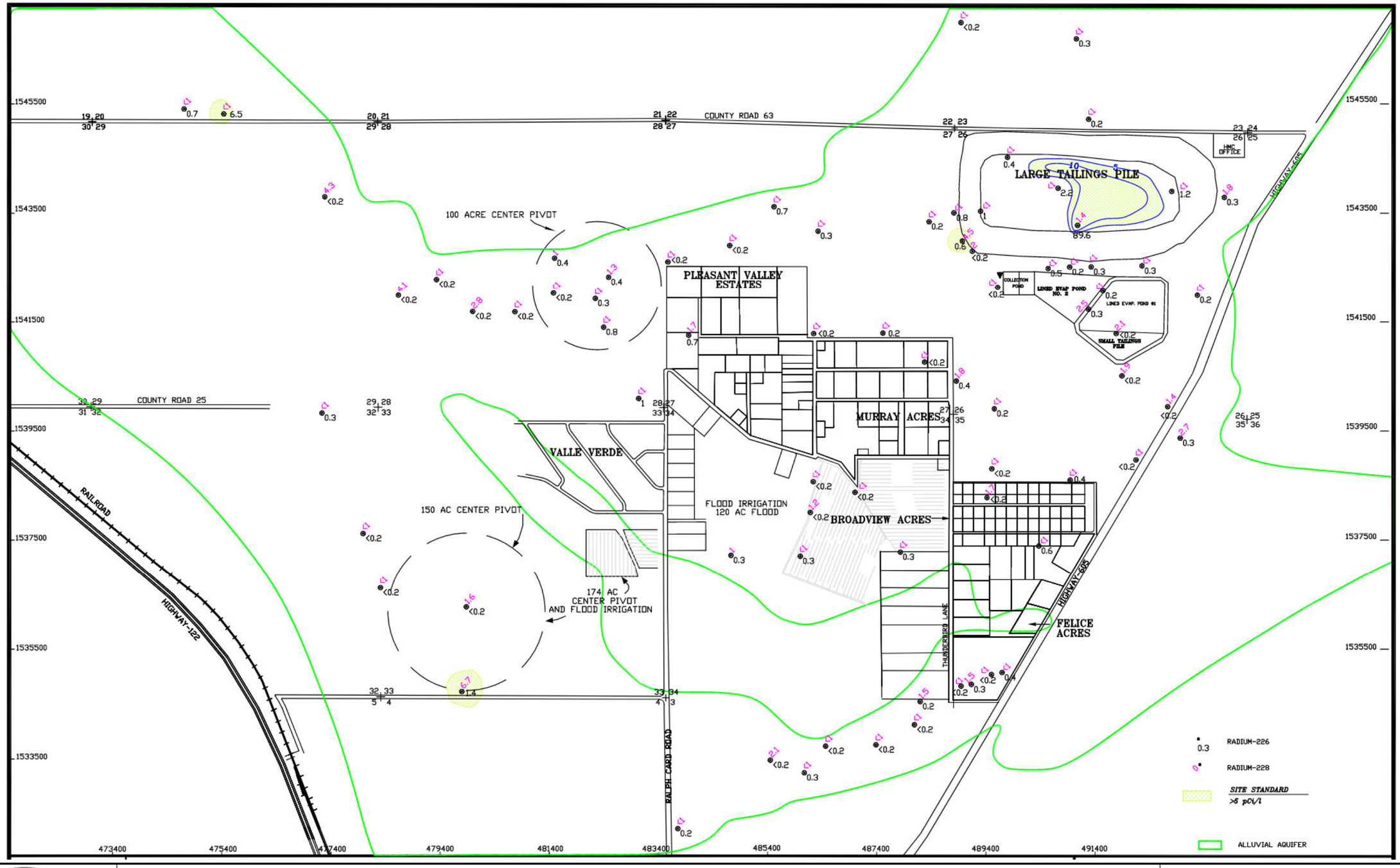

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Figure 1.3-5
Alluvial Groundwater
Radium-226+228 Concentrations, 2024

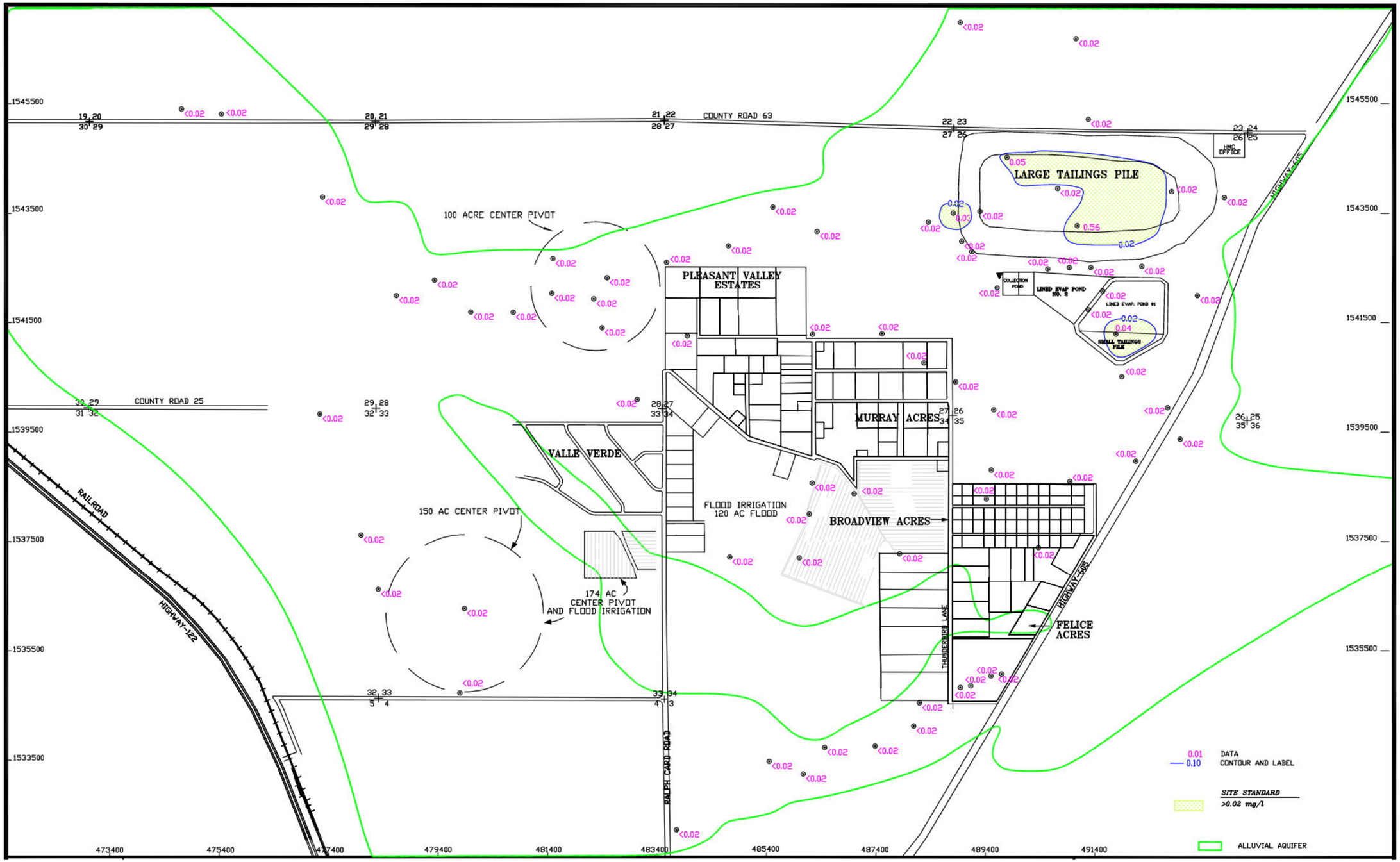

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Figure 1.3-6
Alluvial Groundwater
Vanadium Concentrations, 2024

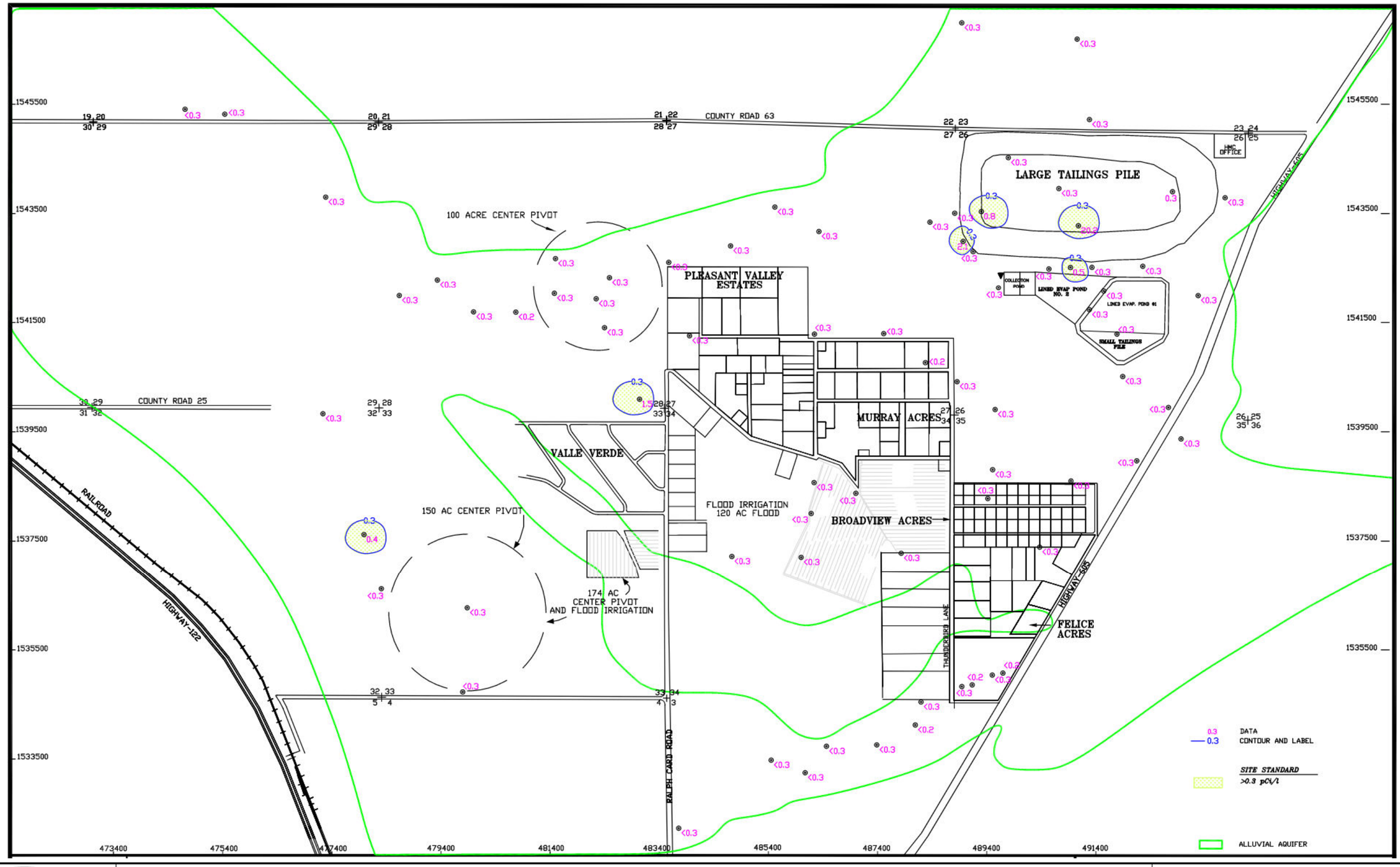

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Figure 1.3-7
Alluvial Groundwater
Thorium-230 Concentrations, 2024

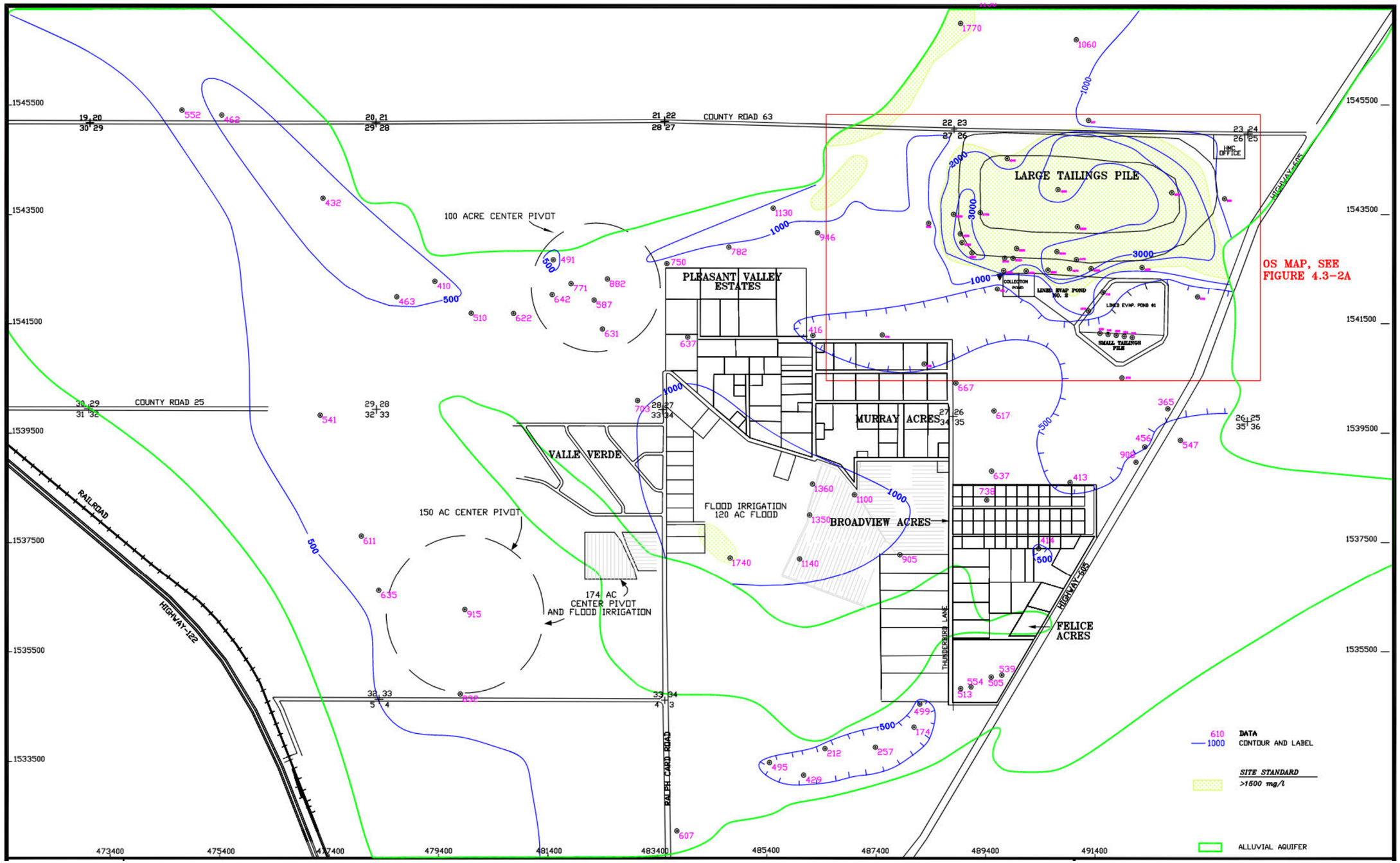

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Figure 1.3-8
Alluvial Groundwater
Sulfate Concentrations, 2024

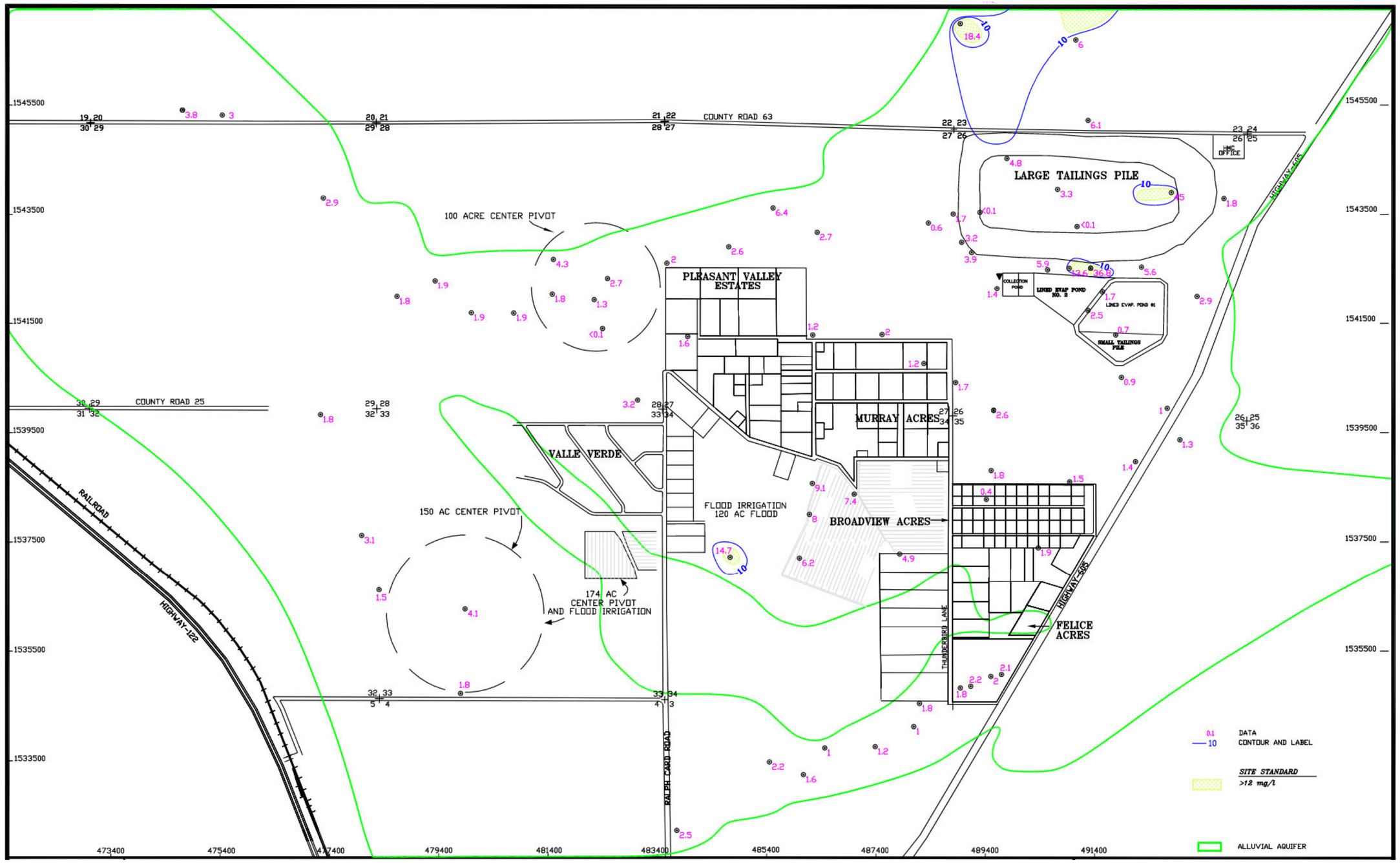

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Figure 1.3-9
Alluvial Groundwater
Nitrate Concentrations, 2024

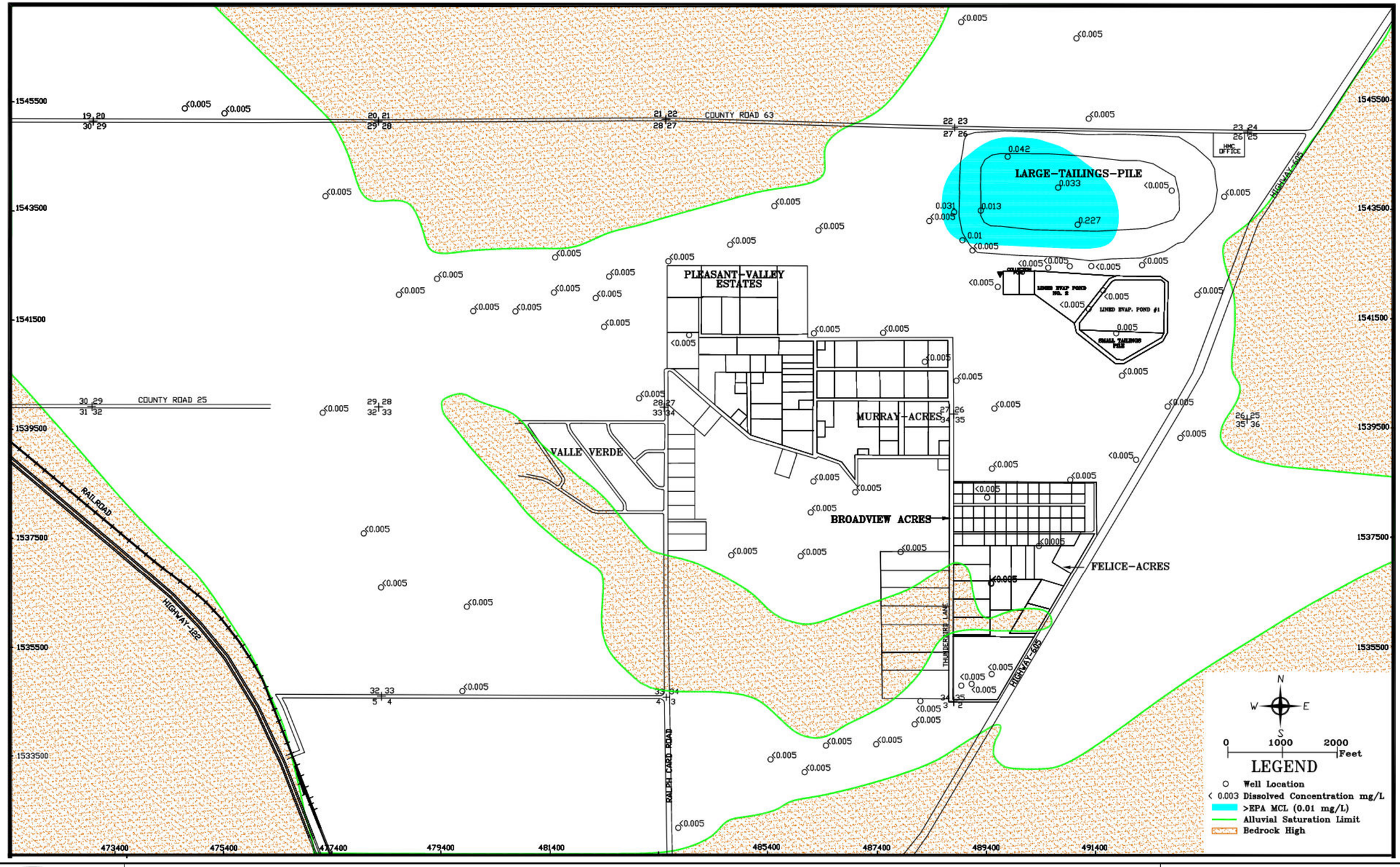

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Figure 1.3-10
Current Extent of Arsenic in Alluvial Groundwater

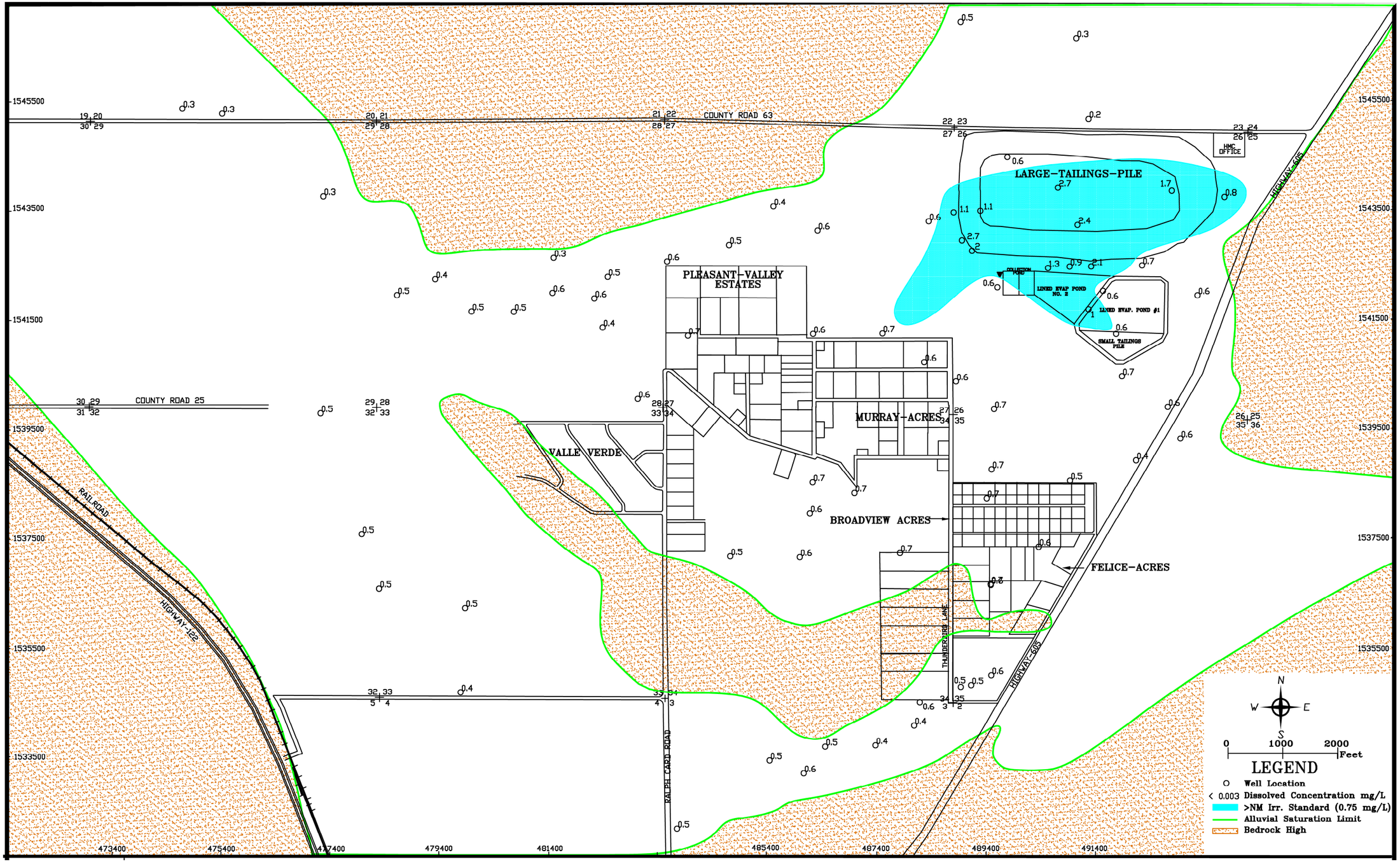

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Figure 1.3-11
Current Extent of Boron in Alluvial Groundwater

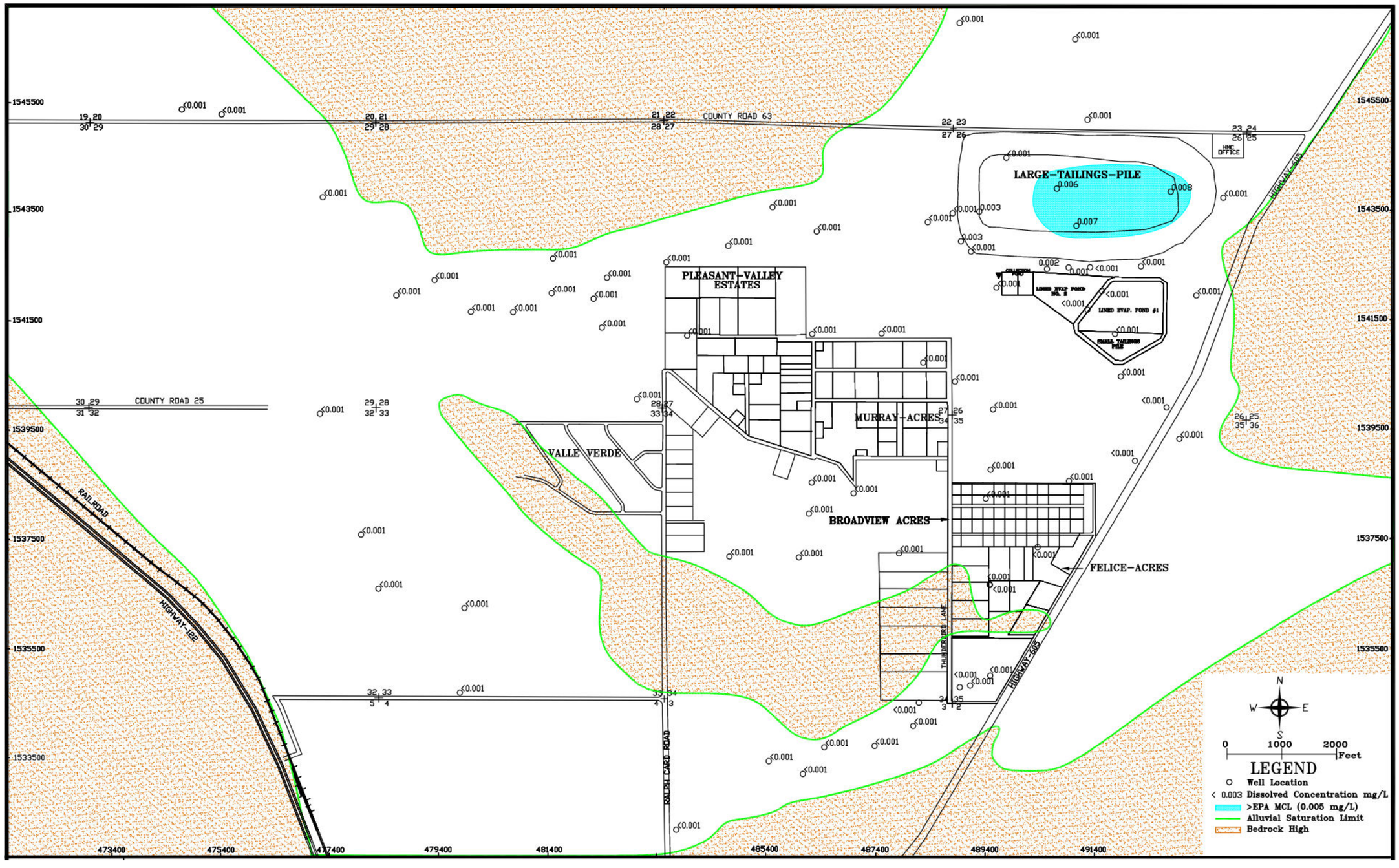

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Figure 1.3-12
Current Extent of Cadmium in Alluvial Groundwater

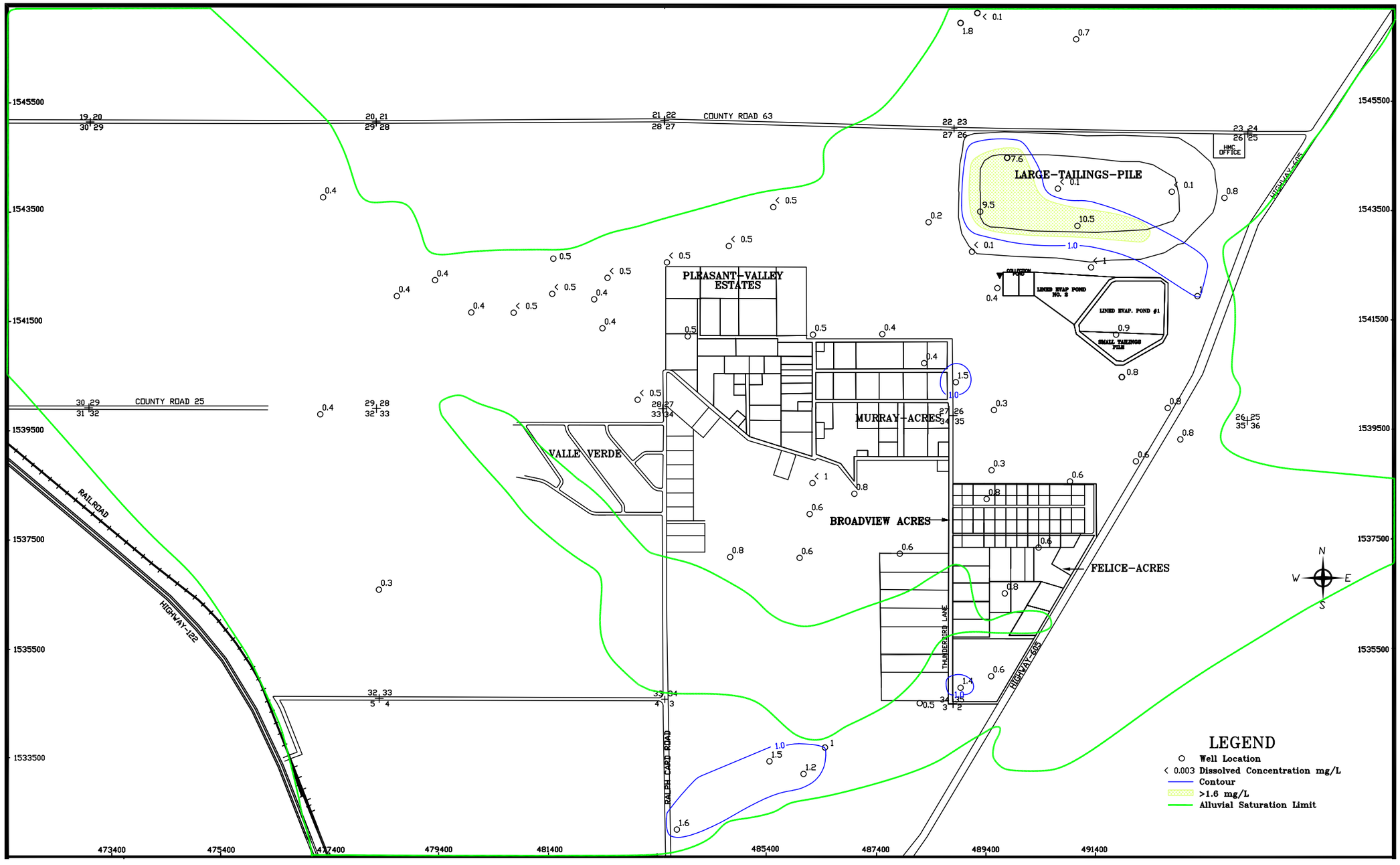

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Figure 1.3-13
Current Extent of Fluoride in Alluvial Groundwater

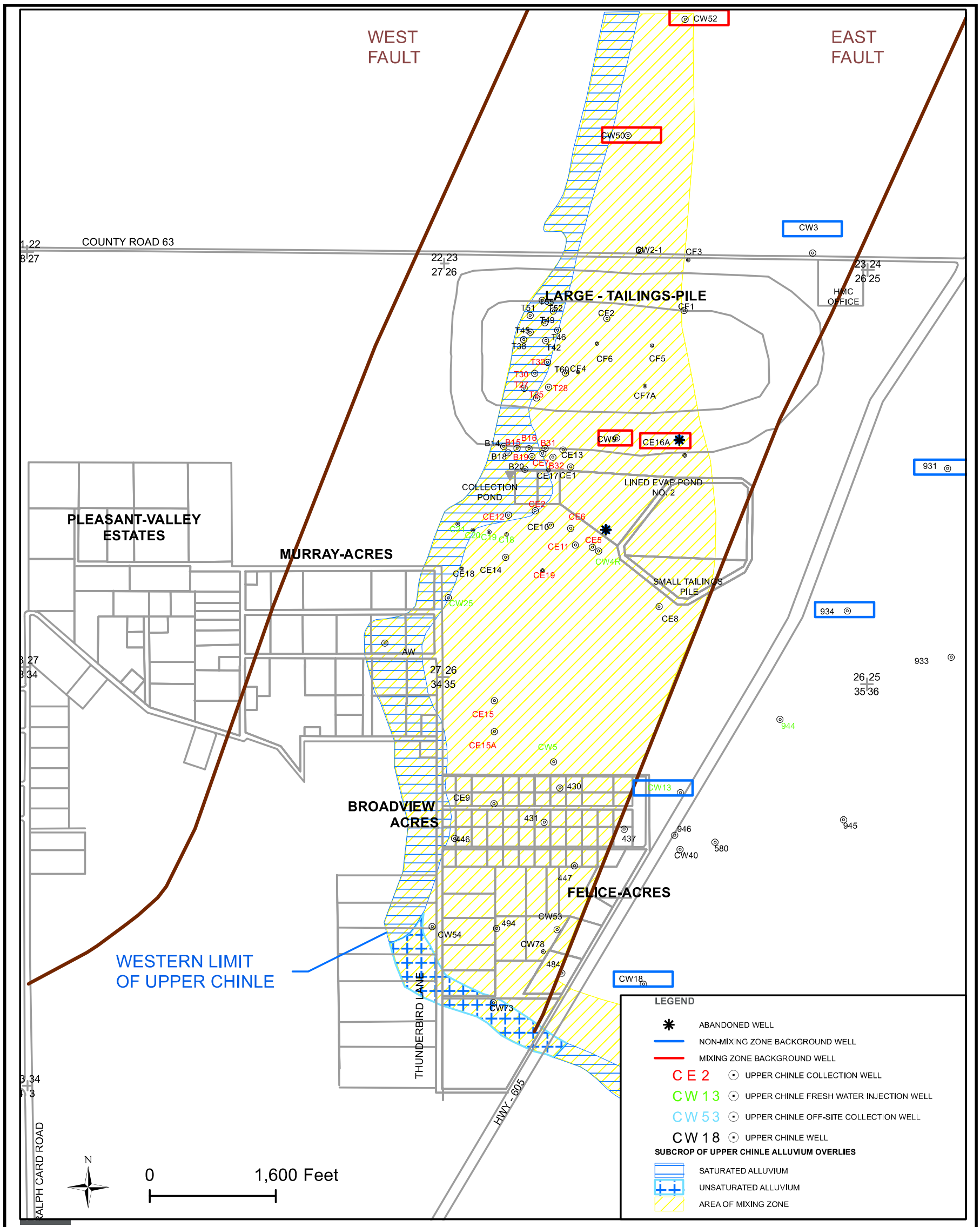

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Figure 1.3-14
Upper Chinle Mixing Zone

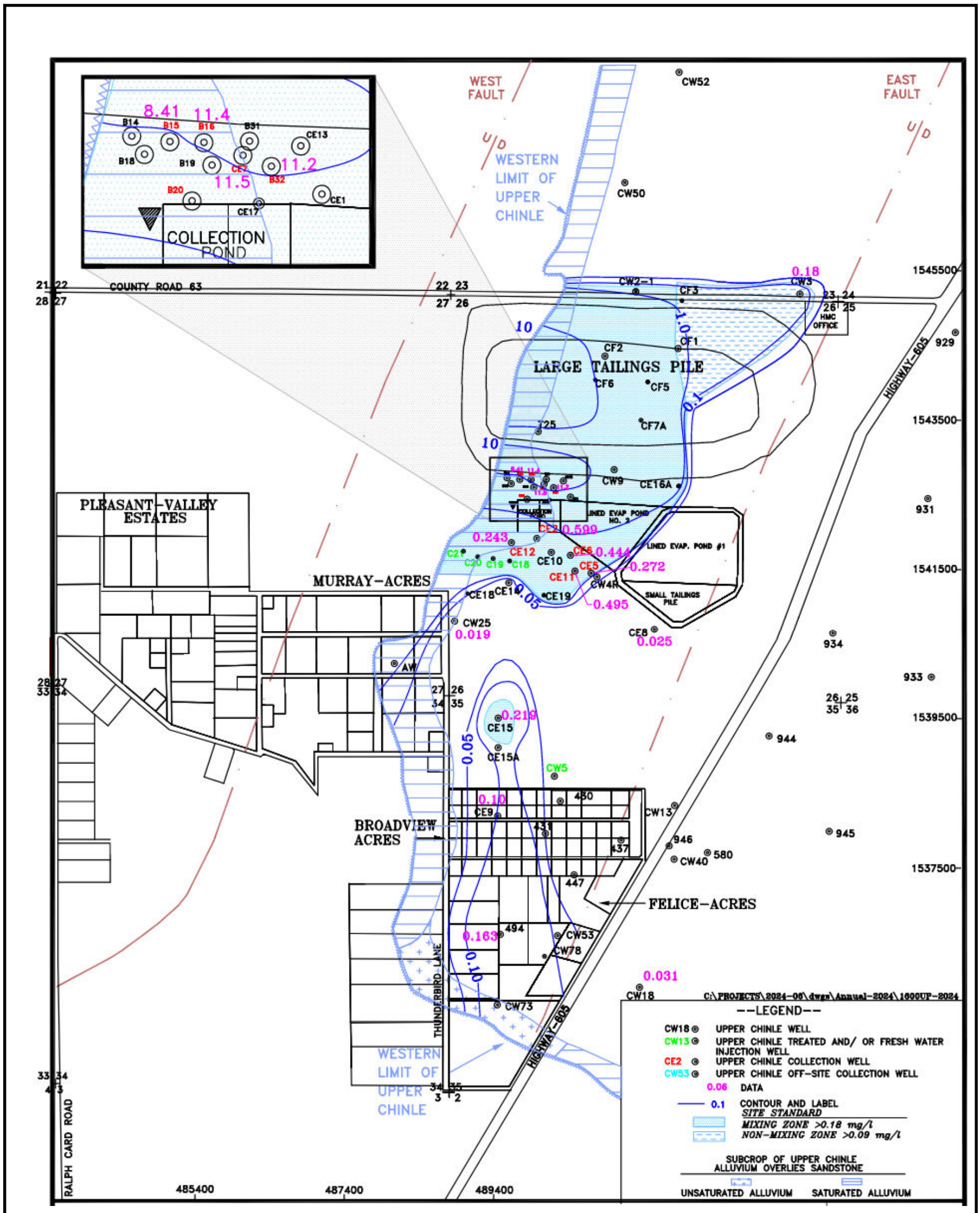

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Figure 1.3-15
Upper Chinle Groundwater
Uranium Concentrations, 2024

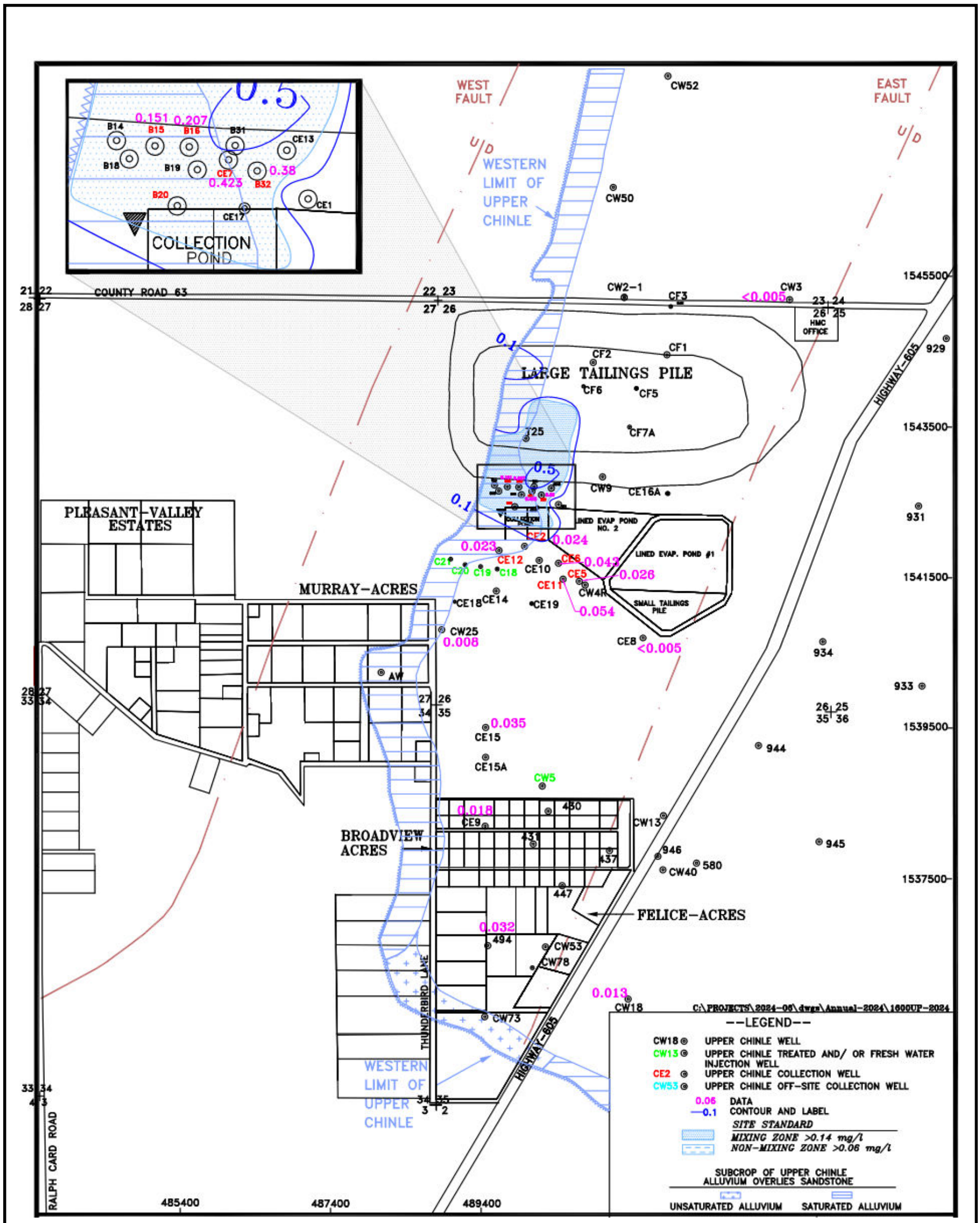

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Figure 1.3-16
Upper Chinle Groundwater
Selenium Concentrations, 2024

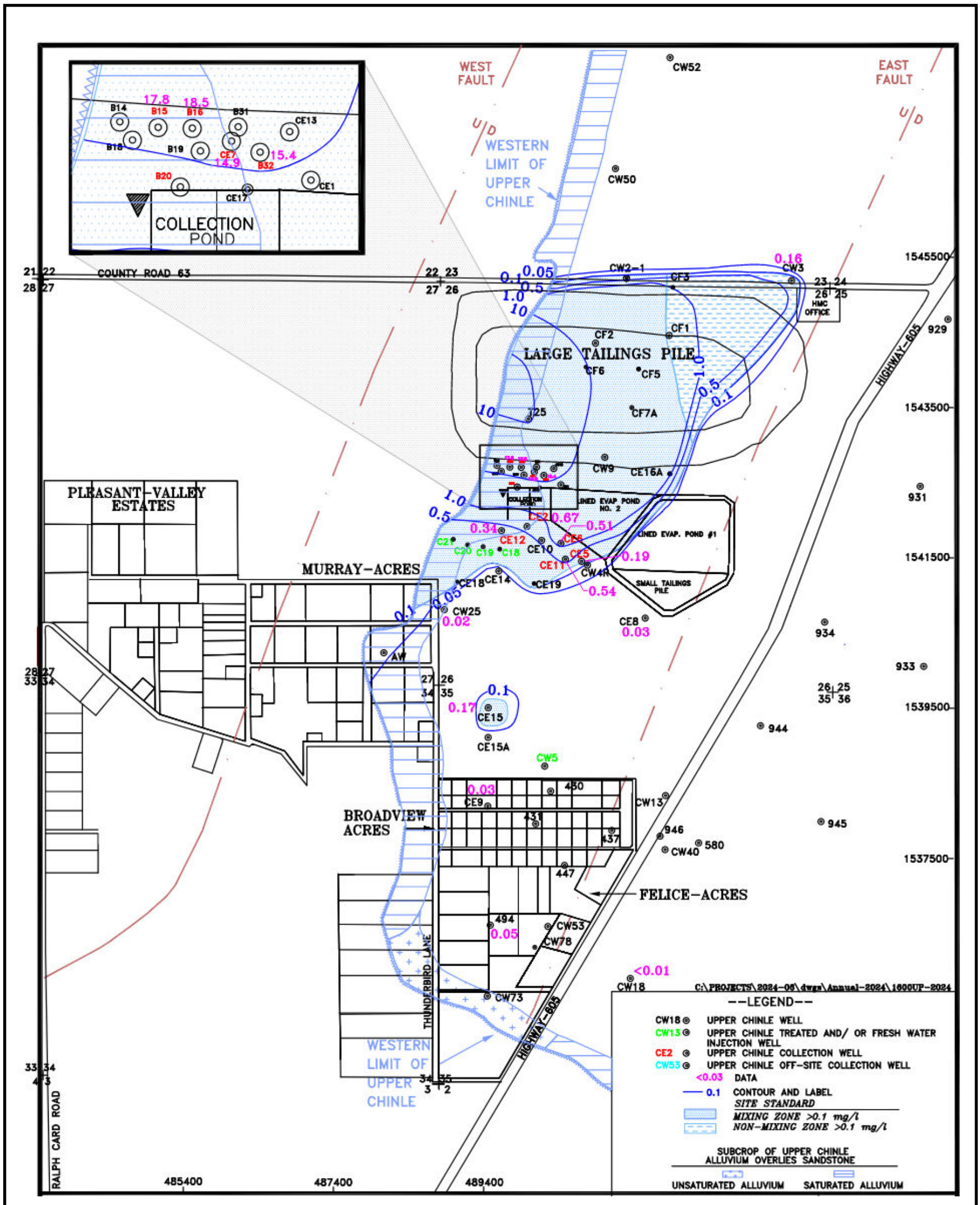

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Figure 1.3-17
Upper Chinle Groundwater
Molybdenum Concentrations, 2024

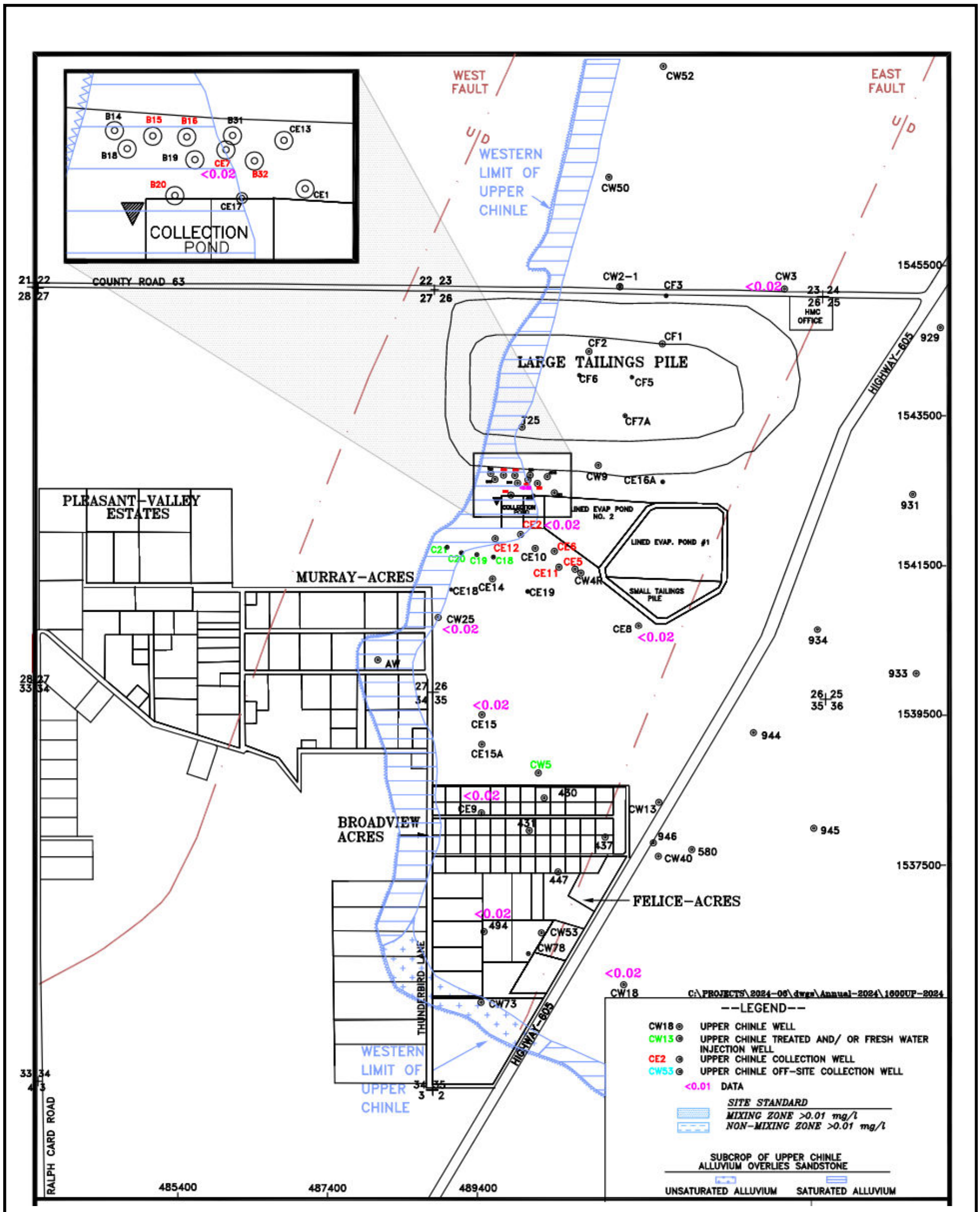

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Figure 1.3-18
Upper Chinle Groundwater
Vanadium Concentrations, 2024

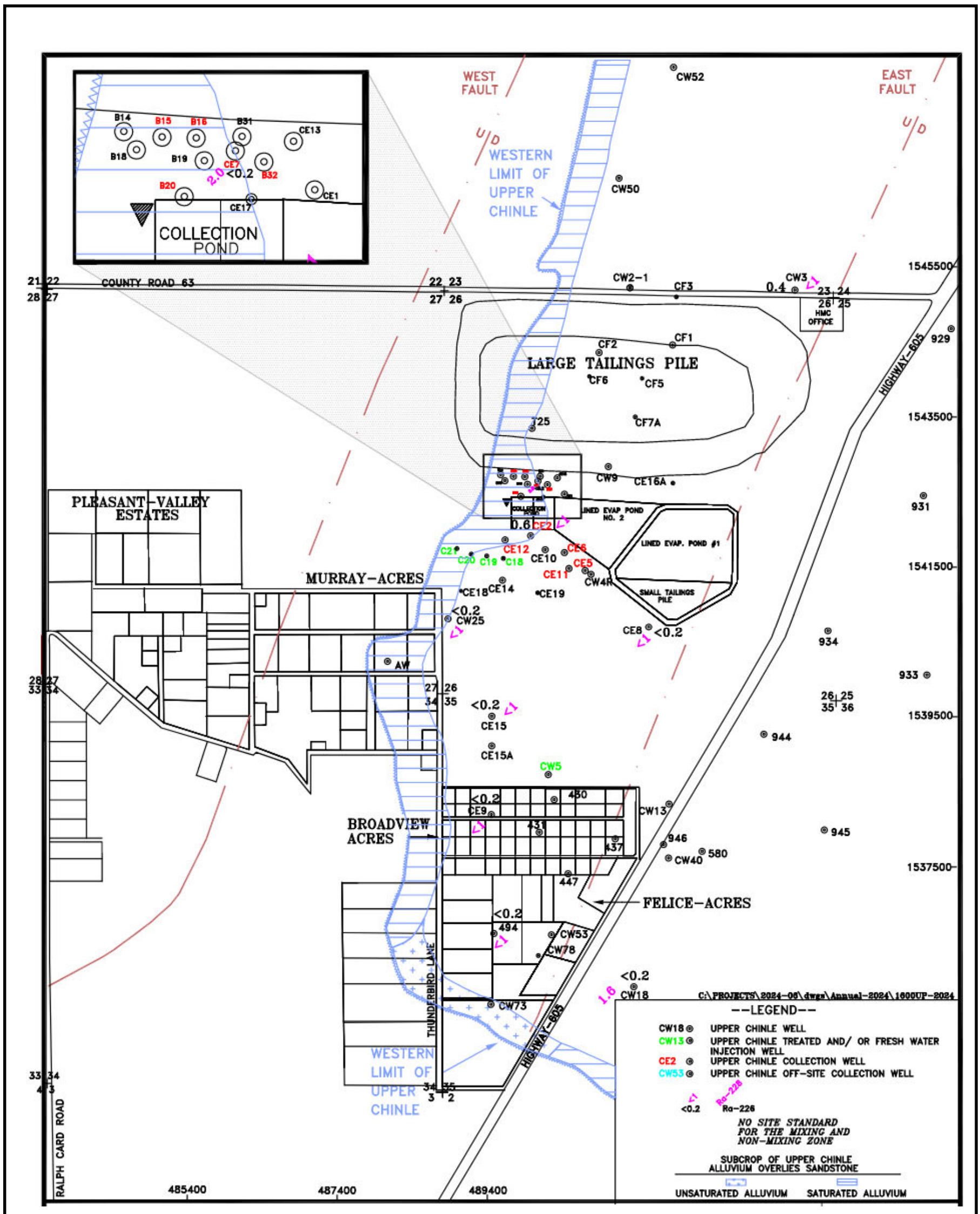

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Figure 1.3-19
Upper Chinle Groundwater
Radium 226+228 Concentrations, 2024

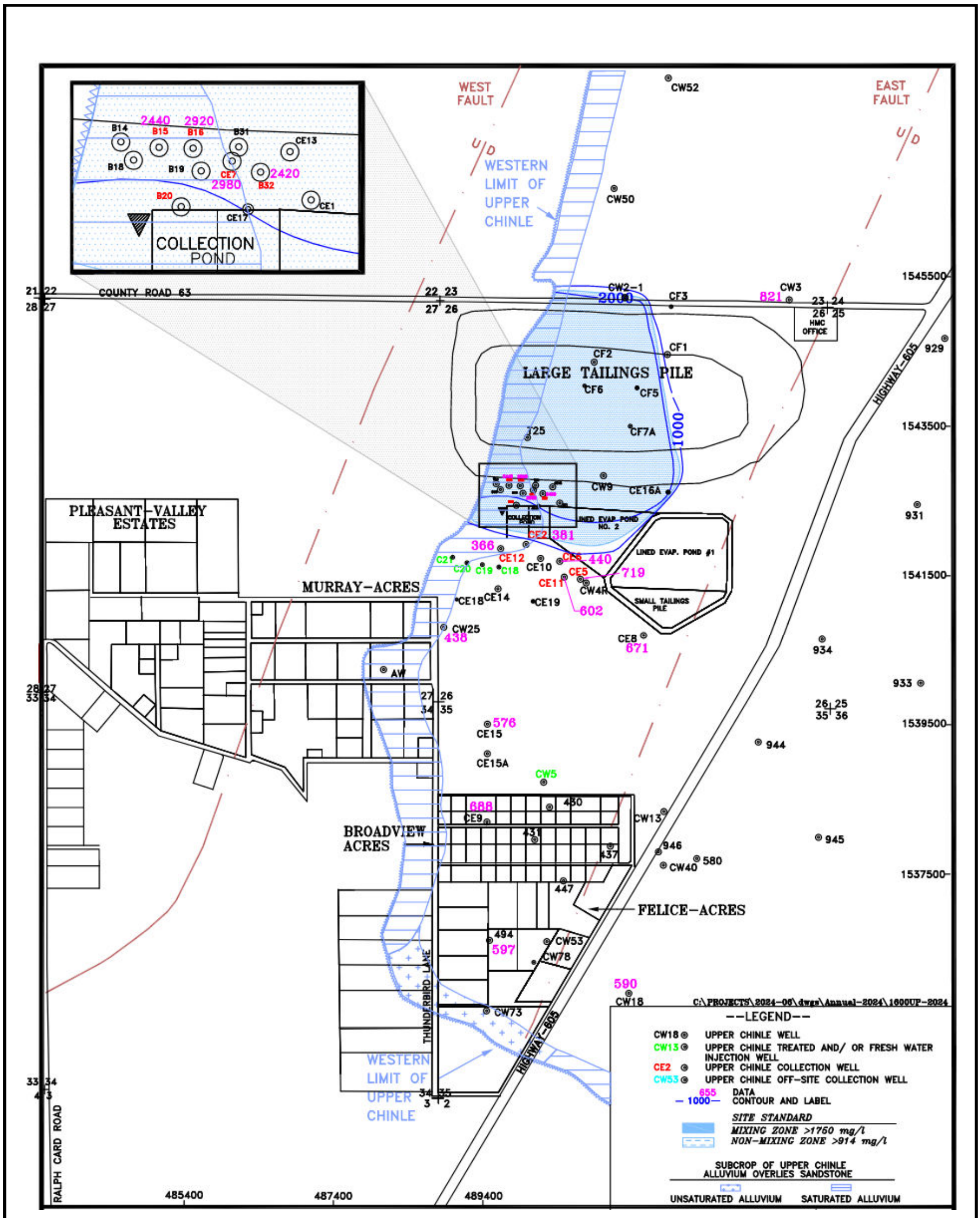

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Figure 1.3-20
Upper Chinle Groundwater
Sulfate Concentrations, 2024

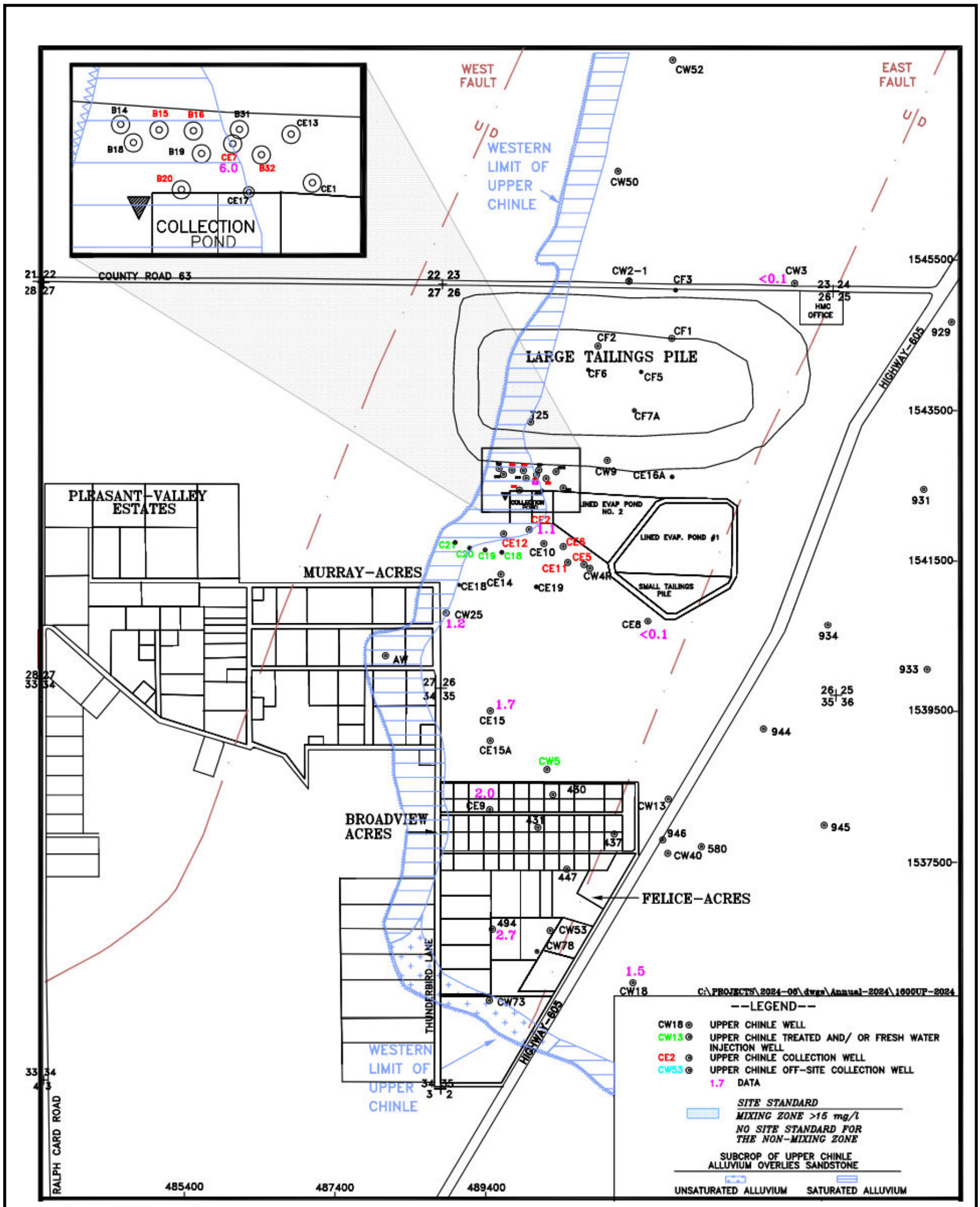

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Figure 1.3-21
Upper Chinle Groundwater
Nitrate Concentrations, 2024

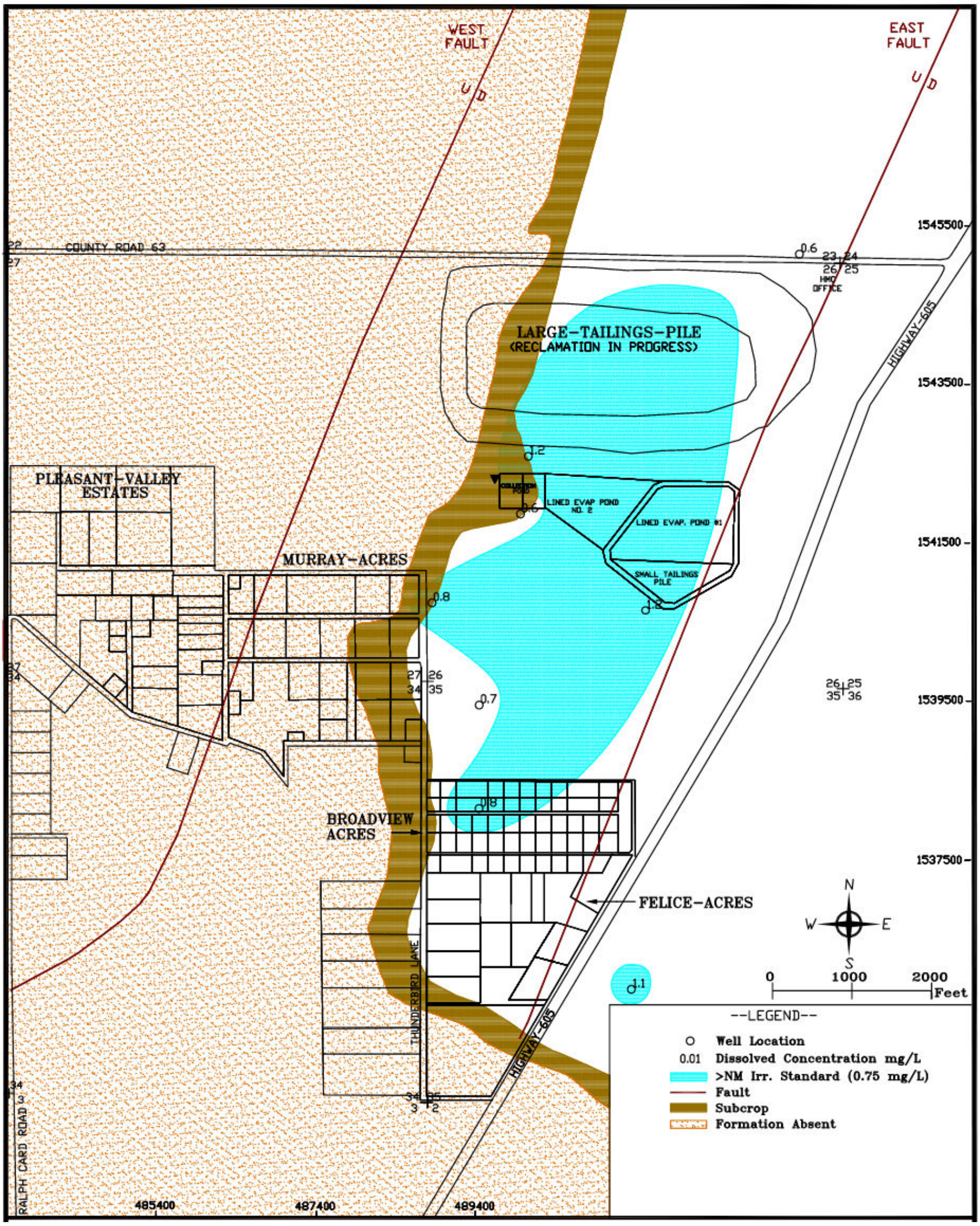

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Figure 1.3-22
Current Extent of Boron in the
Upper Chinle Groundwater, 2024

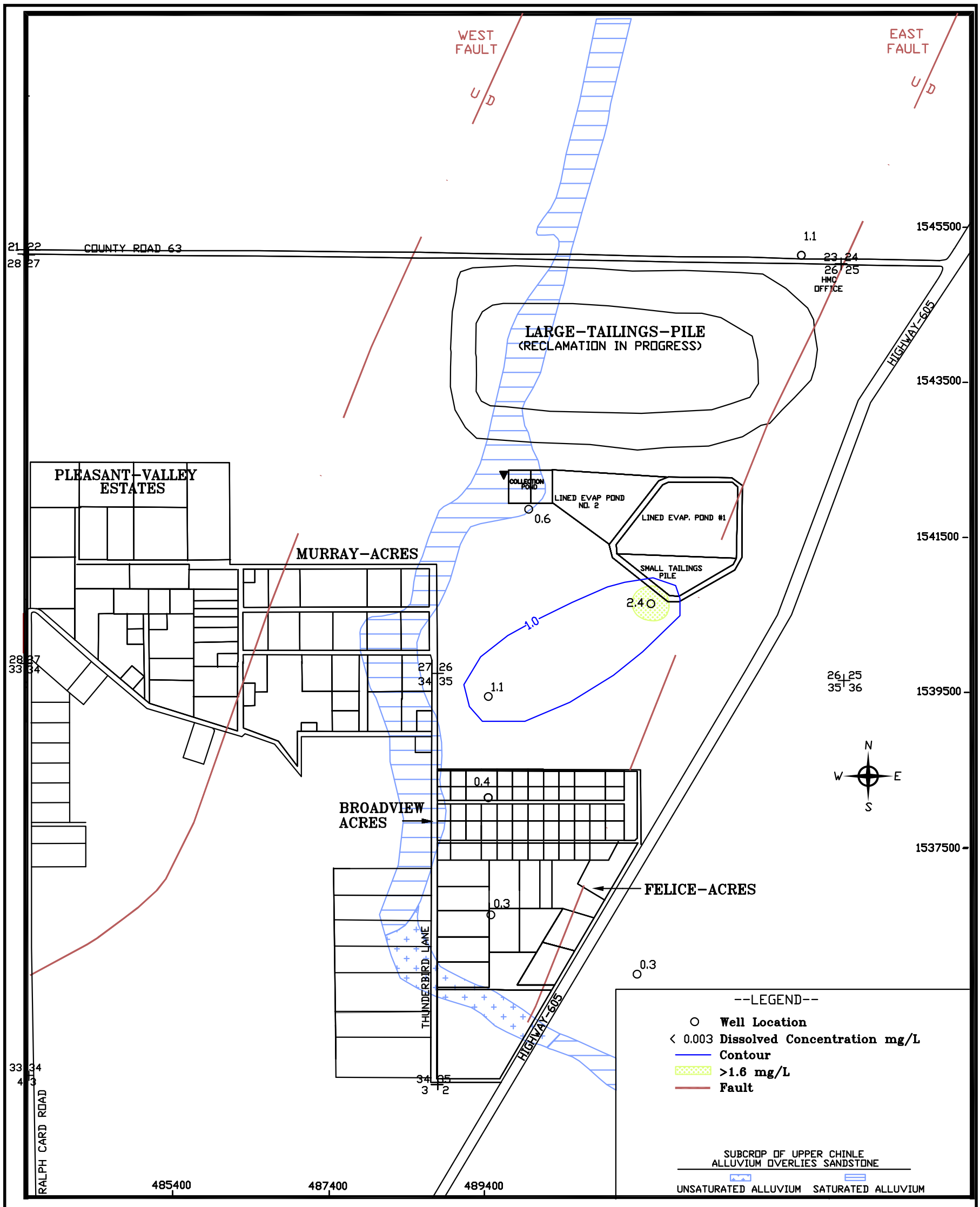

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Figure 1.3-23
Current Extent of Fluoride in the
Upper Chinle Groundwater

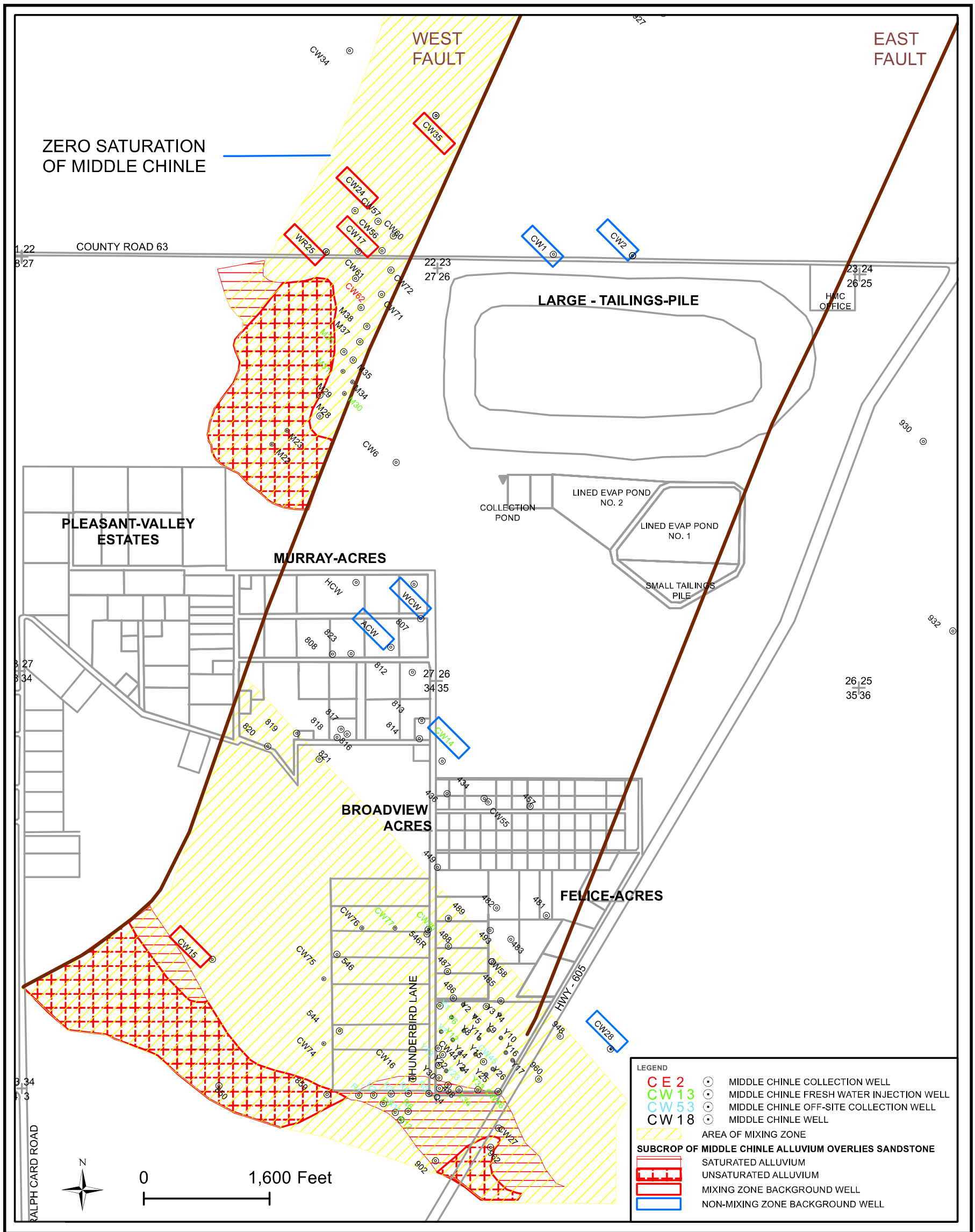

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Figure 1.3-24
Middle Chinle Mixing Zone

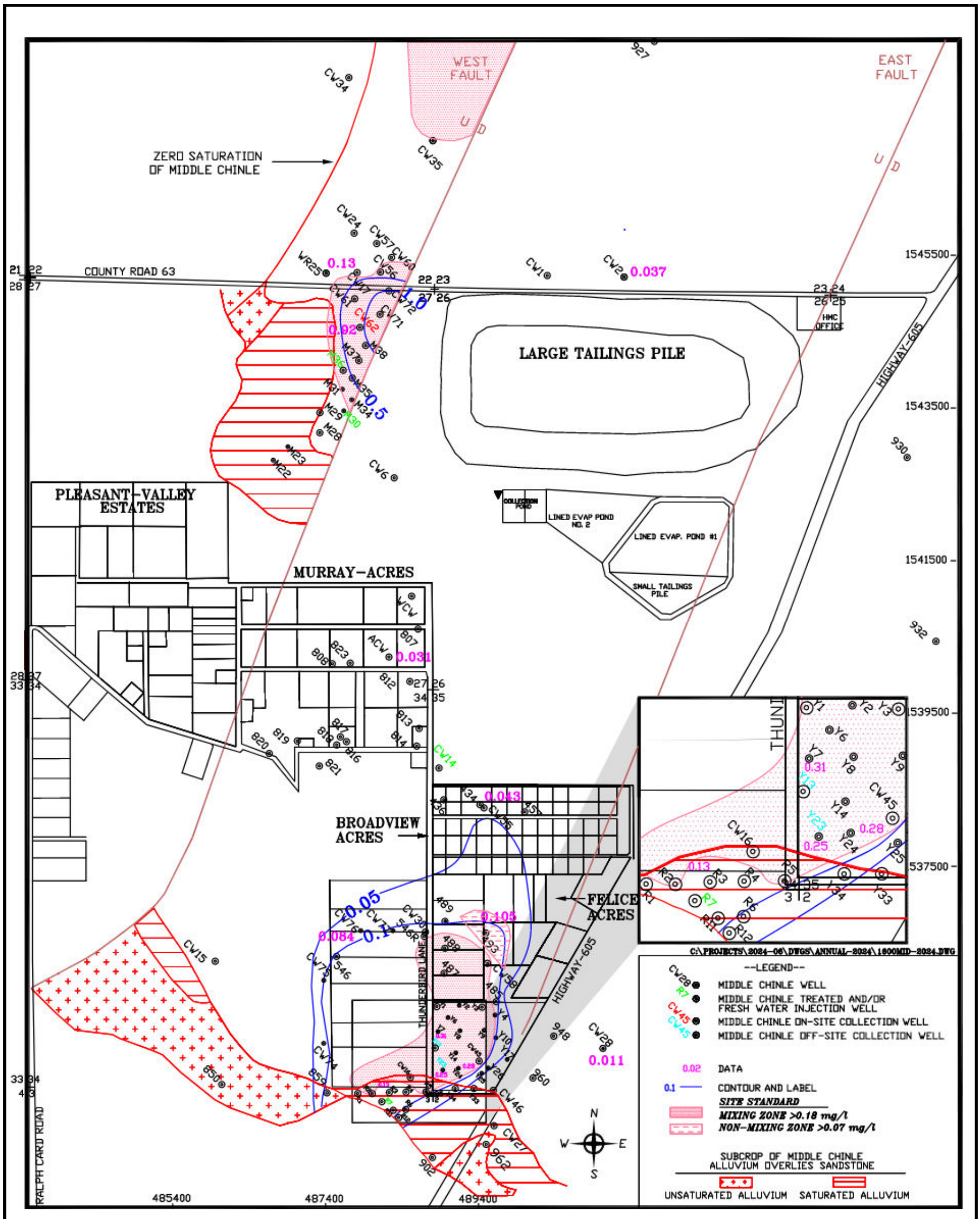

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Figure 1.3-25
Middle Chinle Groundwater
Uranium Concentrations, 2024

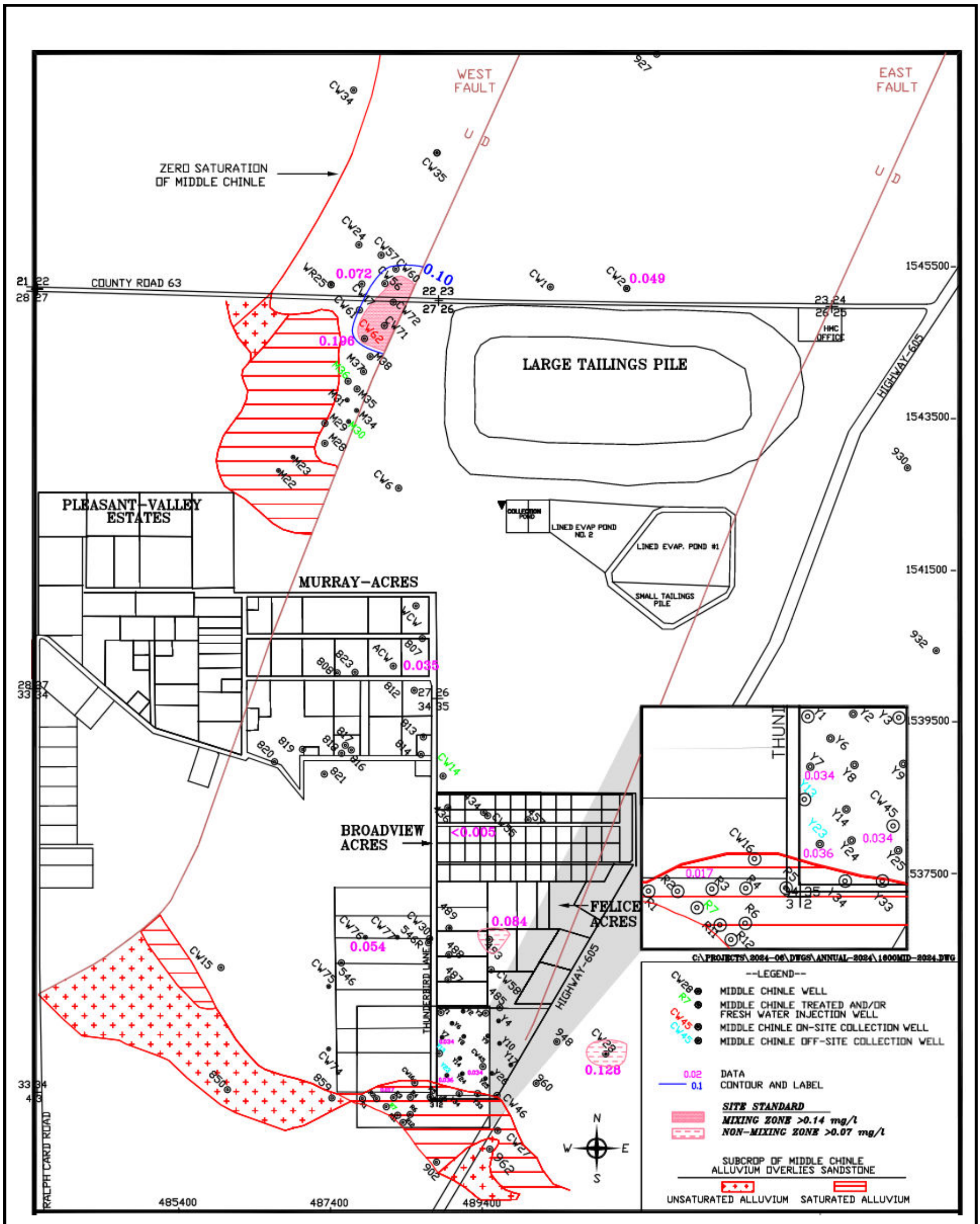

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Figure 1.3-26
Middle Chinle Groundwater
Selenium Concentrations, 2024

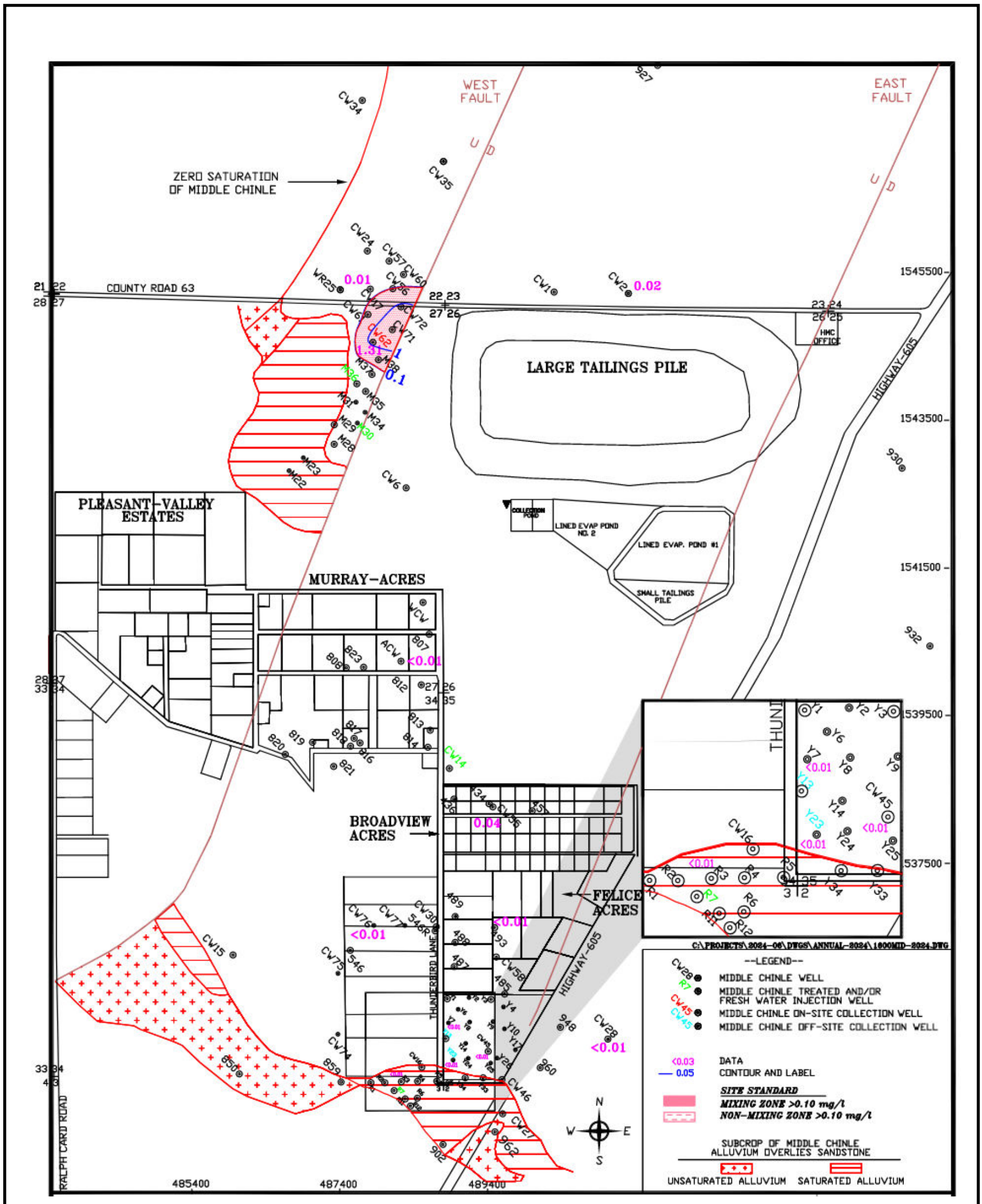

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Figure 1.3-27
Middle Chinle Groundwater
Molybdenum Concentrations, 2024

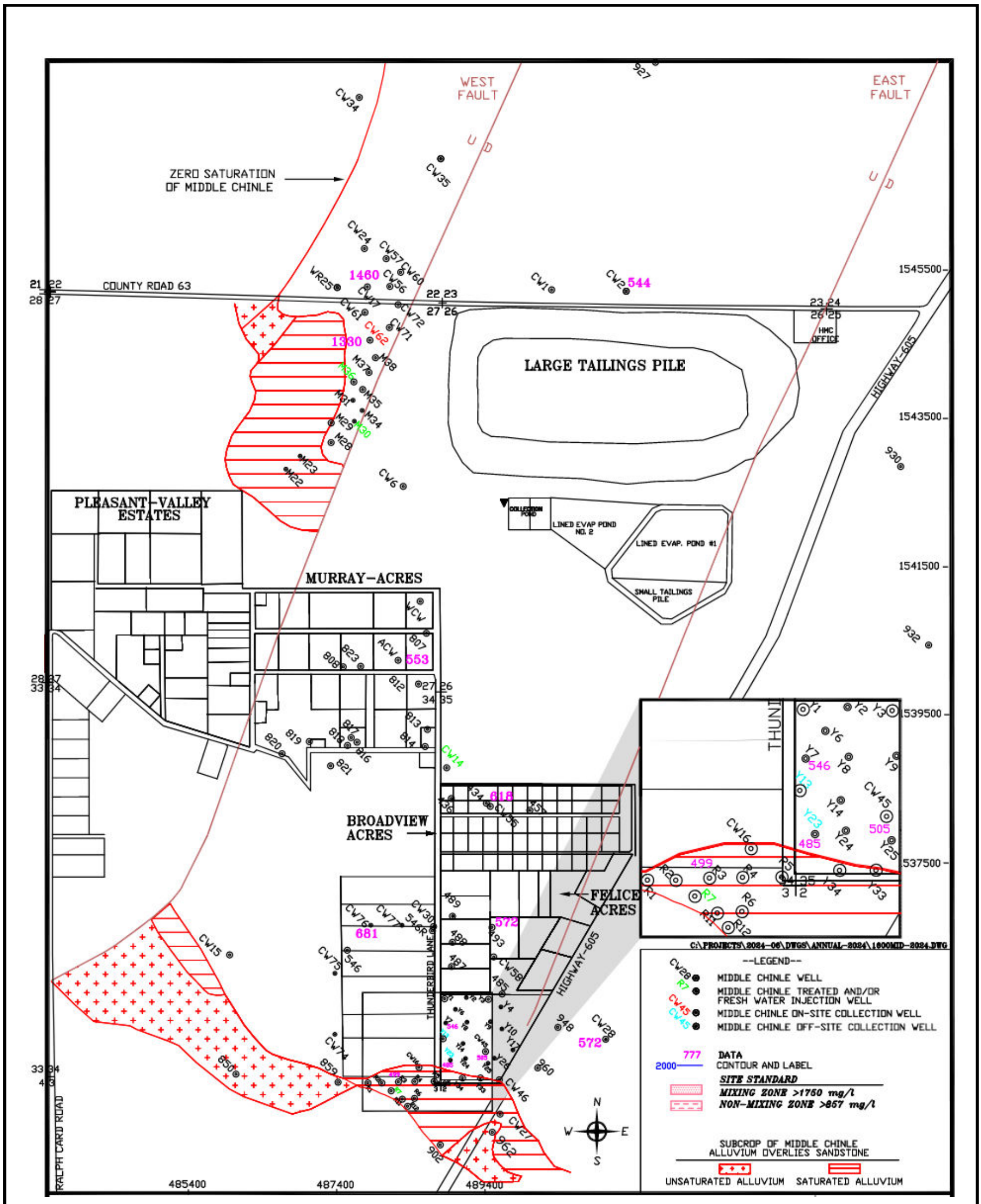

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Figure 1.3-28
Middle Chinle Groundwater
Sulfate Concentrations, 2024

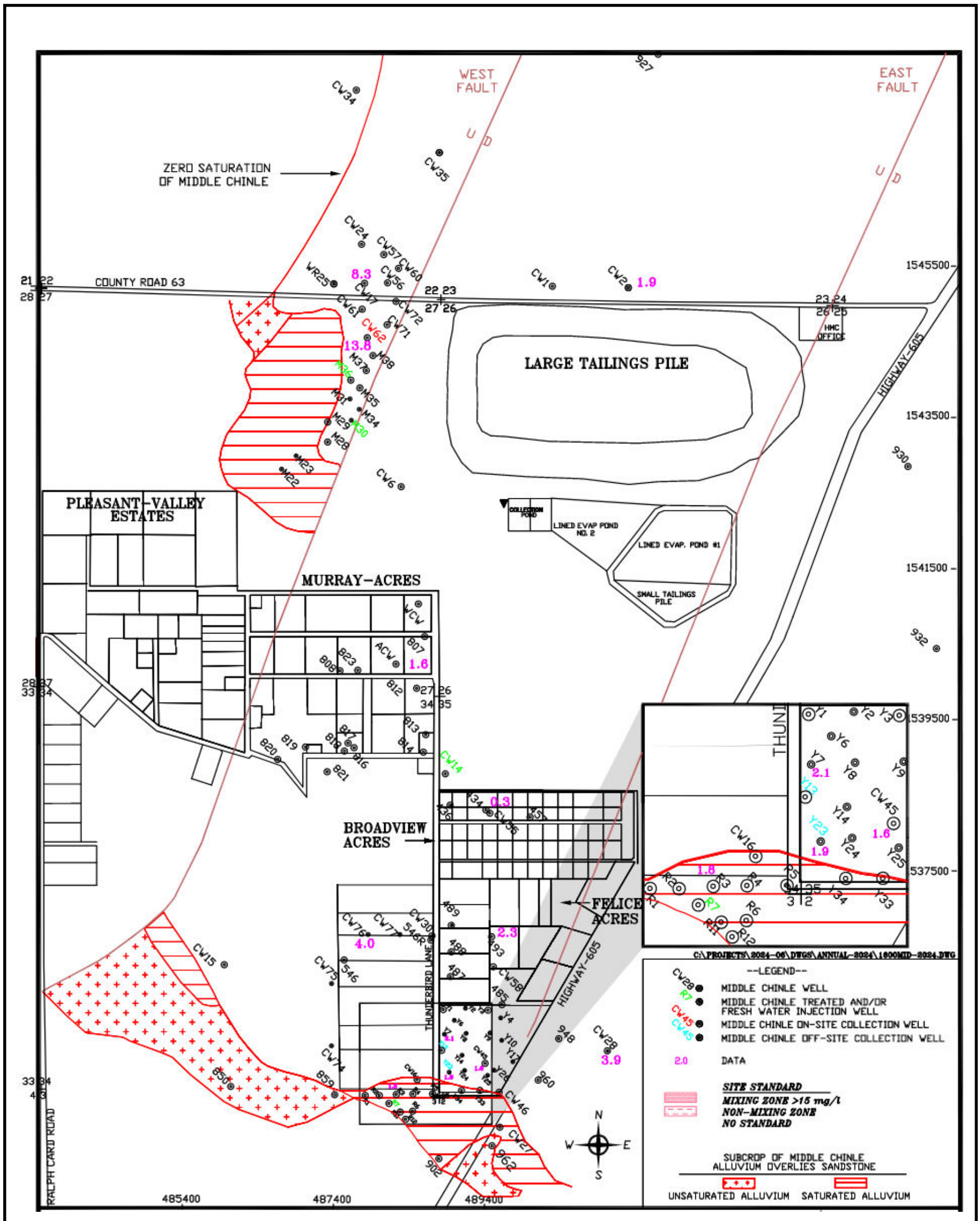

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Figure 1.3-29
Middle Chinle Groundwater
Nitrate Concentrations, 2024

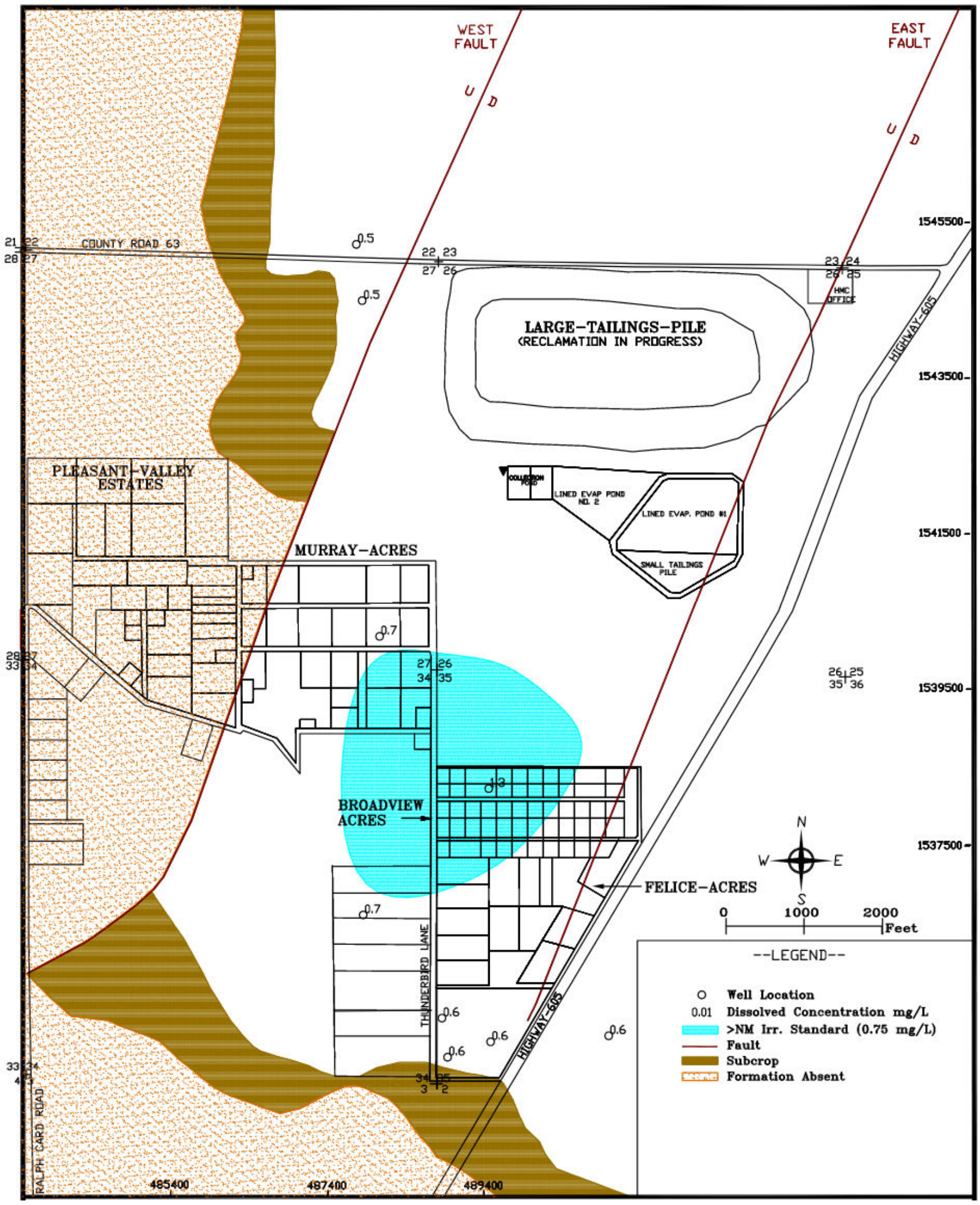

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Figure 1.3-30
Current Extent of Boron in
Middle Chinle Groundwater, 2024

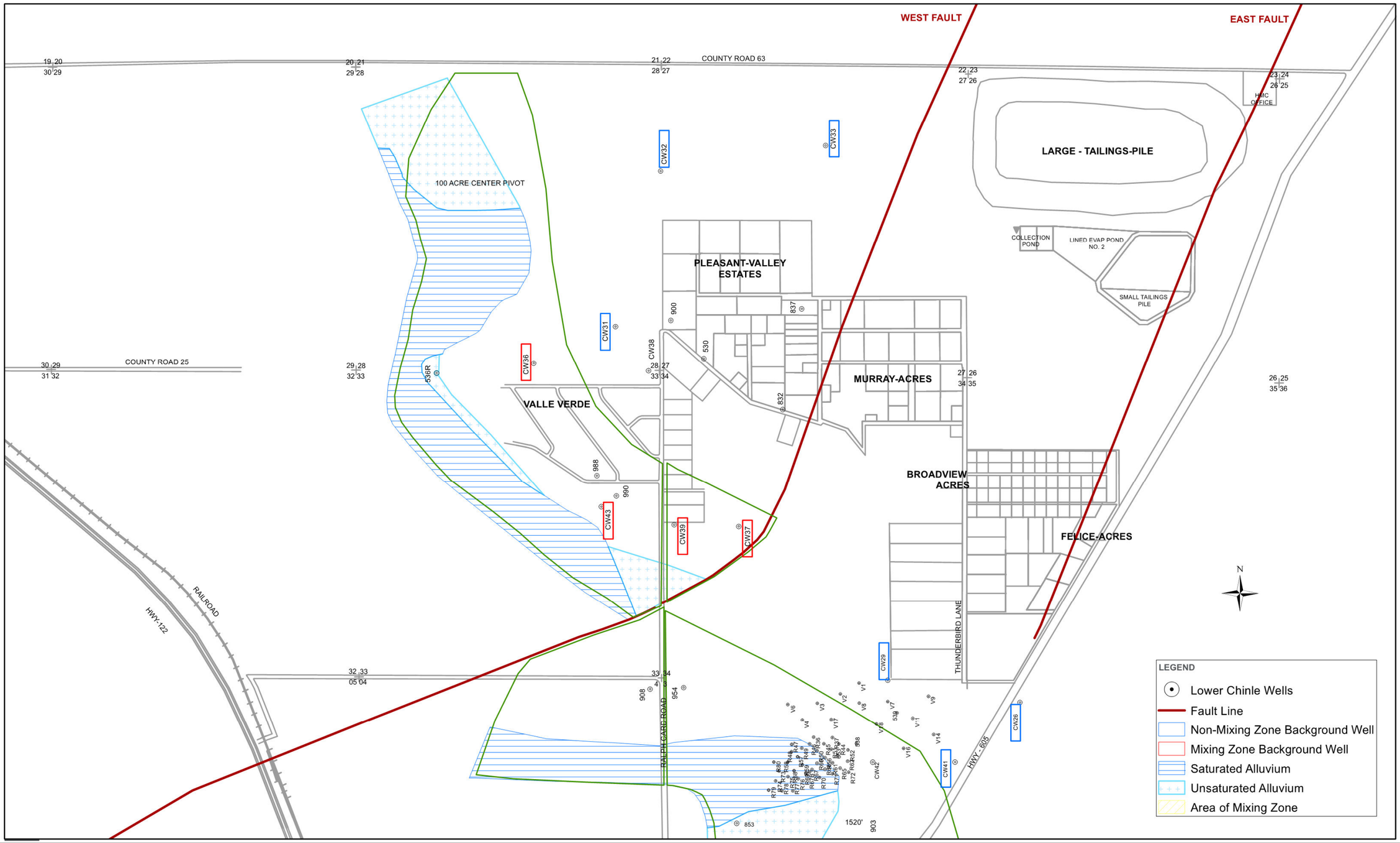

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Figure 1.3-31
Lower Chinle Mixing Zone

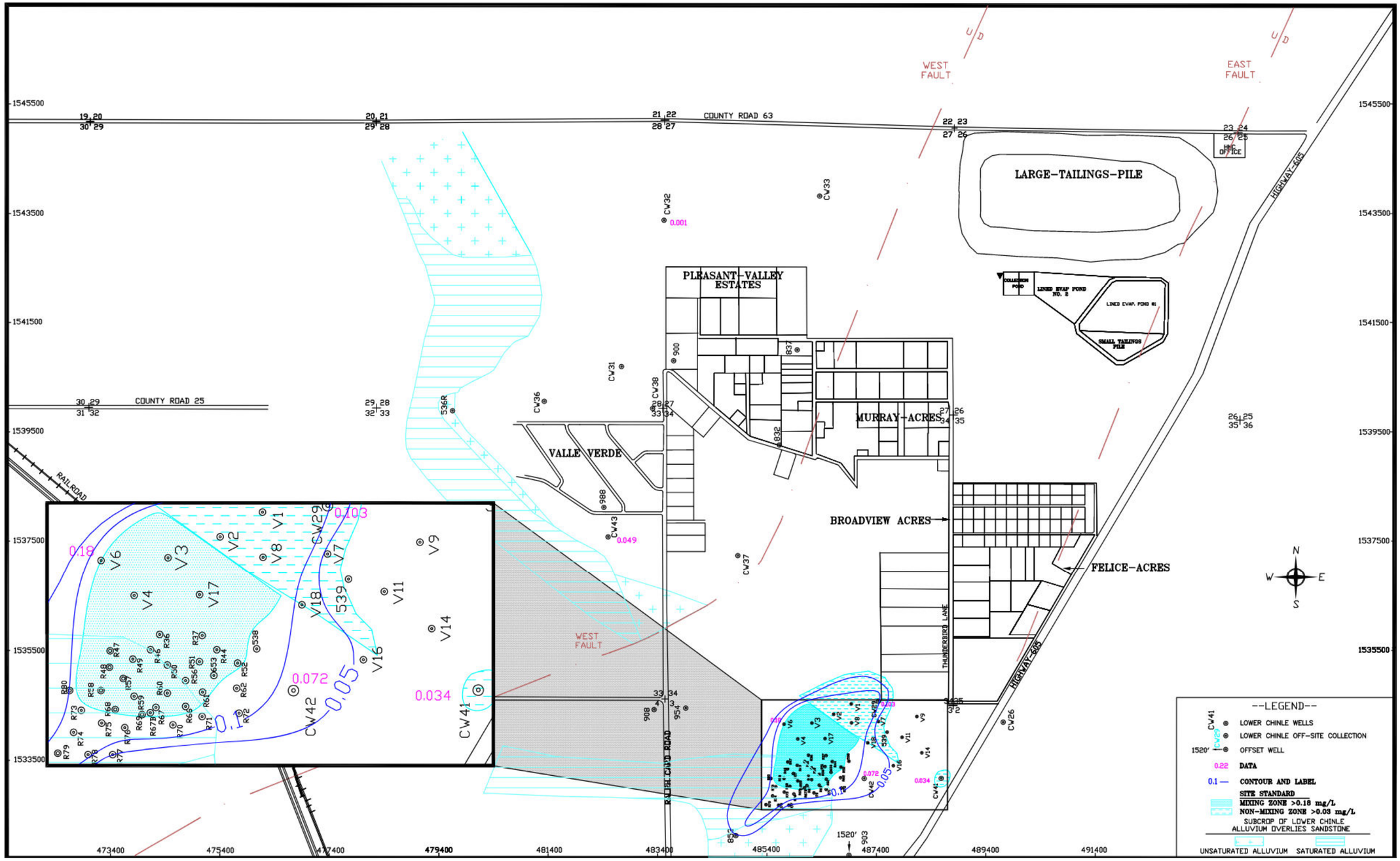

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Figure 1.3-32
Lower Chinle Groundwater
Uranium Concentrations, 2024

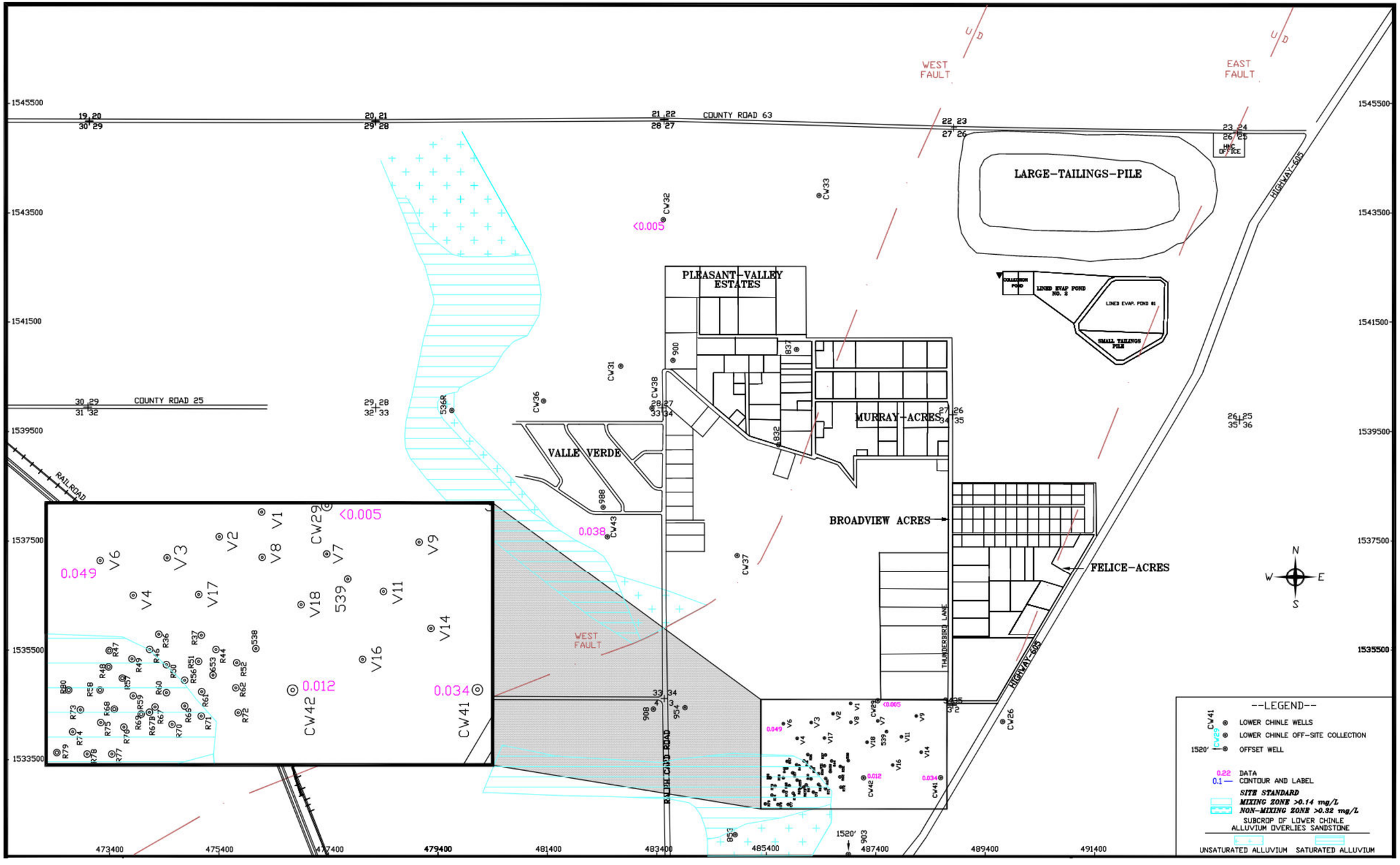

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Figure 1.3-33
Lower Chinle Groundwater
Selenium Concentrations, 2024

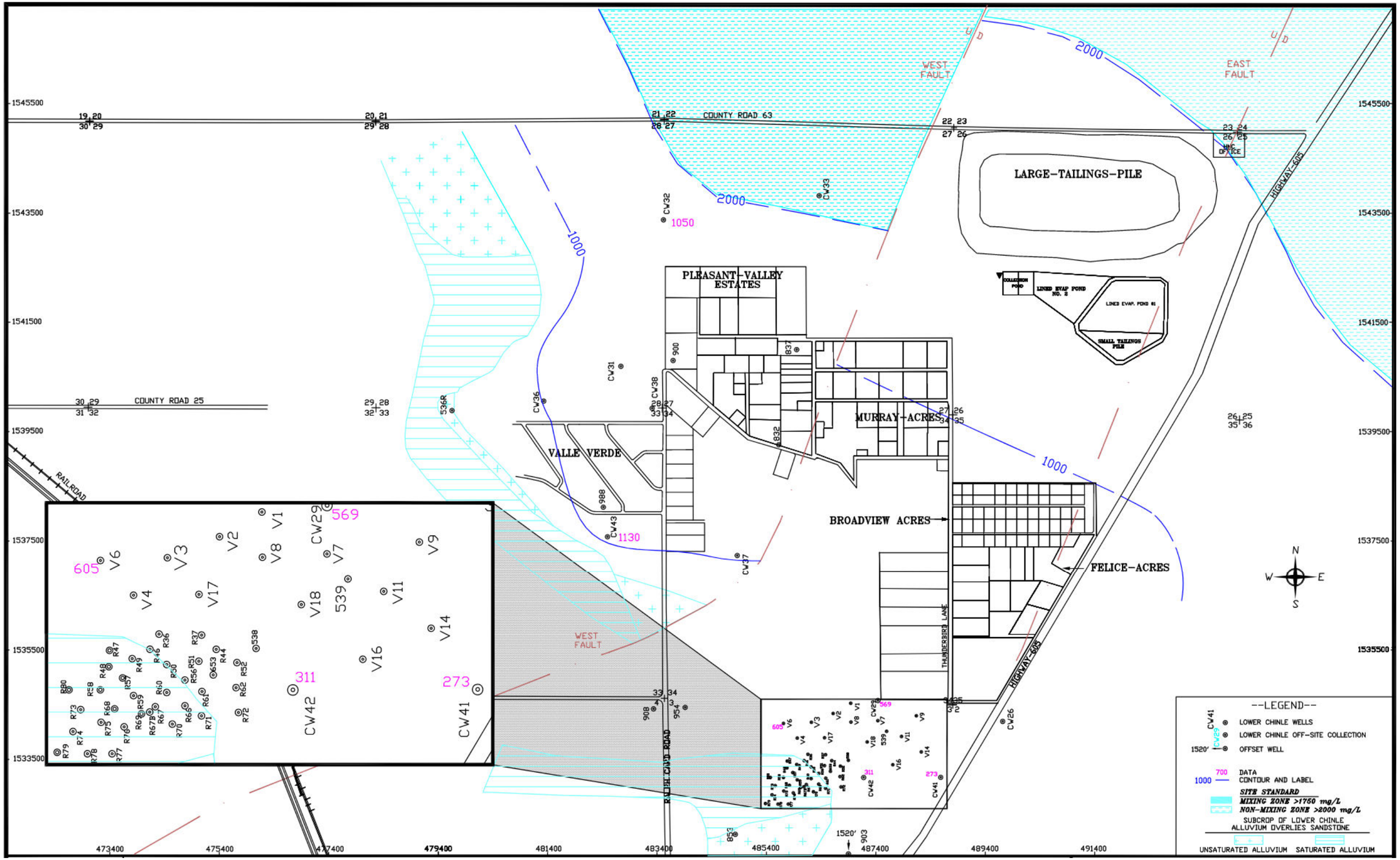

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Figure 1.3-34
Lower Chinle Groundwater
Sulfate Concentrations, 2024

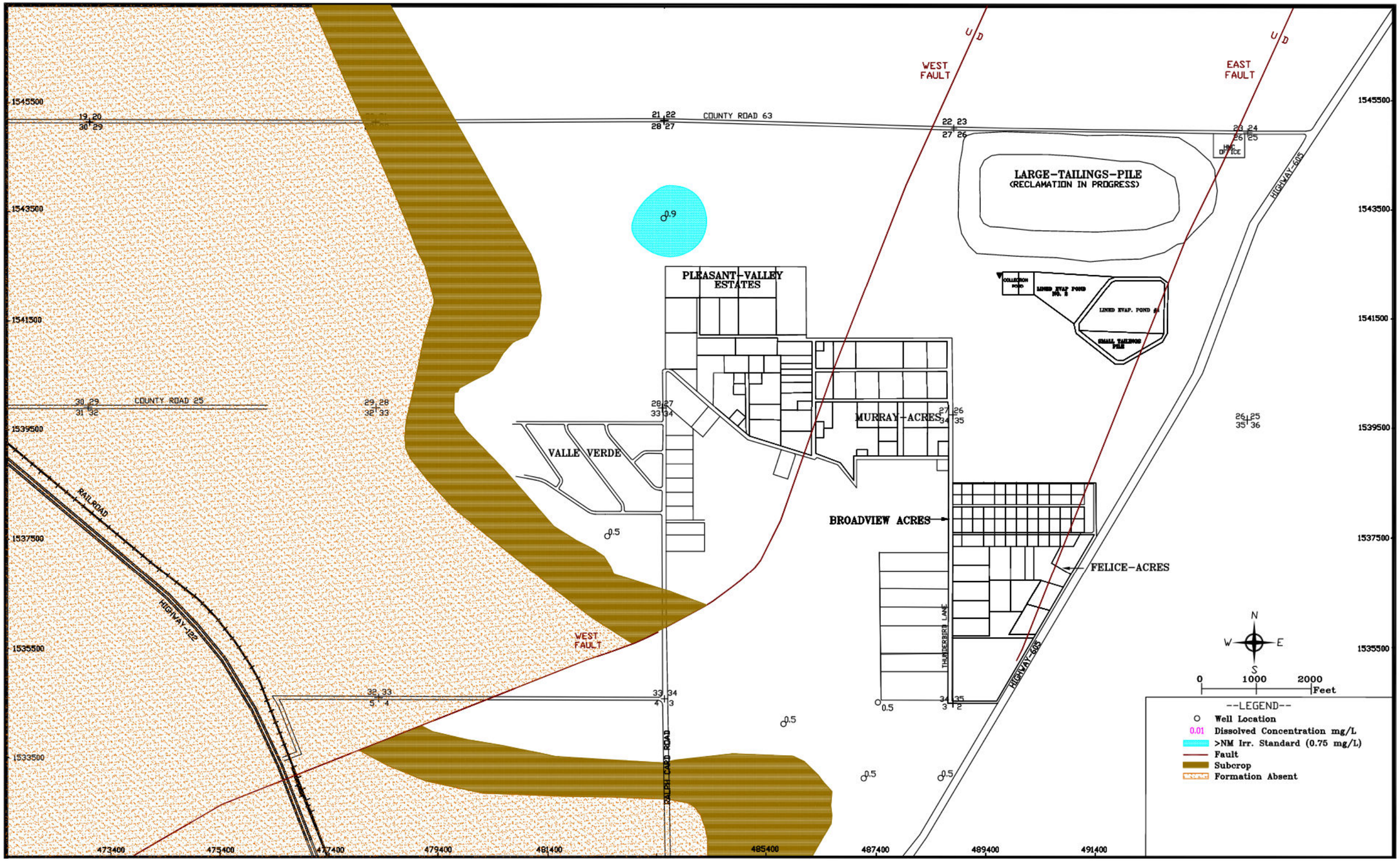

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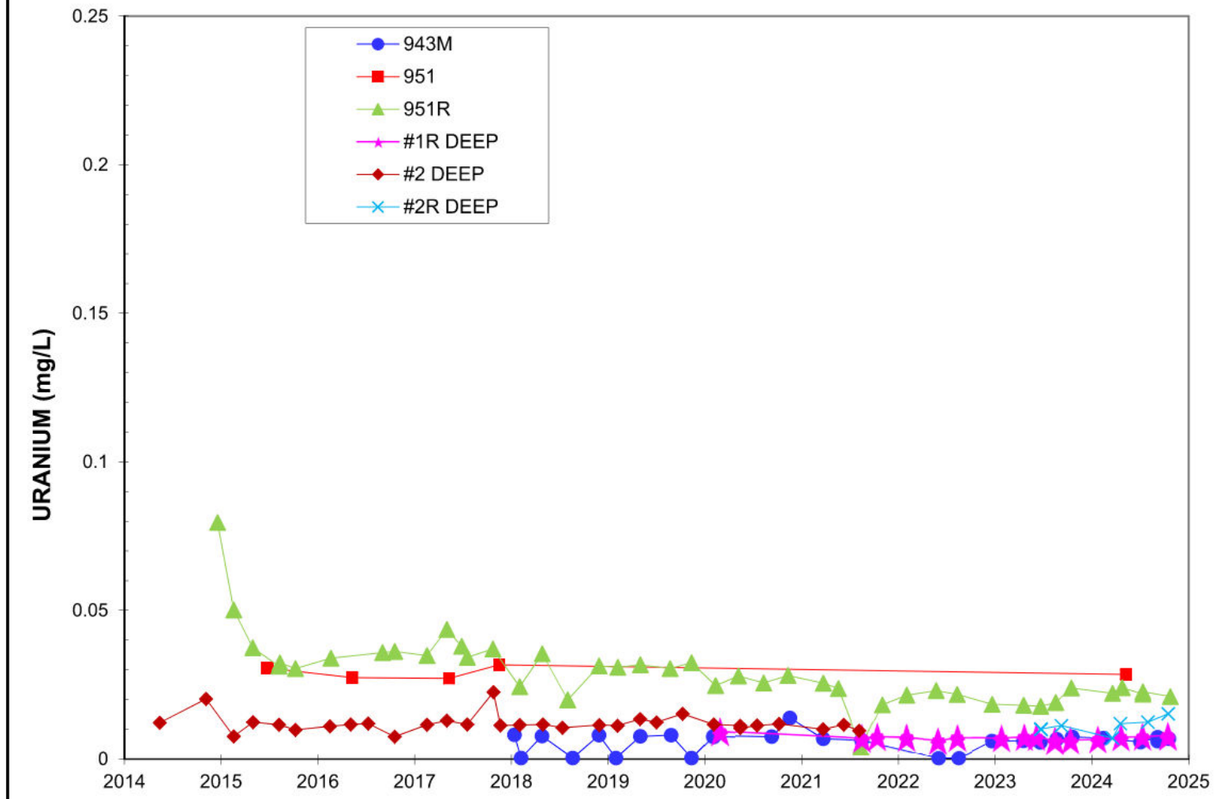
Figure 1.3-35
Current Extent of Boron in
Lower Chinle Groundwater, 2025



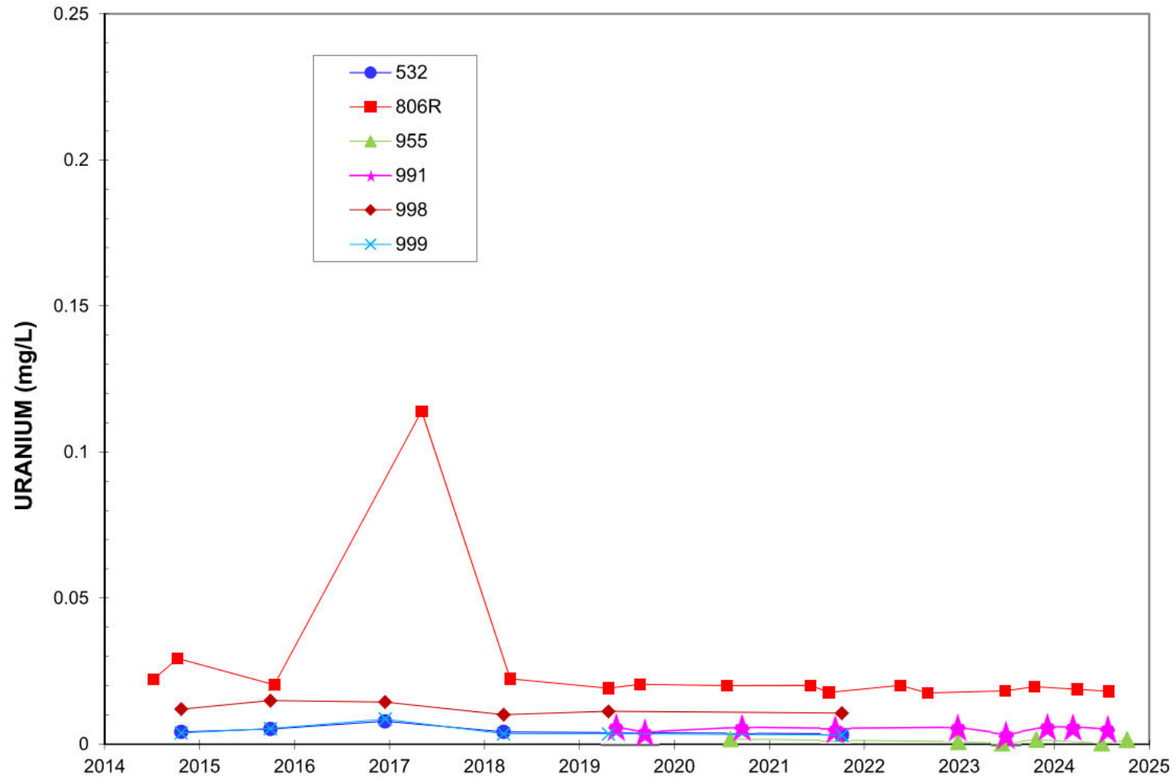


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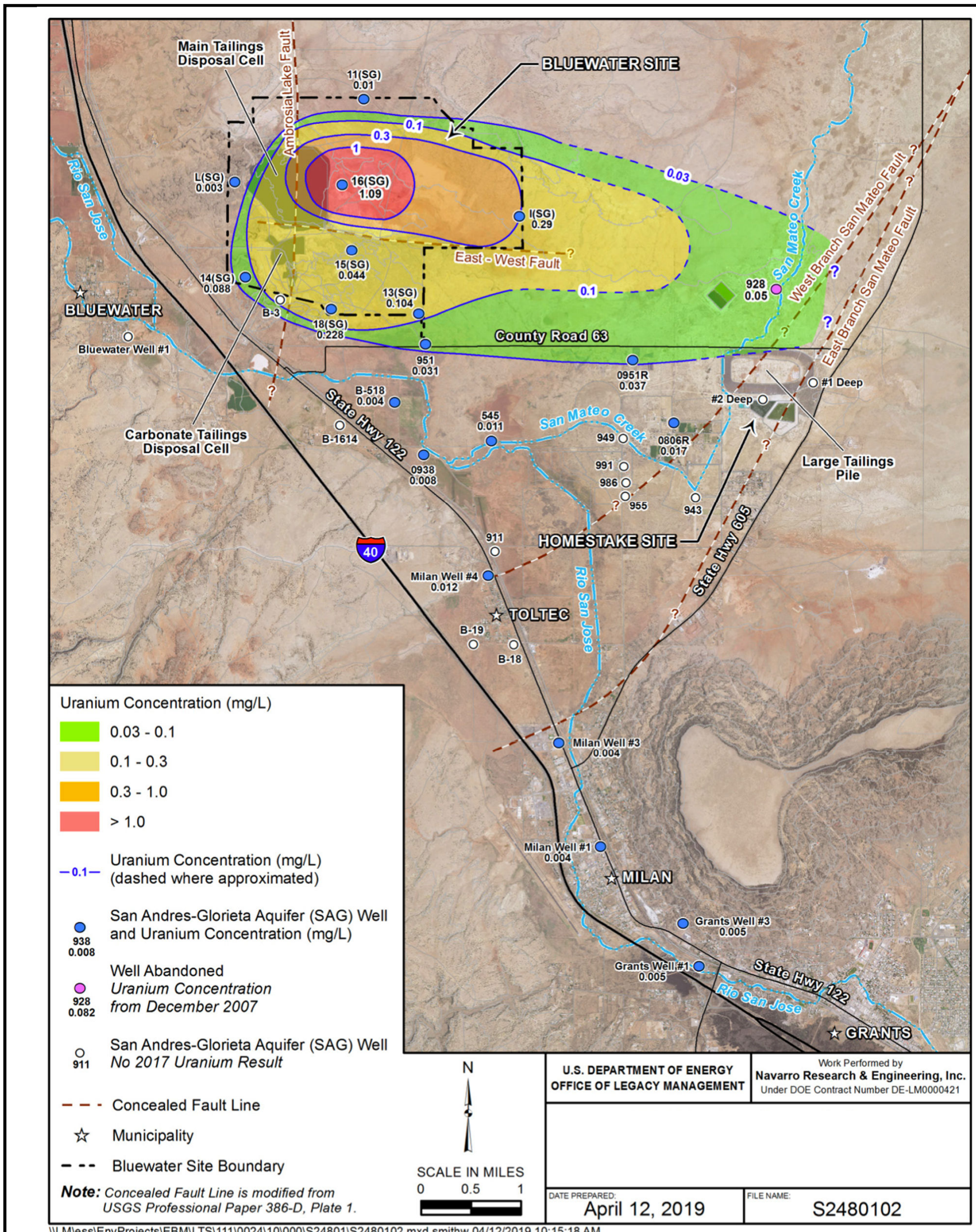
Figure 1.3-36
Uranium Concentration versus Time
In the San Andres-Glorieta Aquifer



Source: DOE, 2020

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Figure 1.3-37
2017 Uranium Concentrations in the
San Andres-Glorieta Aquifer

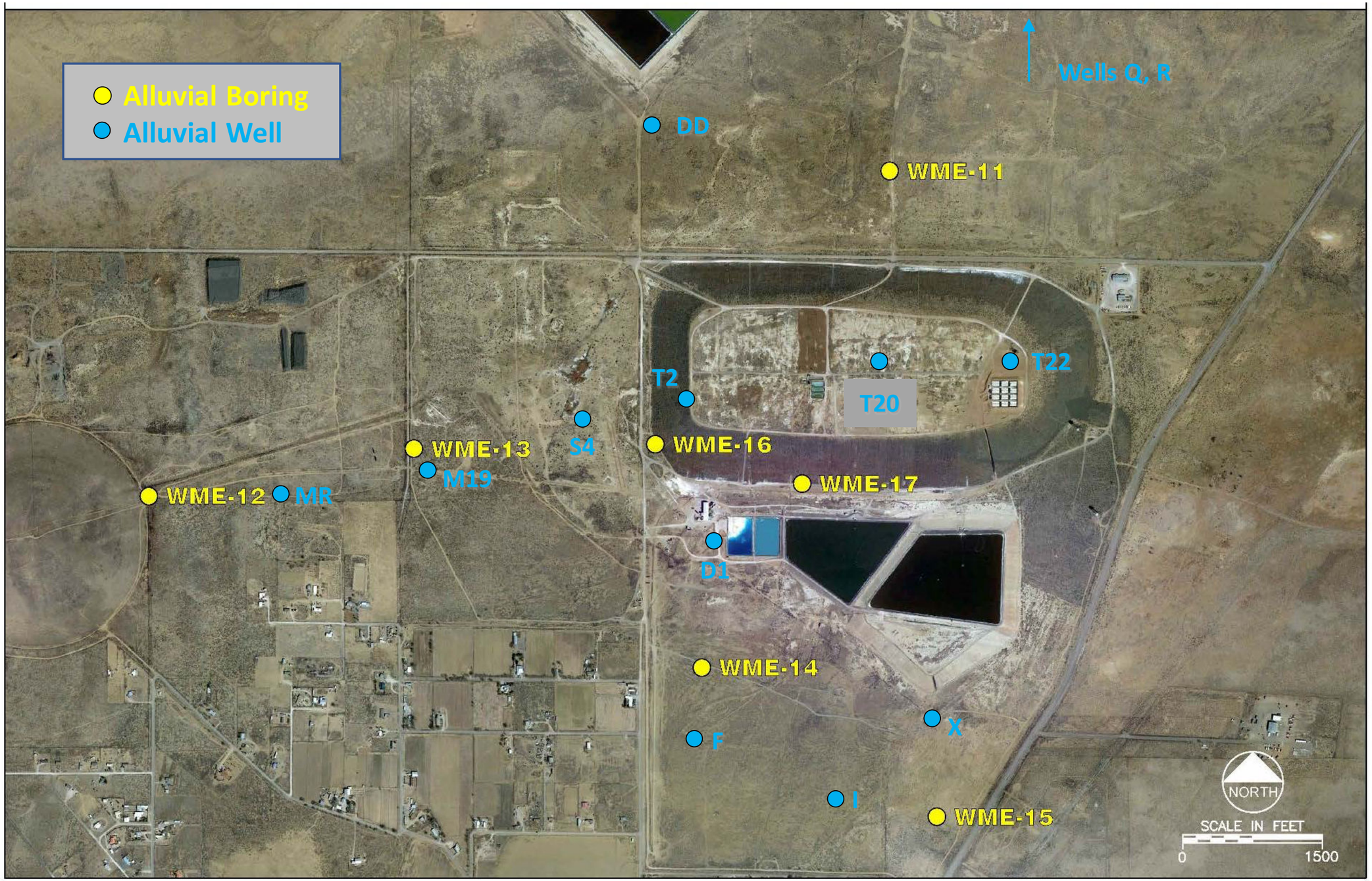

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Figure 1.3-38
Location of Alluvial Borings and Wells for Solids Collection and Groundwater Quality Evaluation

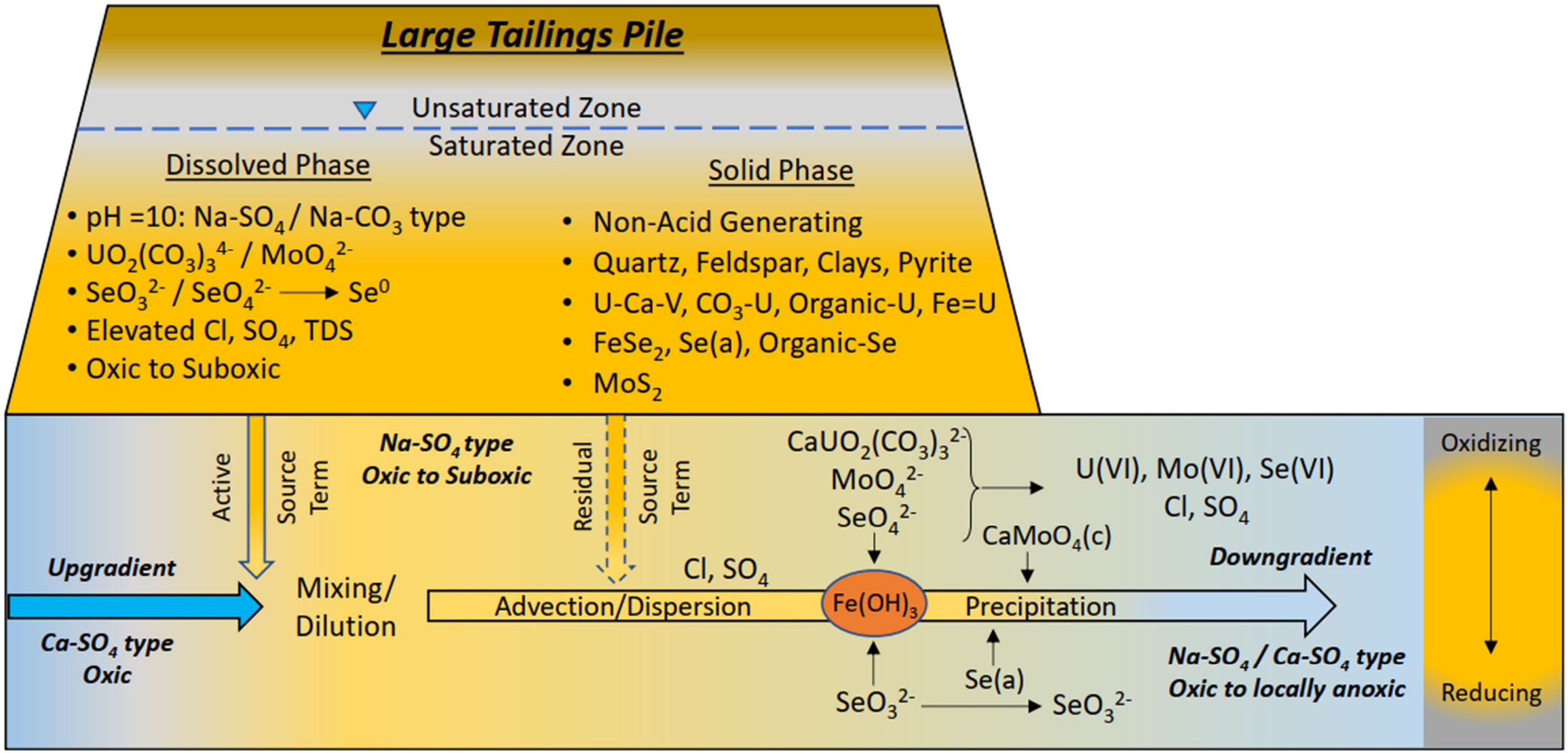
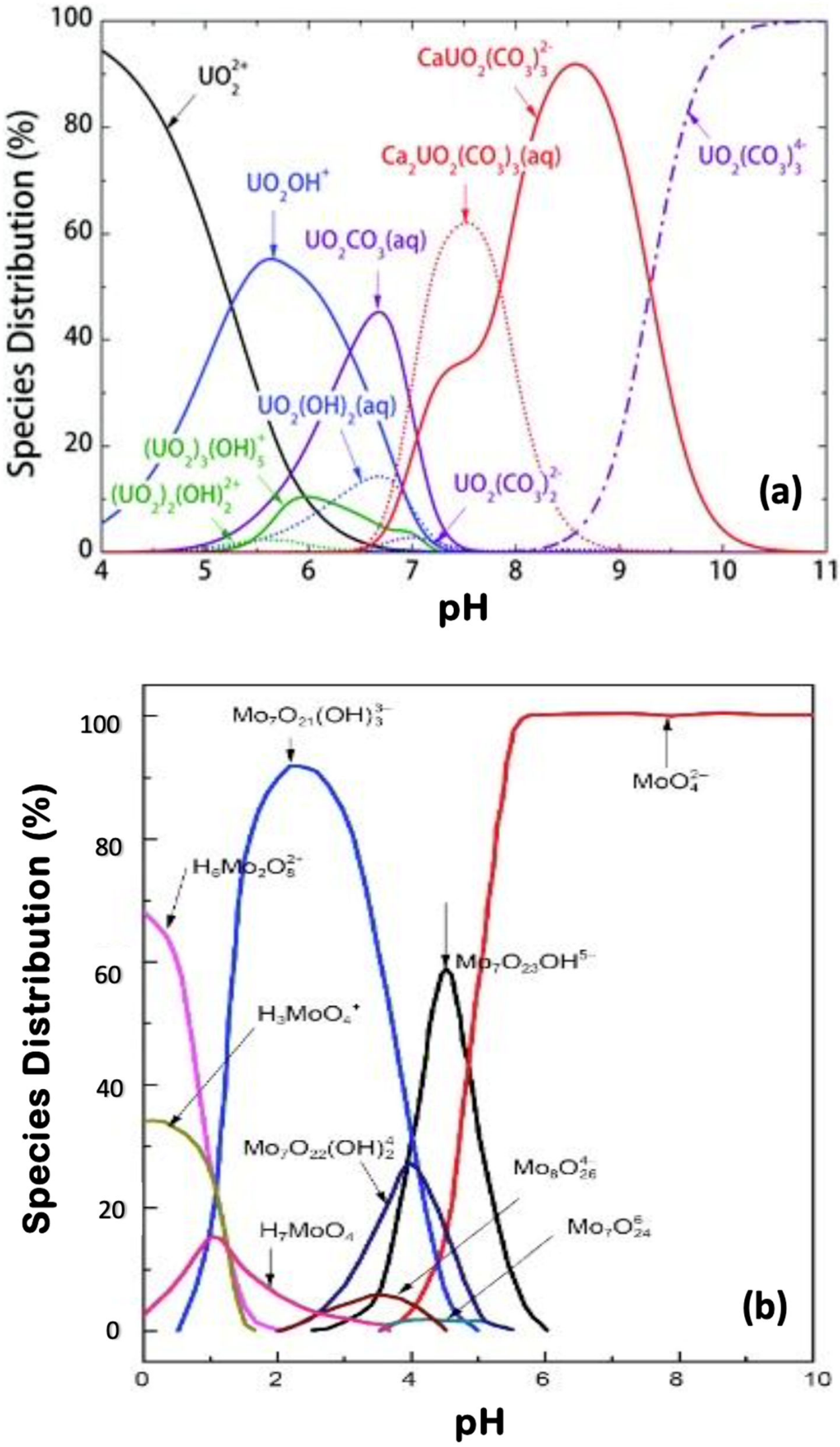


Figure 1.3-39
Conceptual Geochemical Model
for Constituent Sources and Transport



Source: Lee et al. (2011); Lee and Yun (2013)

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Figure 1.3-40
Uranium and Molybdenum Speciation as a Function of pH

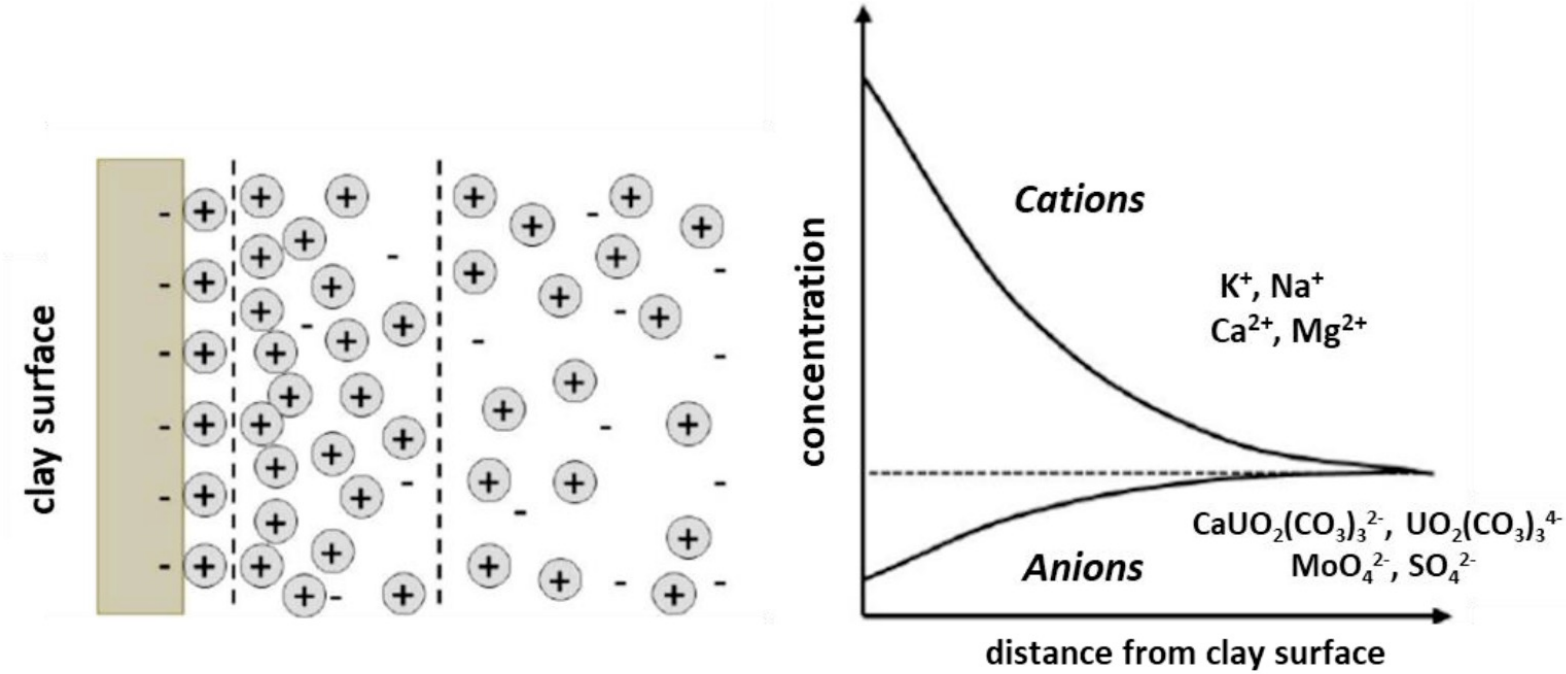

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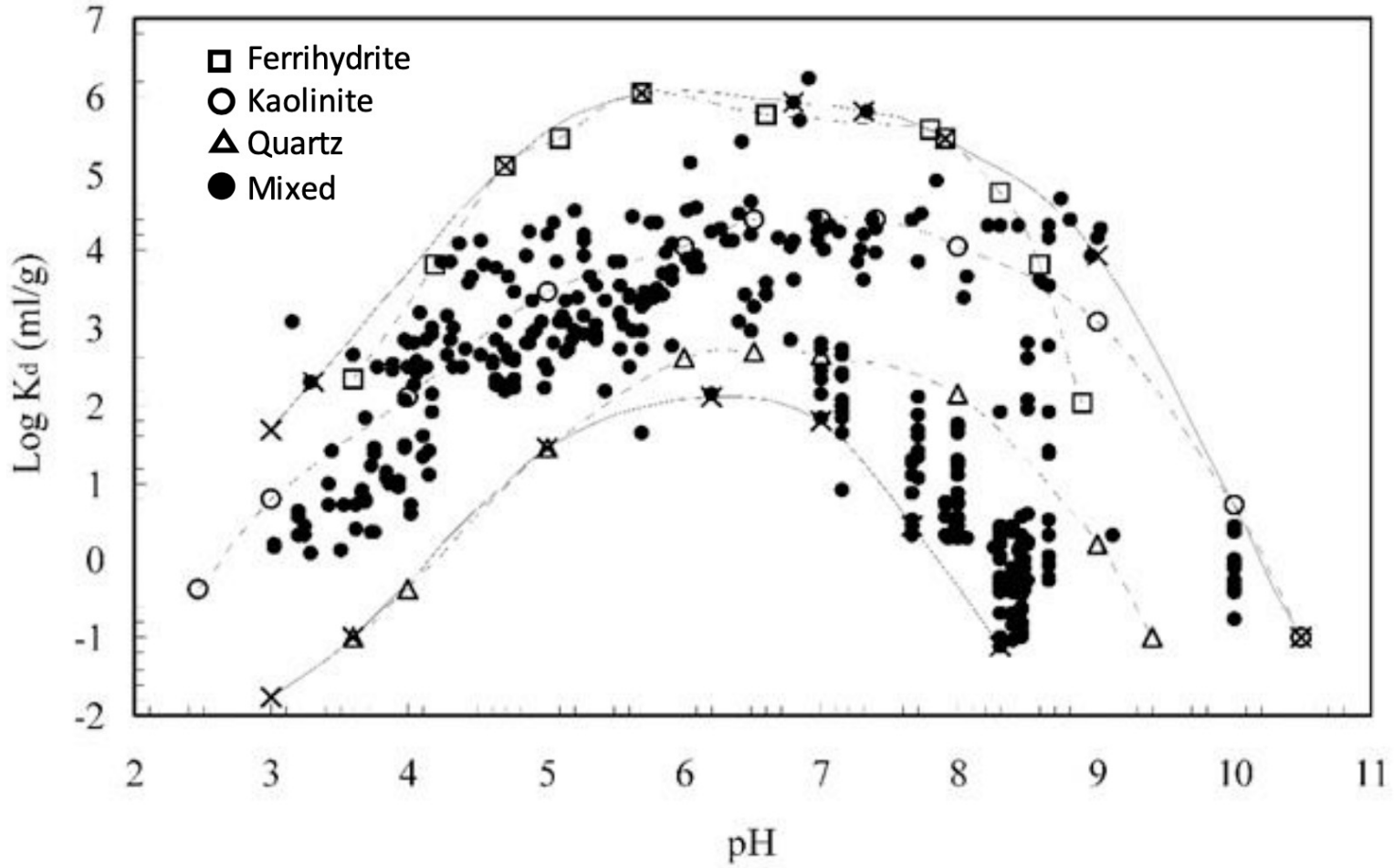
Figure 1.3-41
Distribution of Ions Adjacent to a Clay Surface



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Source: EPA, 1999a

Figure 1.3-42
Range of Uranium K_d Values for Various Minerals

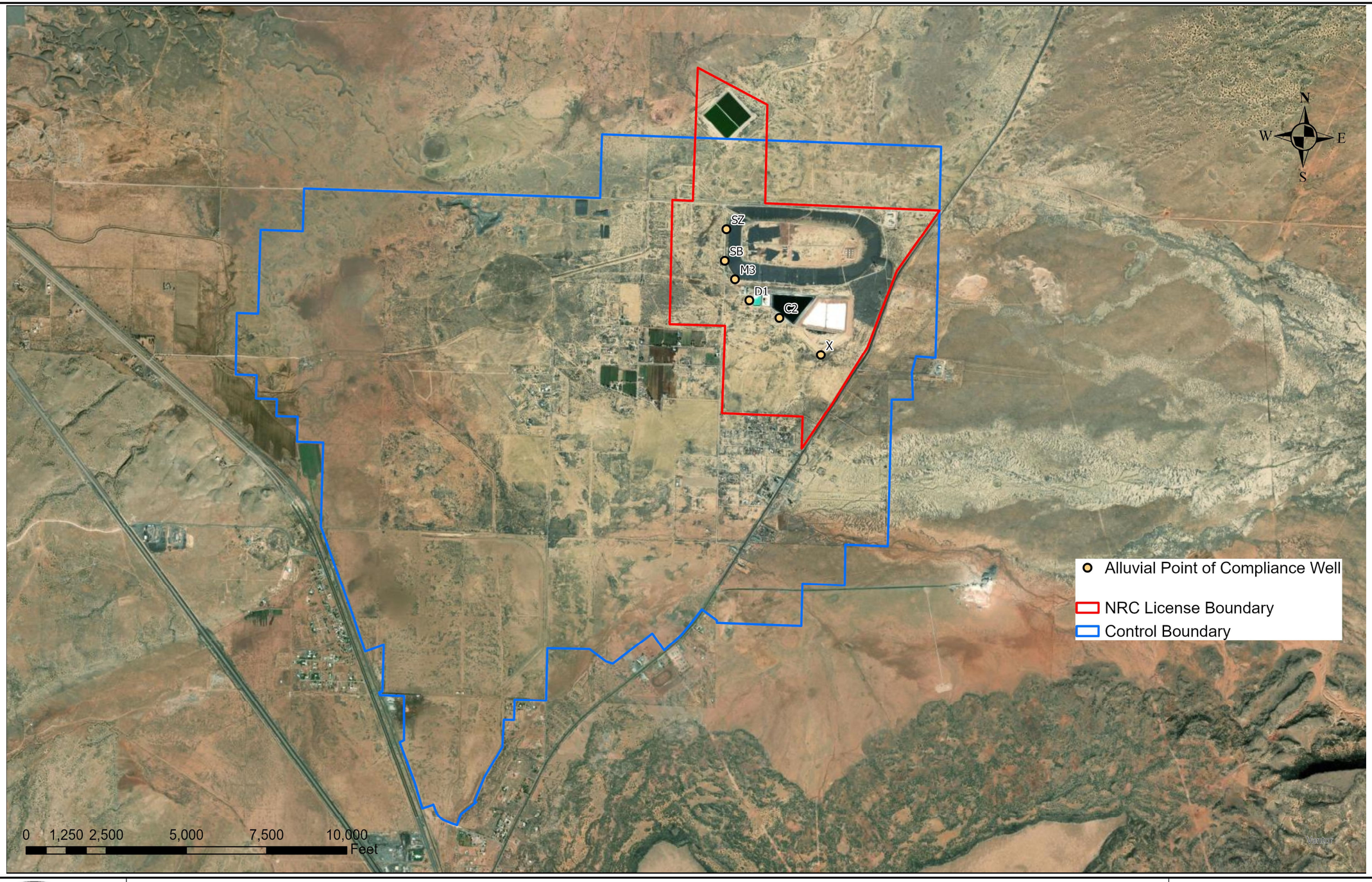

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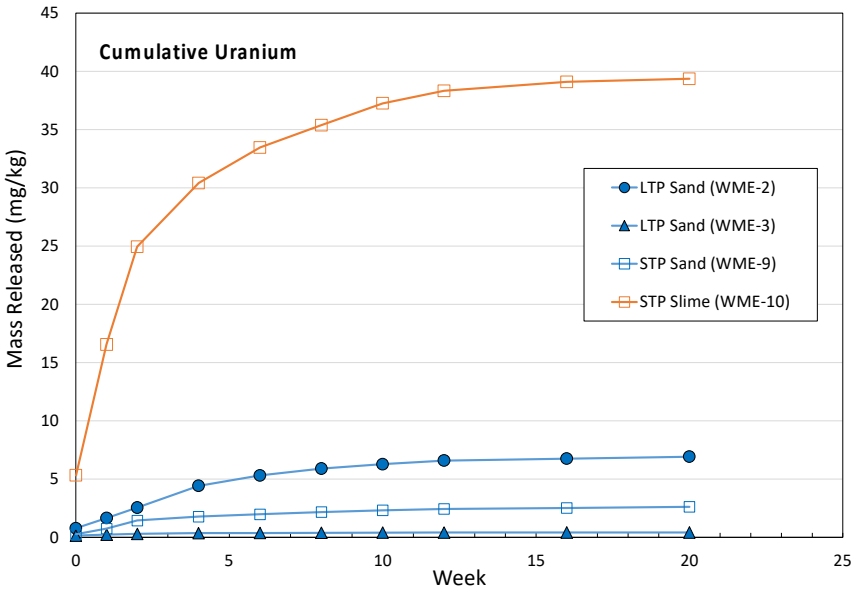
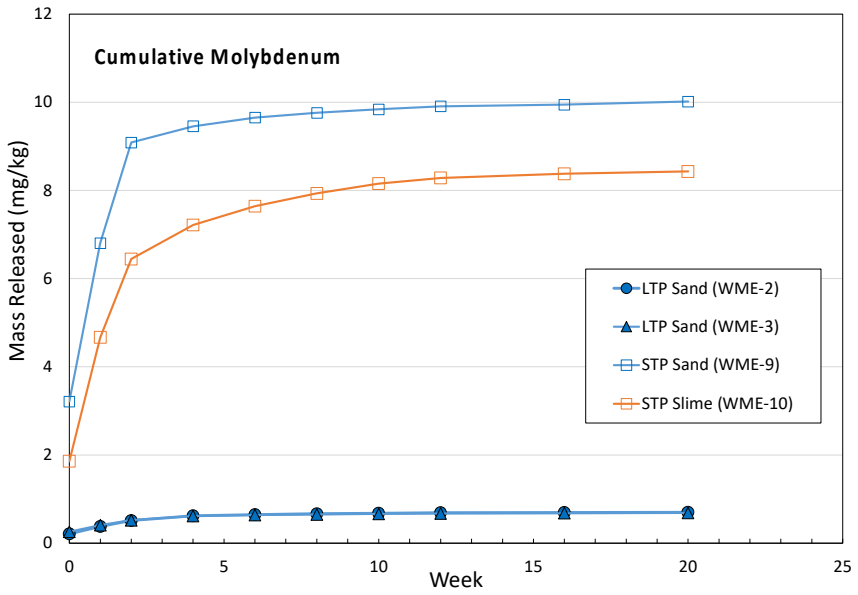
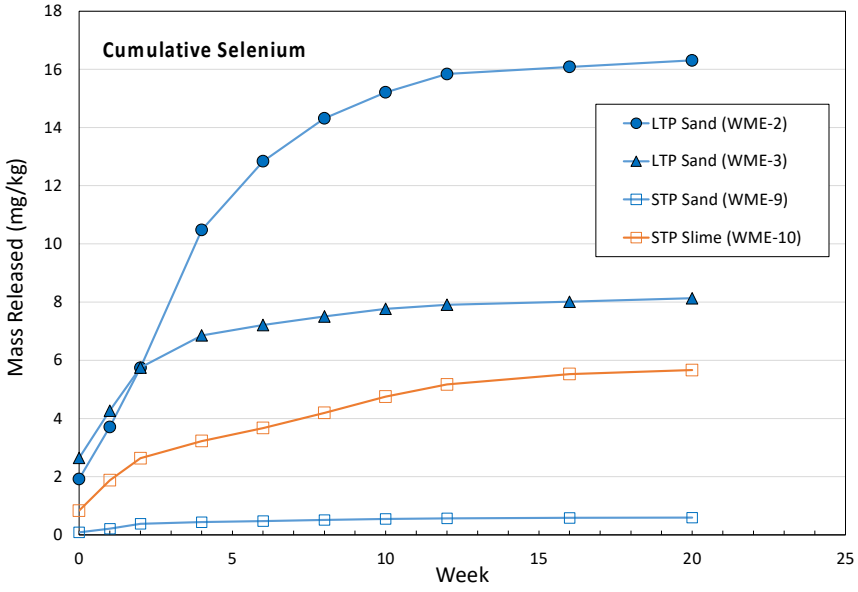
Figure 1.5-1
Control Boundary







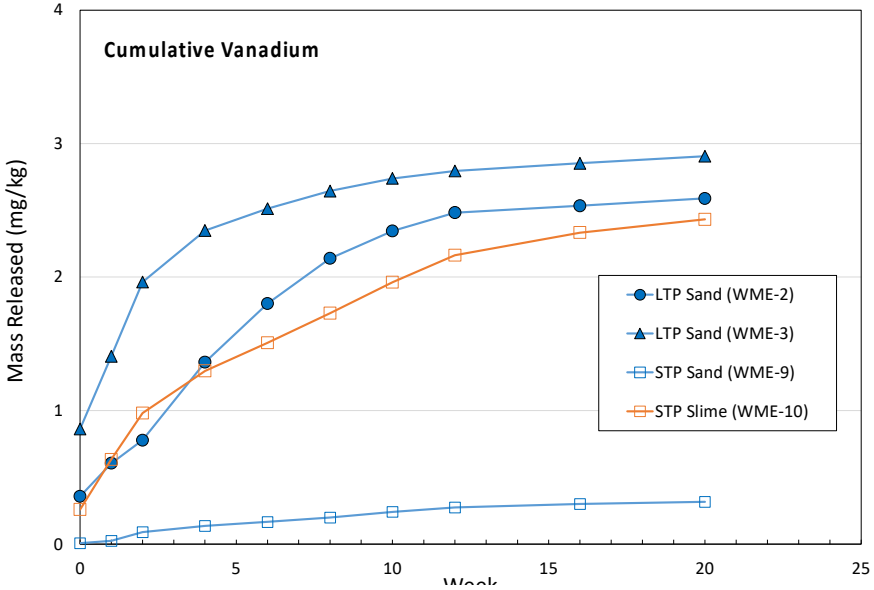


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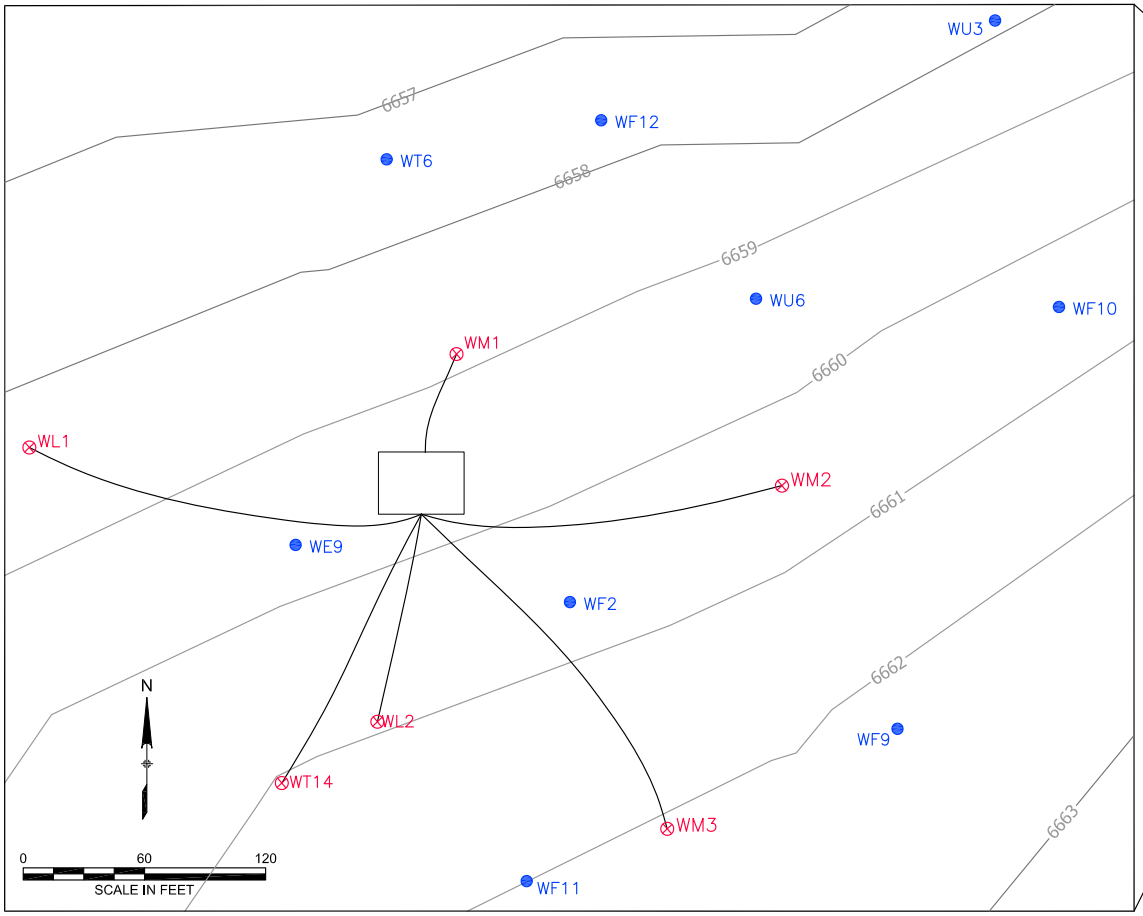
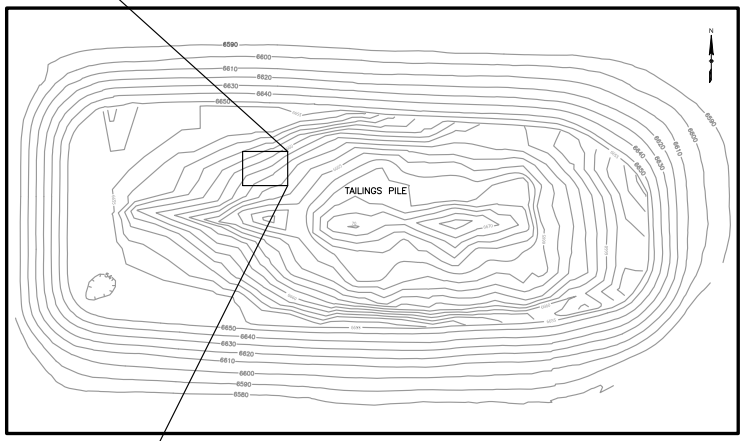
Figure 2.1-1
Cumulative Uranium, Molybdenum, Selenium, and Vanadium from Humidity Cell Tests





LEGEND:

6660 GROUND SURFACE ELEVATION (FEET MSL)

STPP PILOT MONITORING WELL LOCATION

STPP PILOT INJECTION WELL LOCATION

REMEDIATION SHED WITH TRACER TANK HOUSING

1/8" COPPER TUBING

REBOUND EVALUATION WELL NETWORK

PwP_opt_Log1

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Source: ARCADIS, 2012

Figure 2.1-2
Tailings Rebound Study Wells

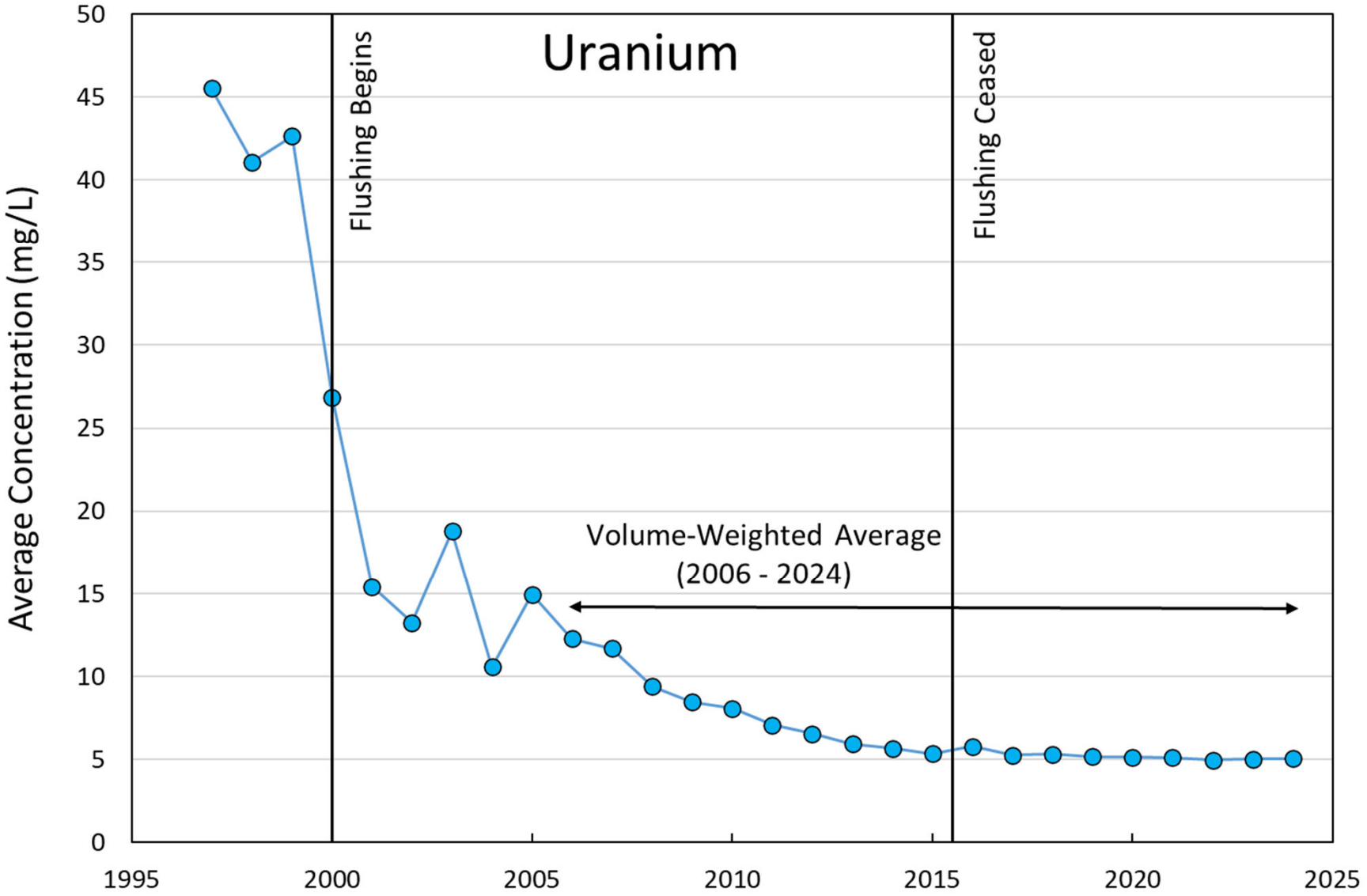

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Figure 2.1-3
Average Uranium Concentration for
Large Tailings Pile Wells (1997-2024)

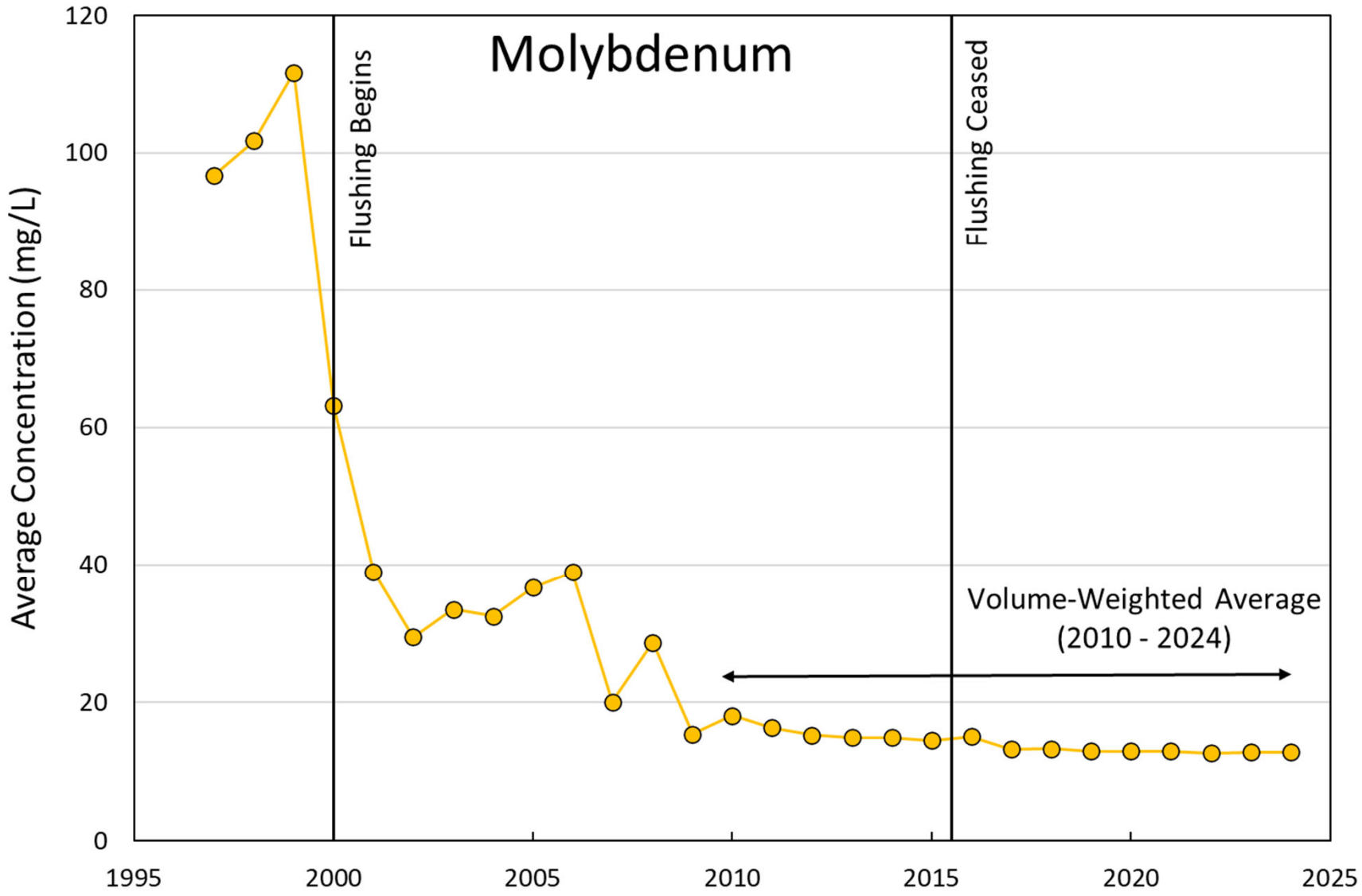

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Figure 2.1-4
Average Molybdenum Concentration for Large Tailings Pile Wells (1997-2024)

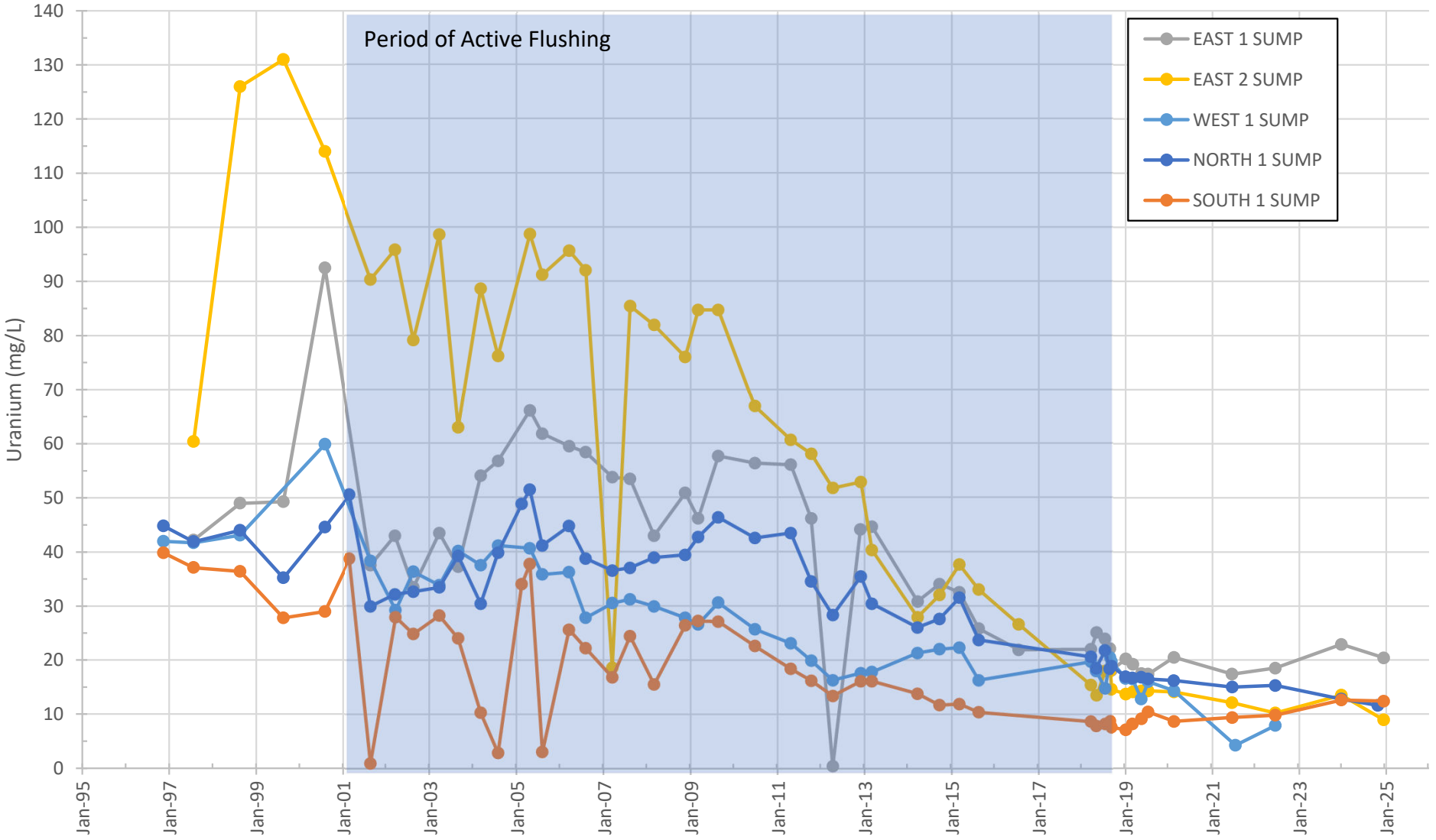

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Figure 2.1-5
Uranium Concentrations for Large Tailings Pile Sumps (1995-2024)

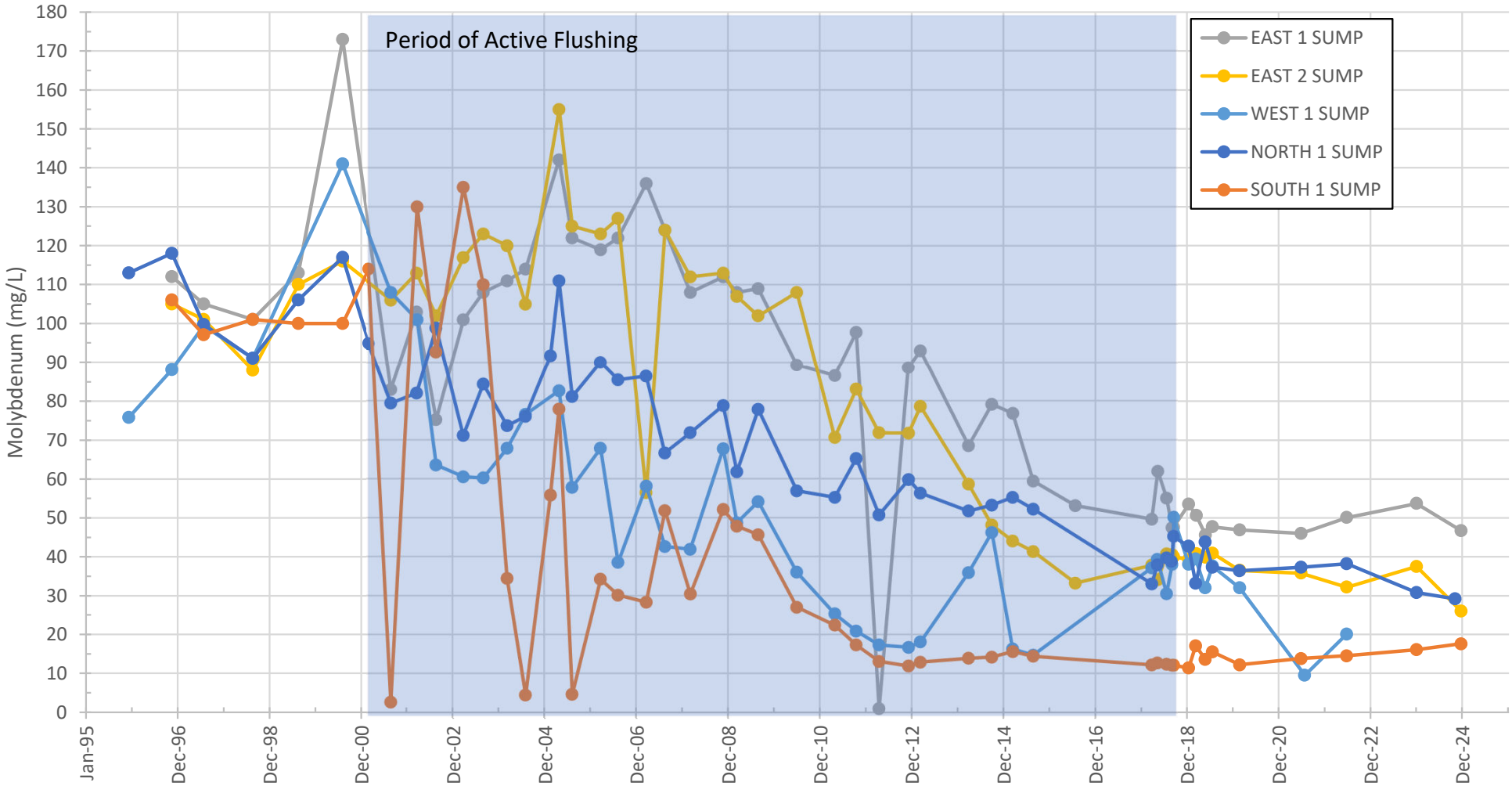

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Figure 2.1-6
Molybdenum Concentrations for Large Tailings Pile Sumps (1995-2024)

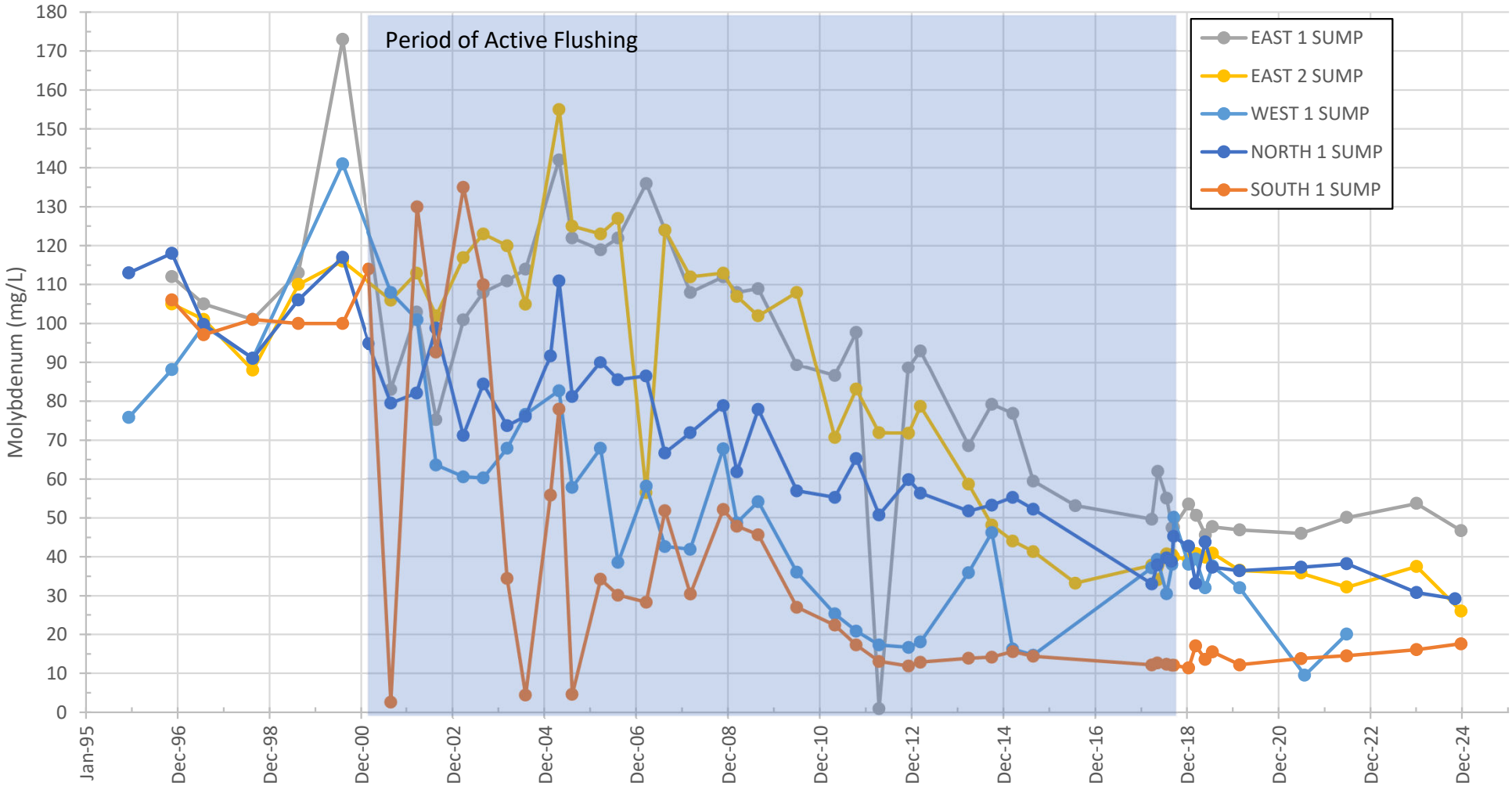

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Figure 2.1-7
Selenium Concentrations for Large Tailings Pile Sumps (1995-2024)

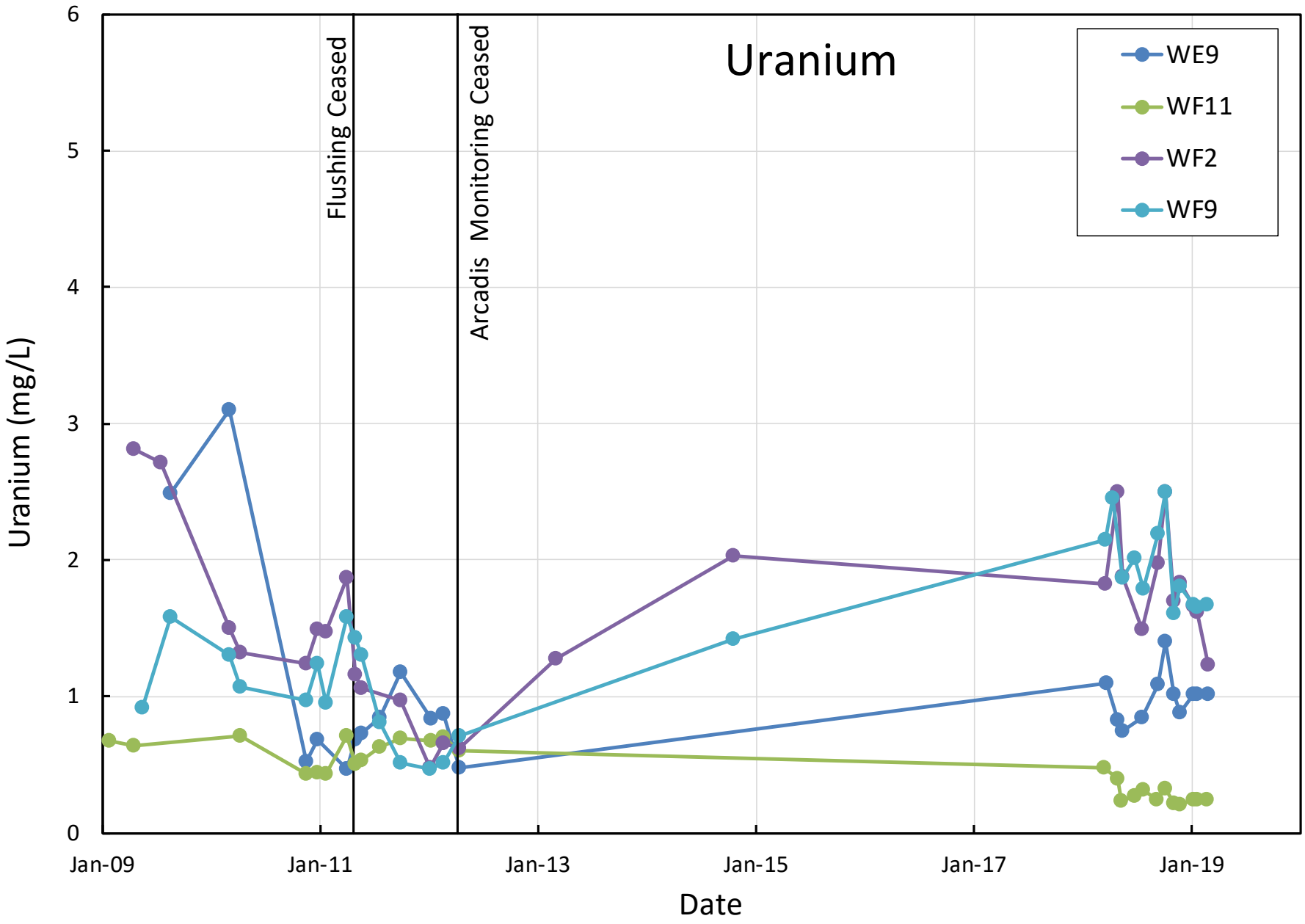

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Figure 2.1-8
Uranium Concentrations for Large Tailings Pile Arcadis Wells (2009-2019)

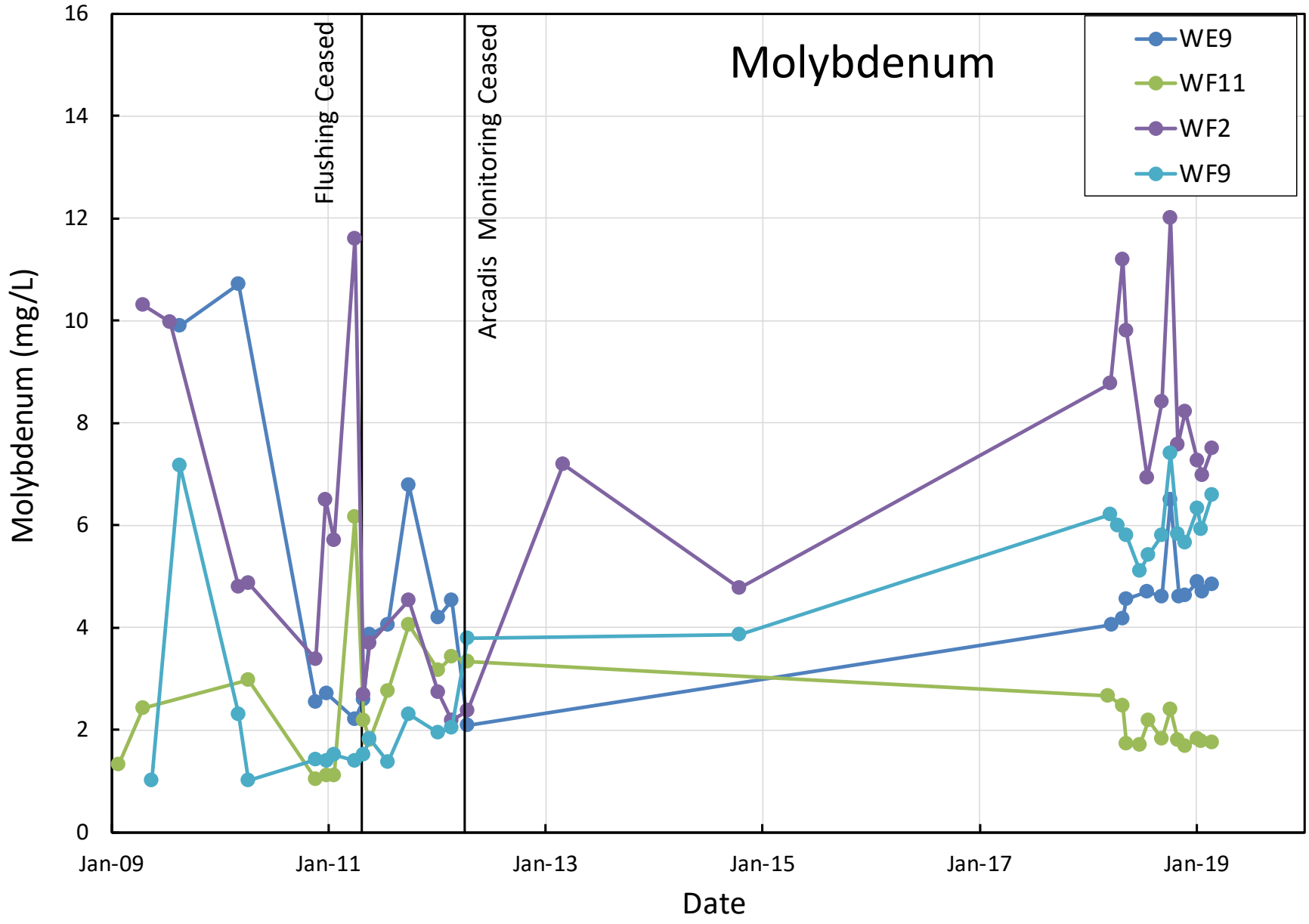

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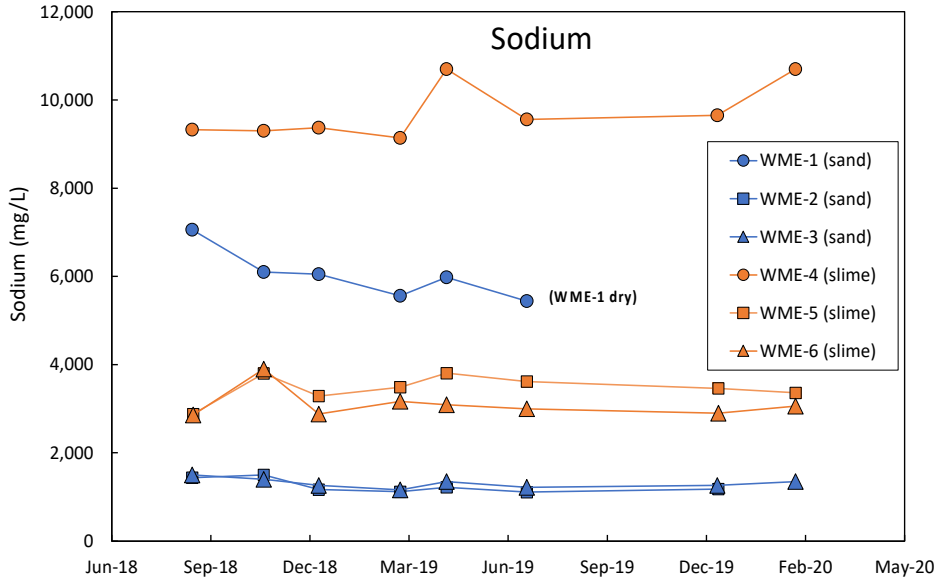
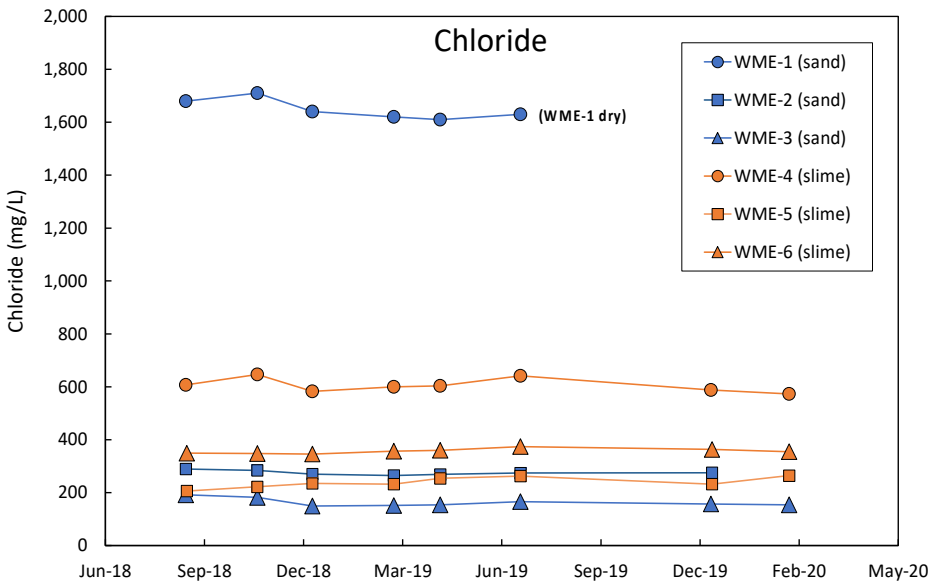
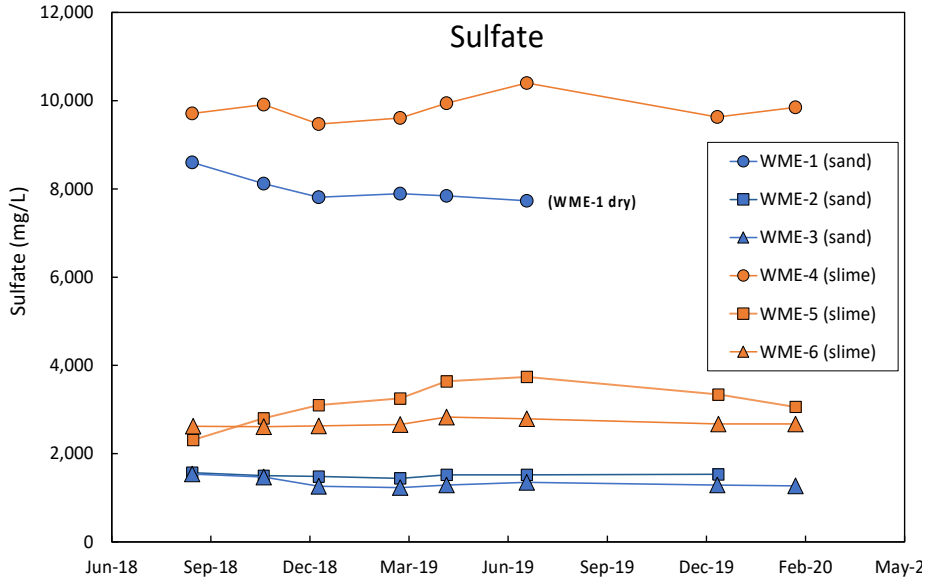
Figure 2.1-9
Molybdenum Concentrations for Large Tailings Pile Arcadis Wells (2009-2019)







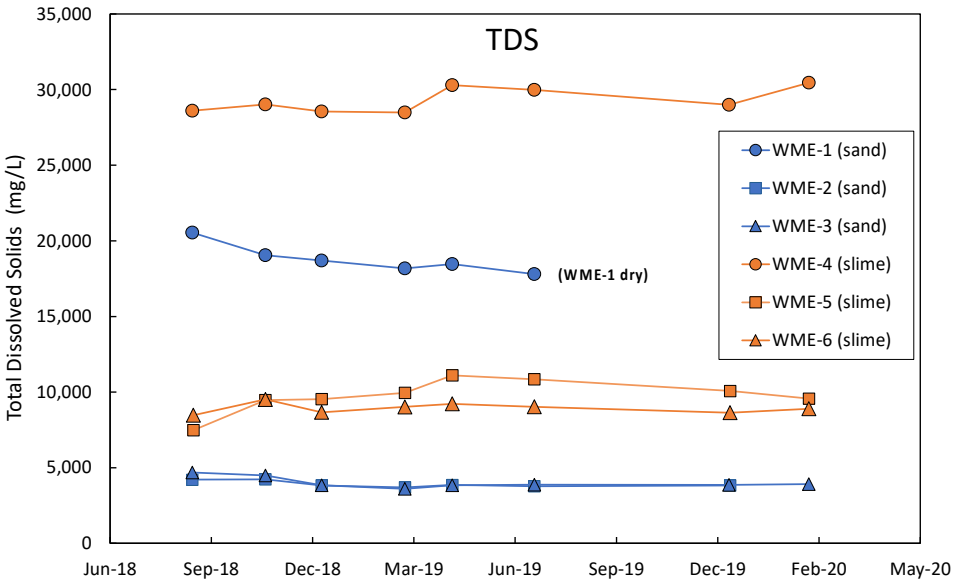


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Figure 2.1-10
Concentration Trends in Short-Screen Large Tailings Pile Wells

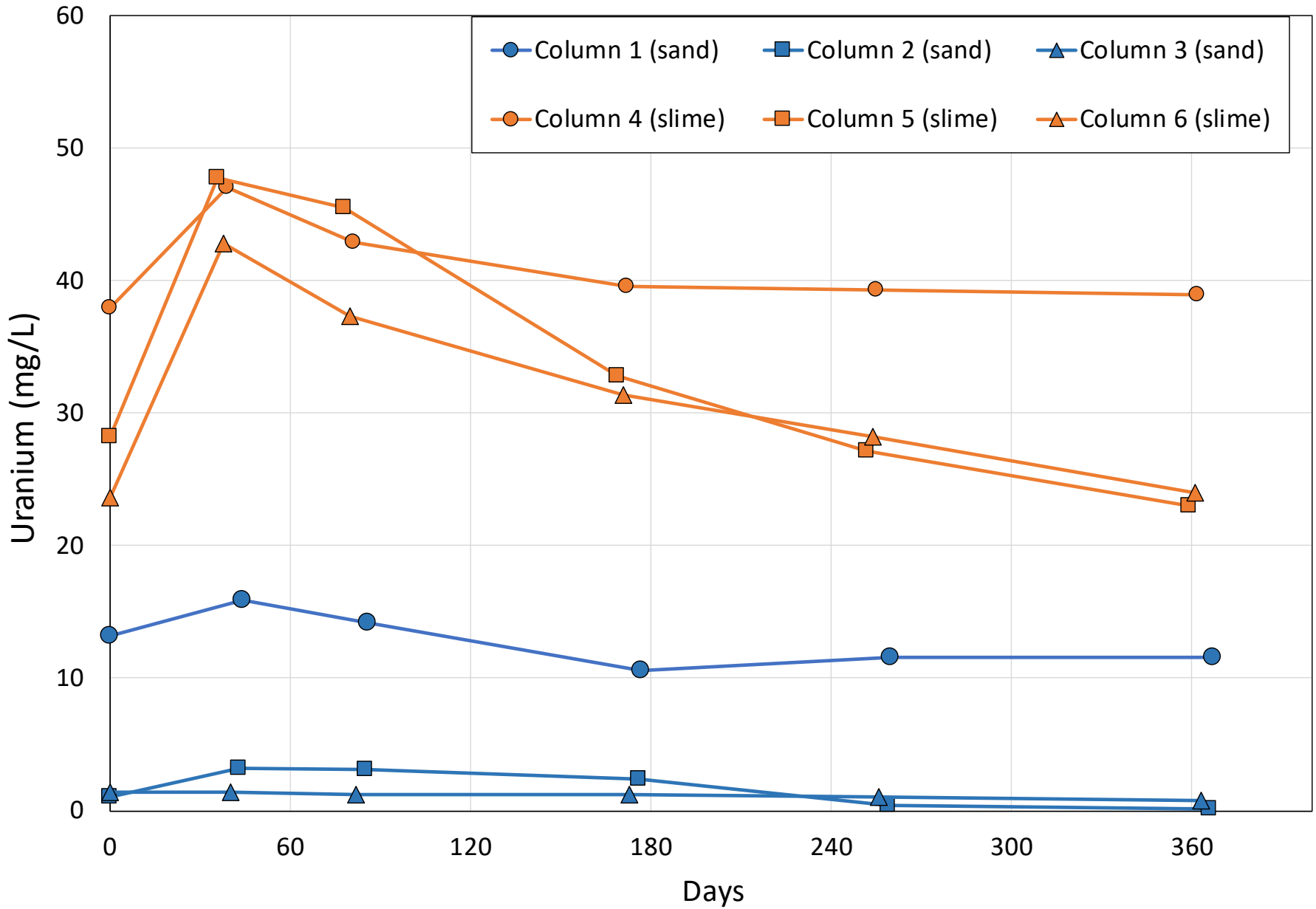

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Figure 2.1-11
Uranium Concentrations in
Large Tailings Pile Static Columns

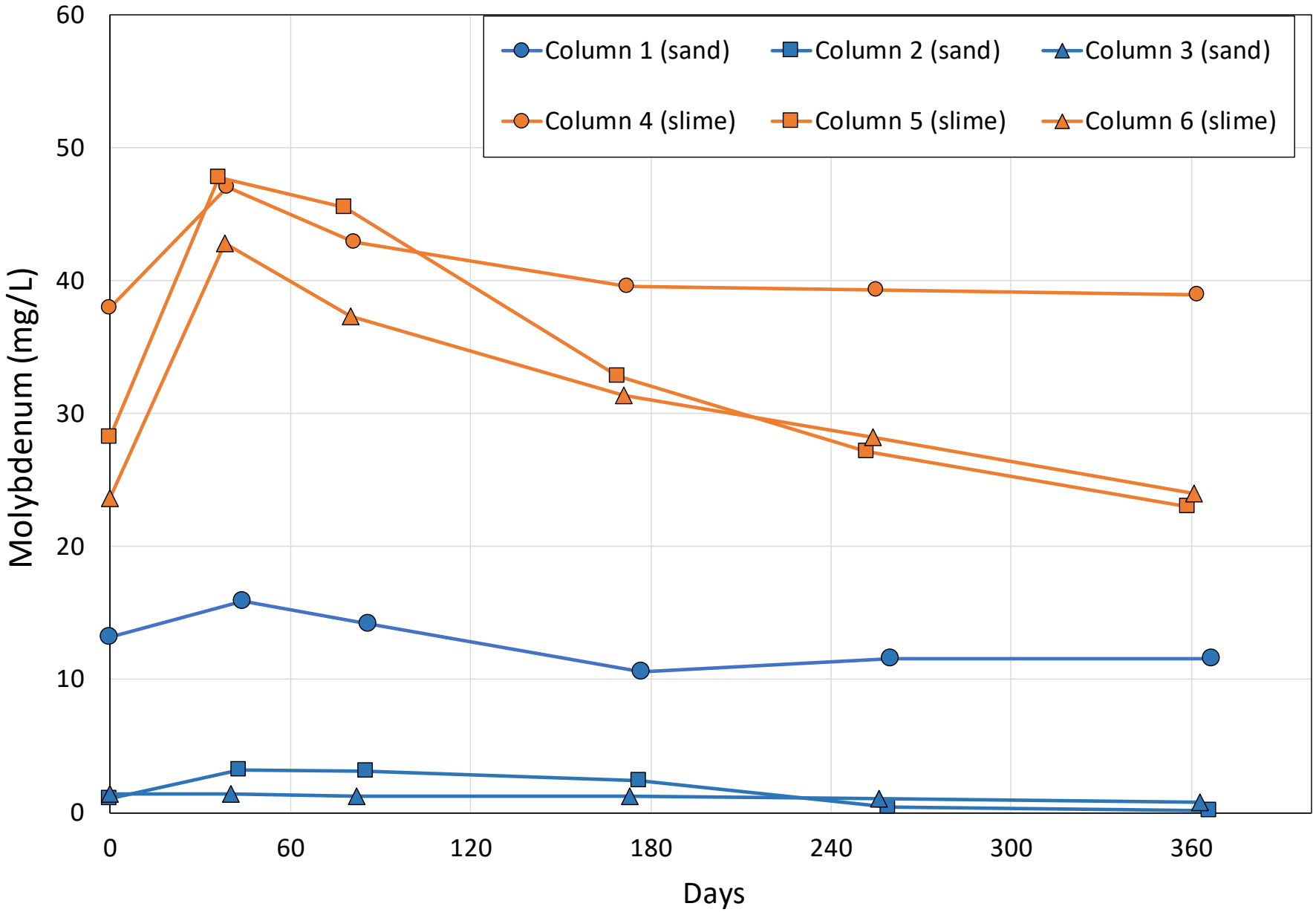

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Figure 2.1-12
Molybdenum Concentrations in
Large Tailings Pile Static Columns

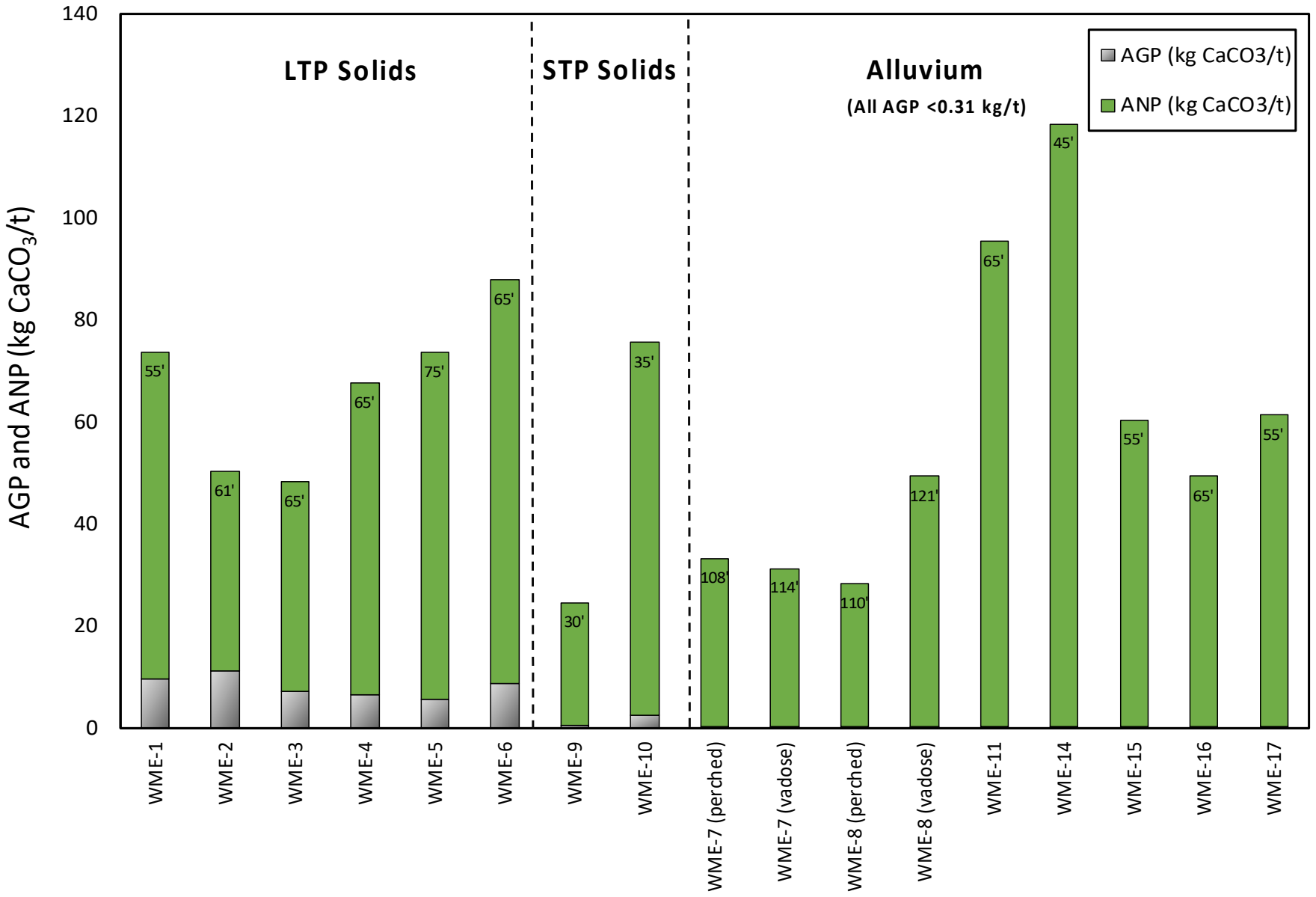

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Figure 2.1-13
Acid Base Accounting Results for AGP and ANP in Tailings and Alluvium

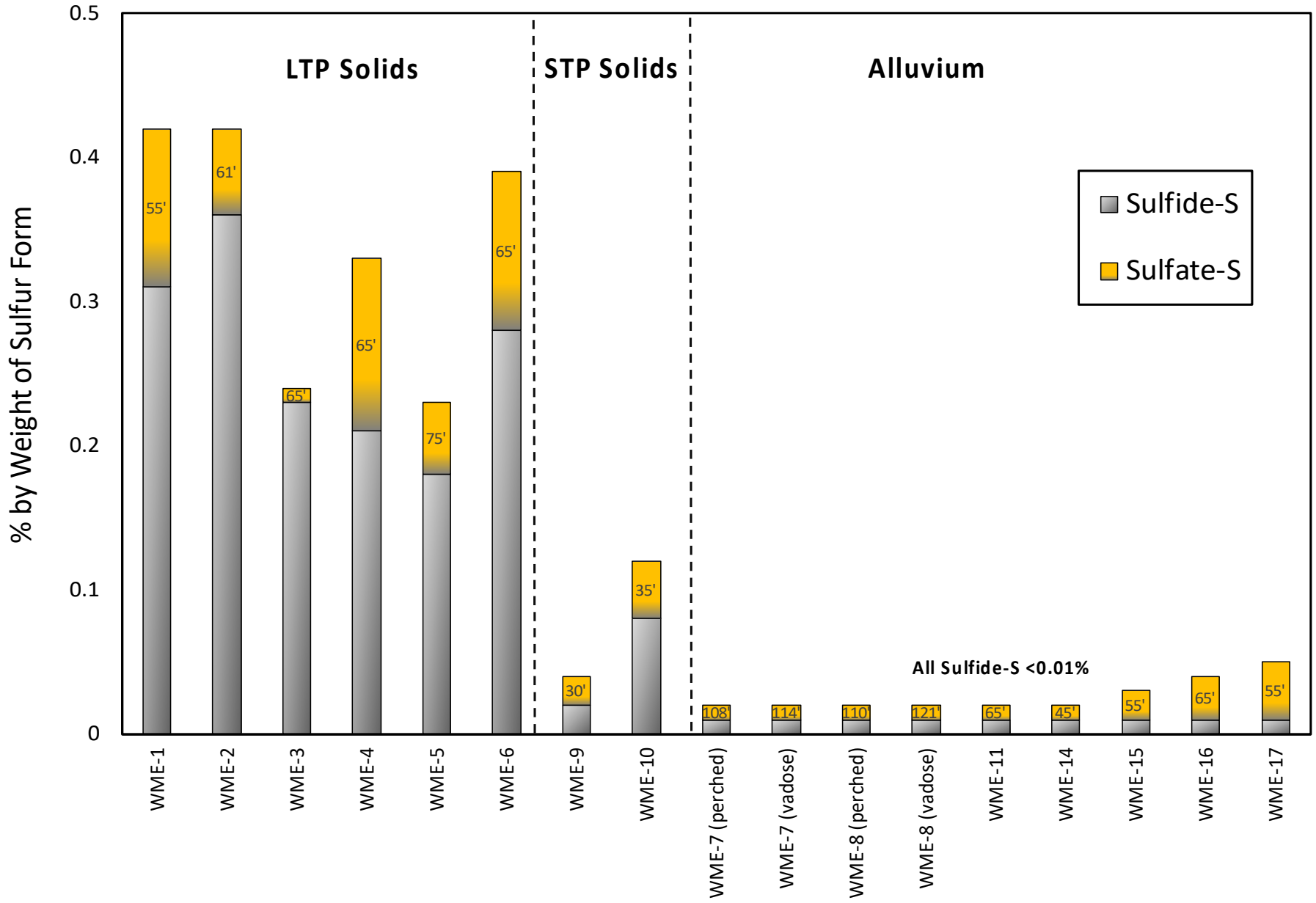

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Figure 2.1-14
Acid Base Accounting Results for Sulfur Forms in Tailings and Alluvium

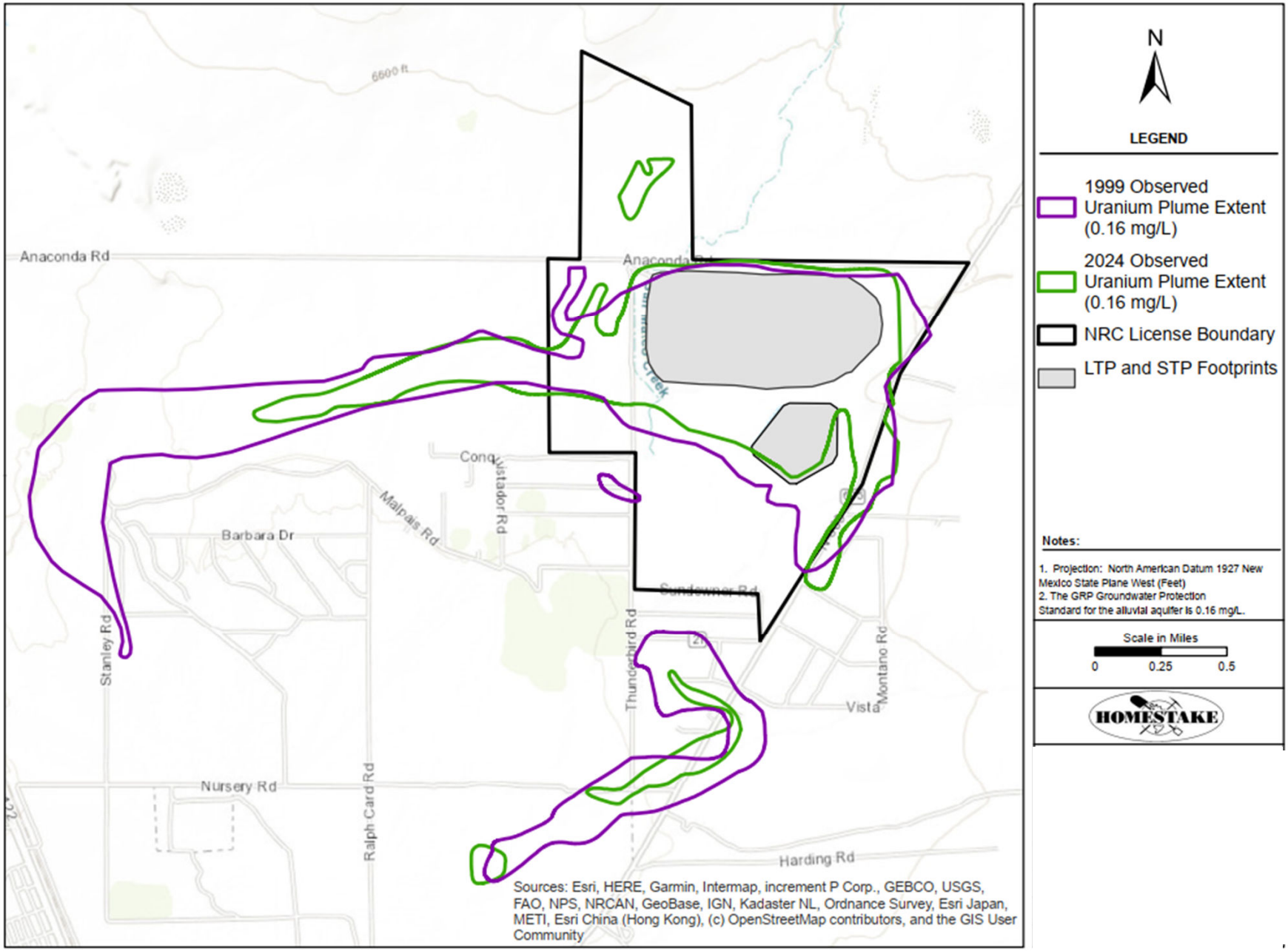

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Figure 3.1-1
Alluvial Aquifer Uranium
Plume Extent - 1999 vs. 2024

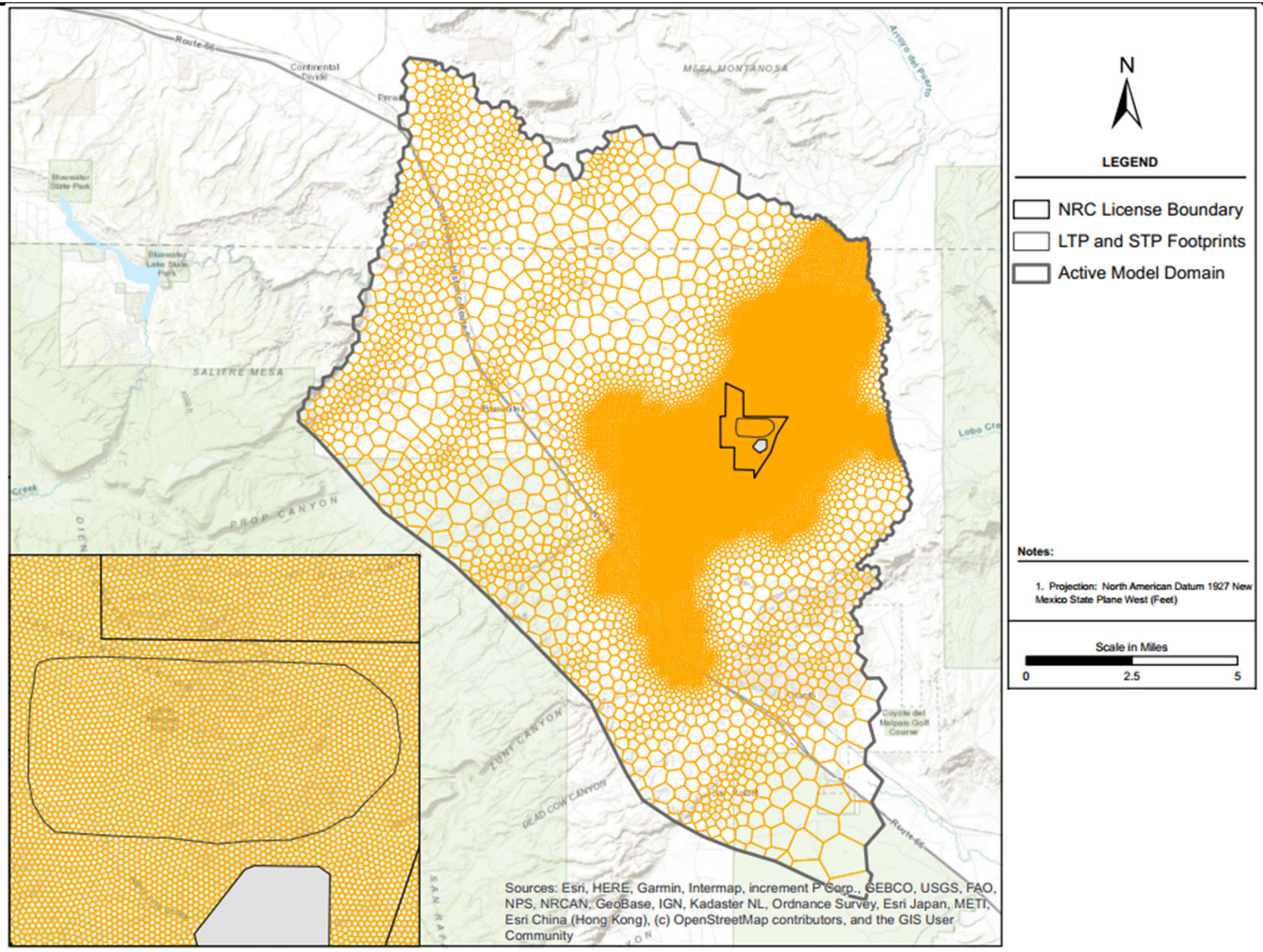

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Figure 3.1-2
Groundwater Model Voronoi Polygon Unstructured Grid

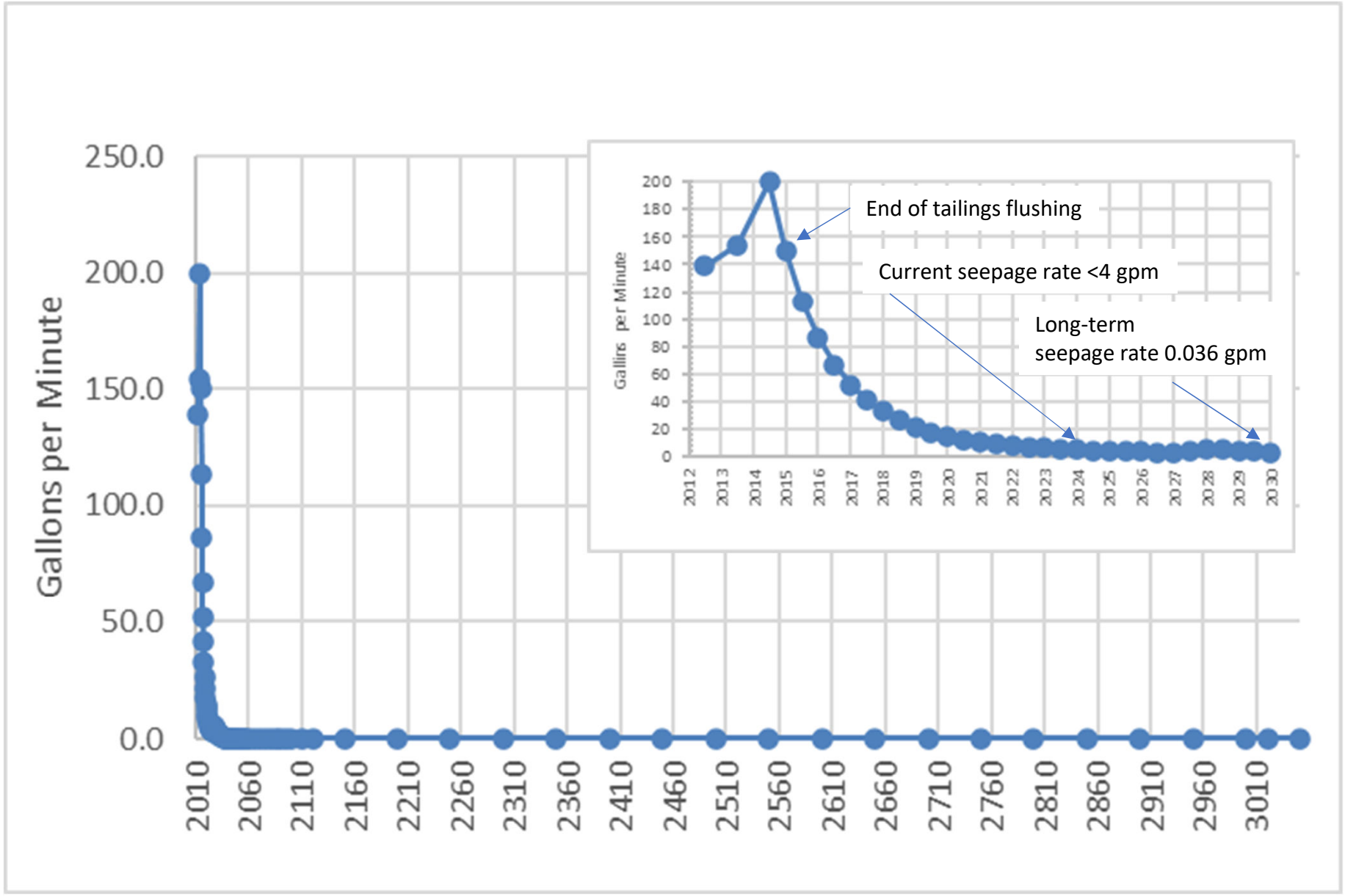

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Figure 3.1-3
Large Tailings Pile
Predicted Seepage Rates

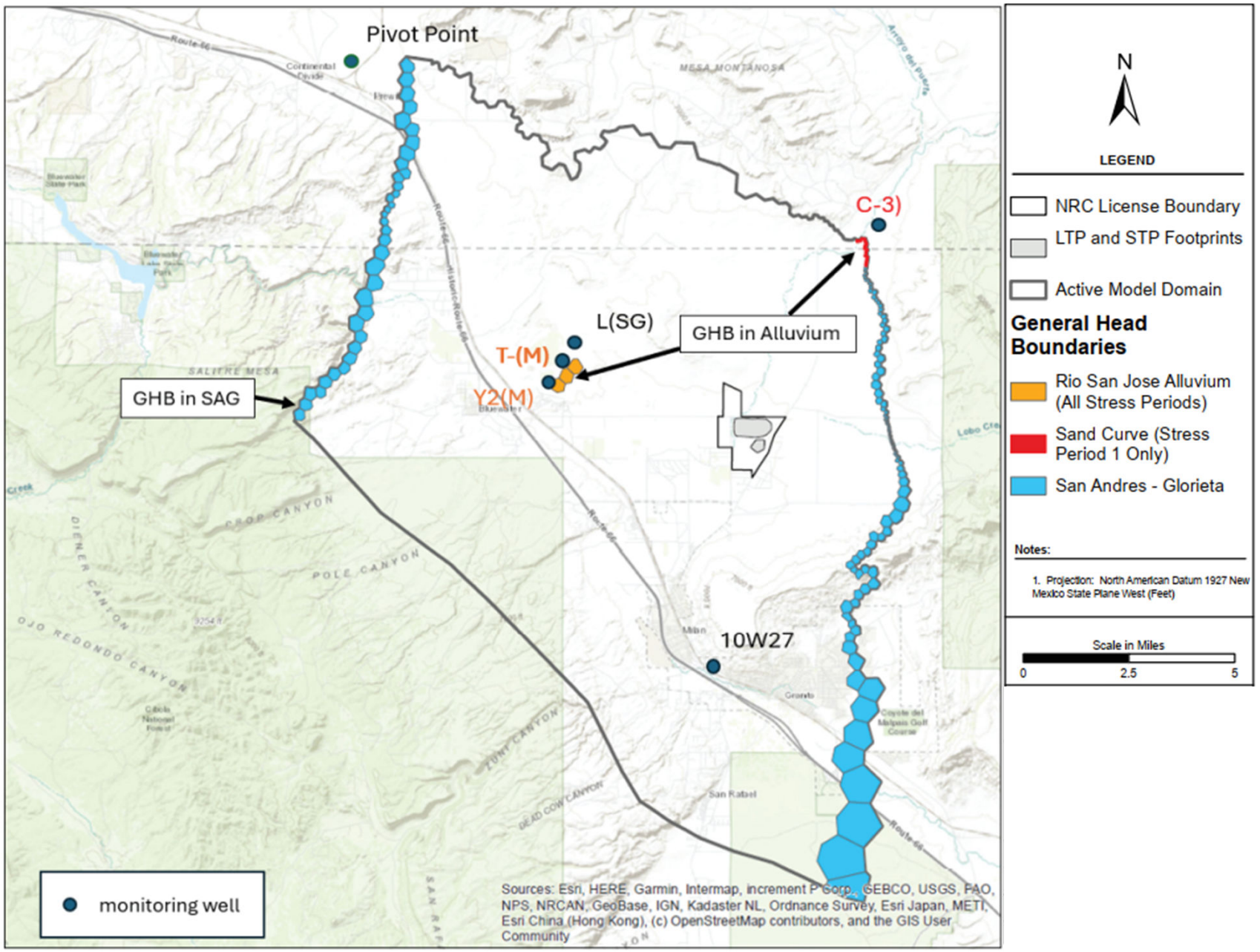

Figure 3.1-4
General Head Boundaries

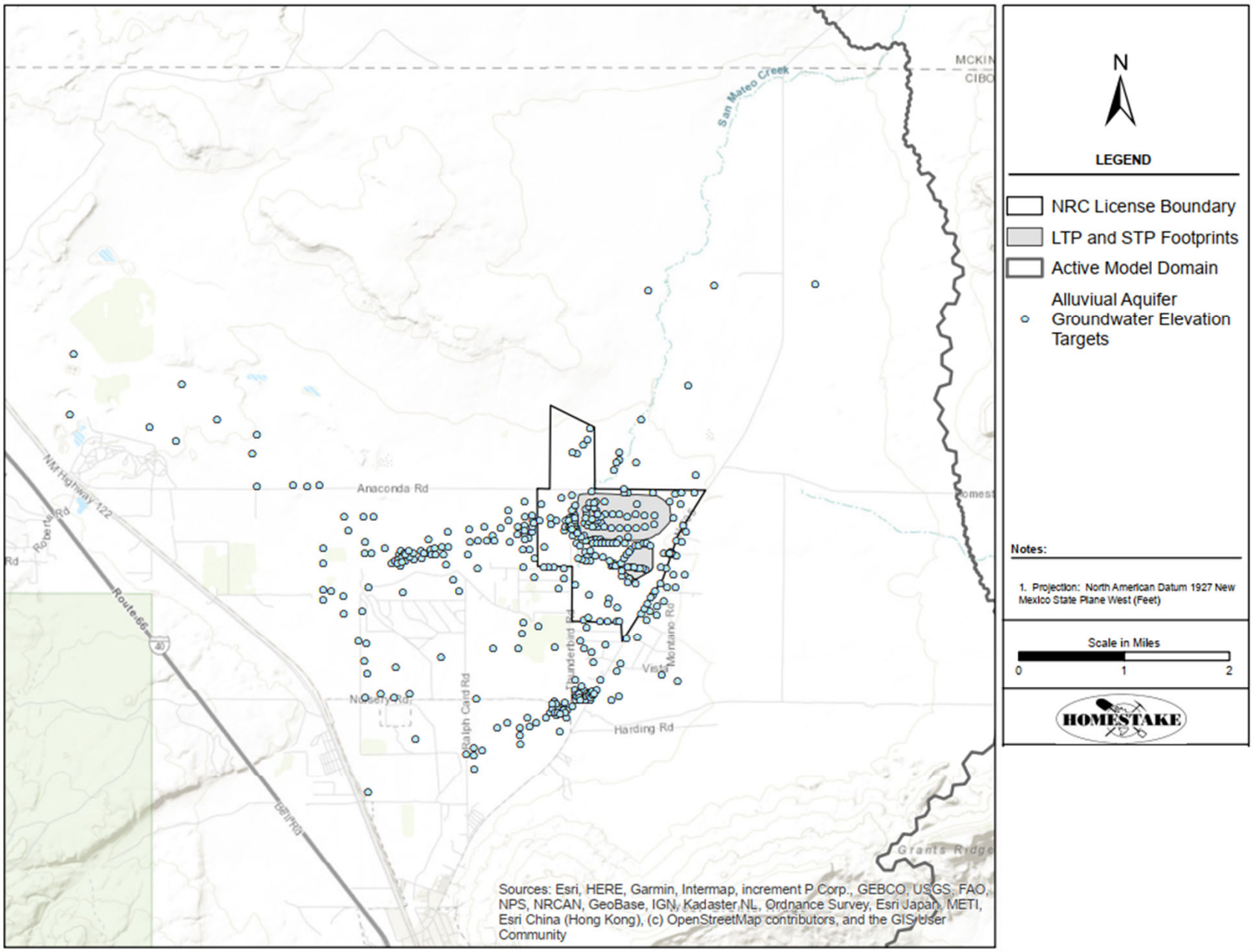

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Figure 3.1-5
Alluvial Groundwater
Elevation Target Locations

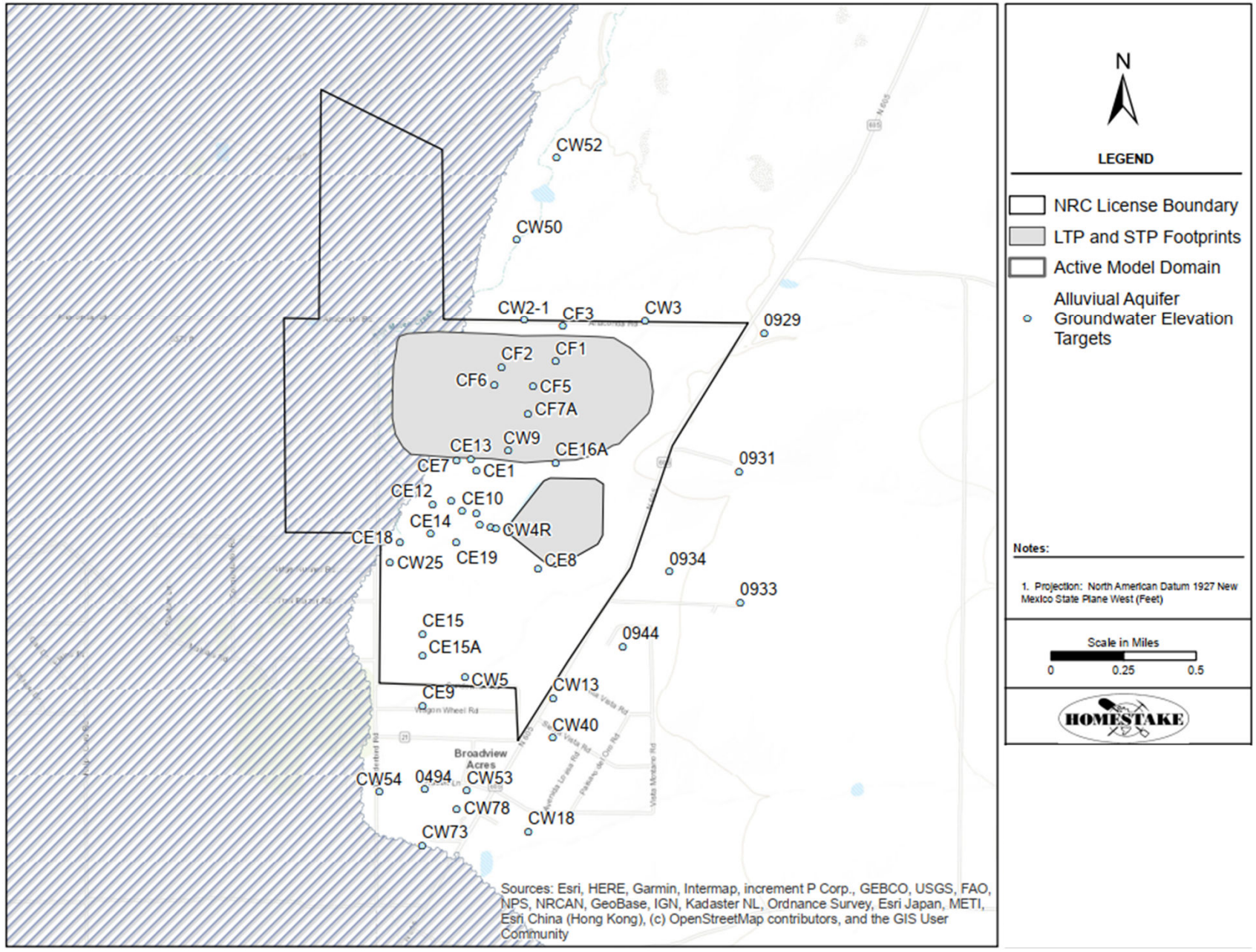

Figure 3.1-6
Upper Chinle Groundwater Elevation Target Locations

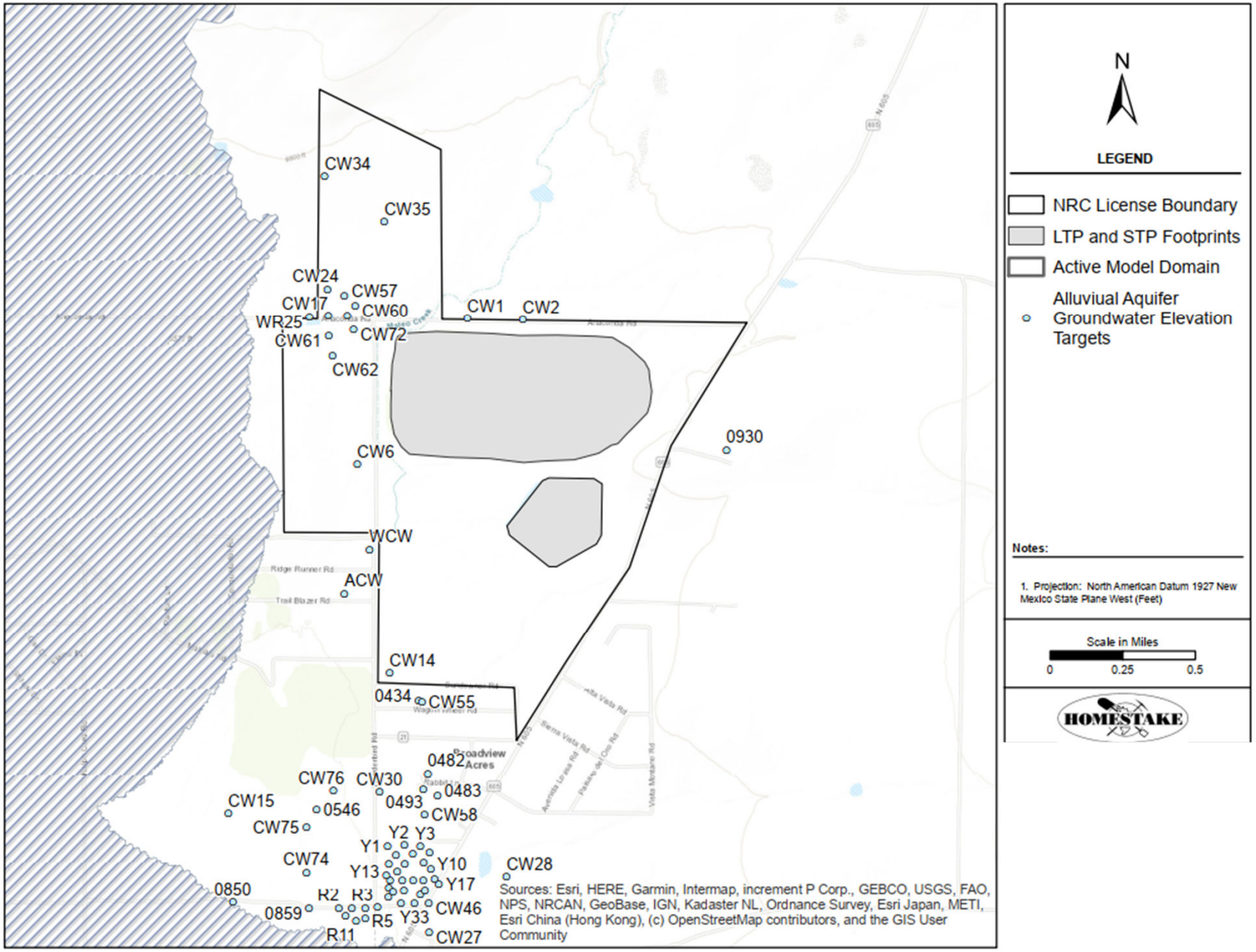

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Figure 3.1-7
Middle Chinle Groundwater Elevation Target Locations

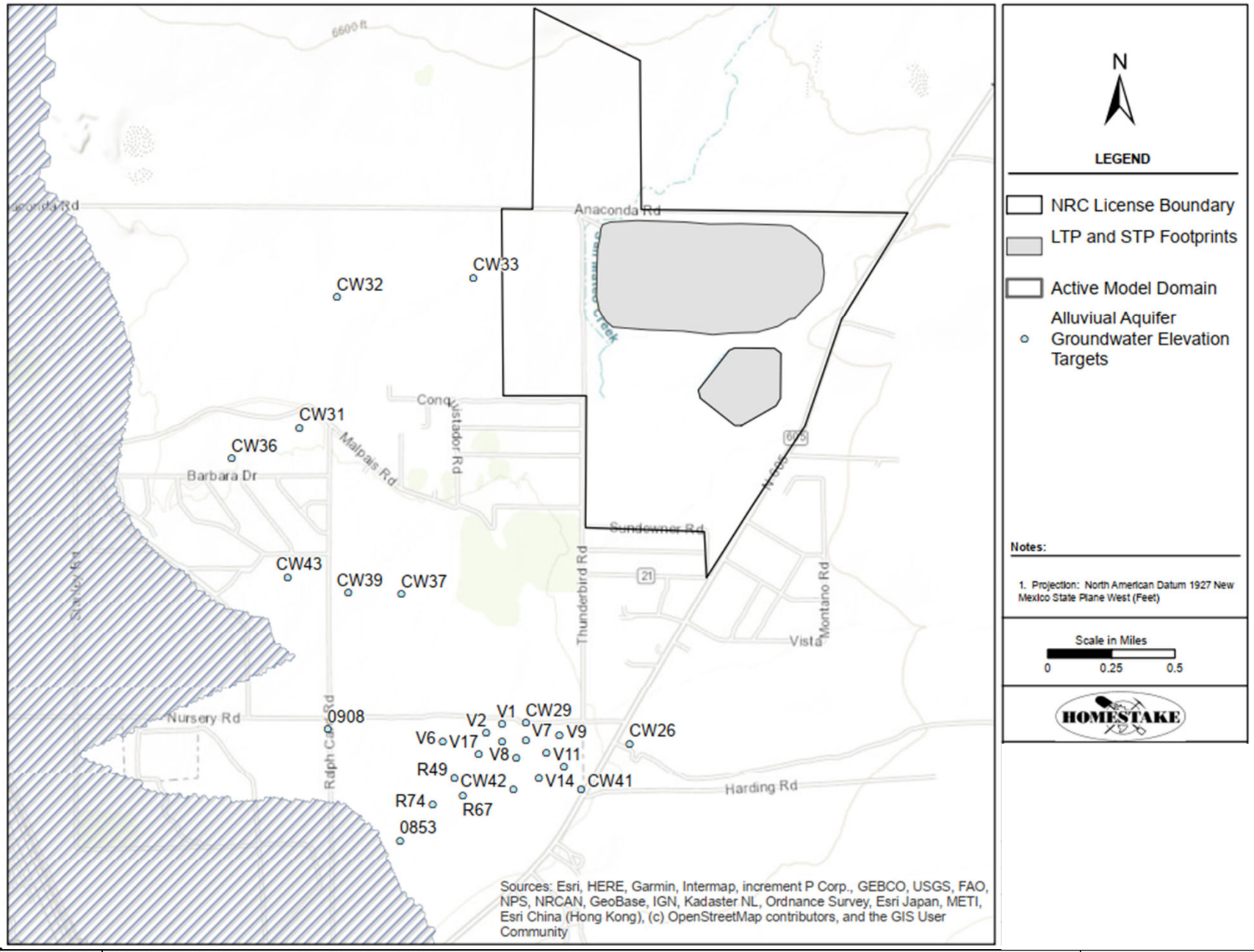
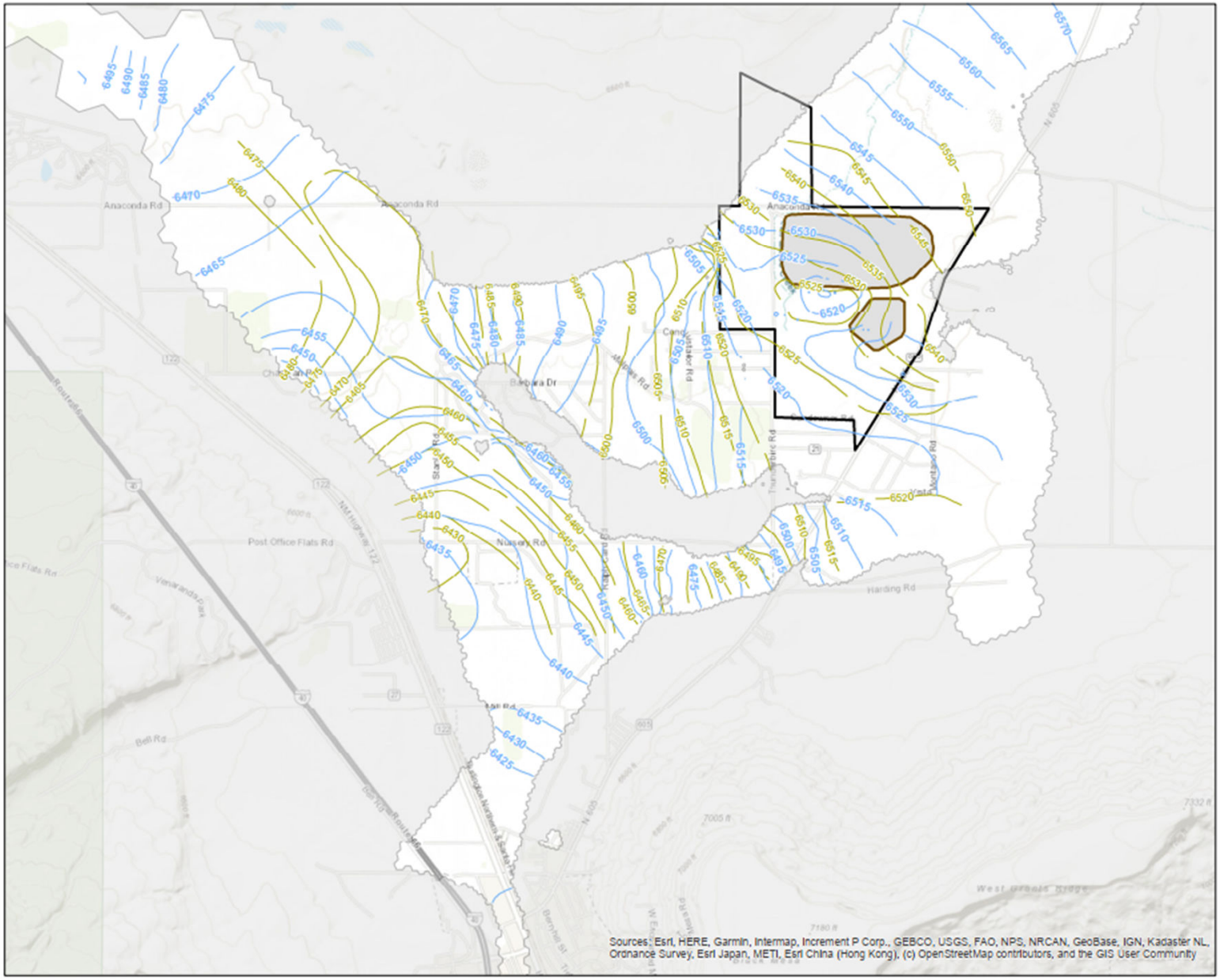


Figure 3.1-8
Lower Chinle Groundwater Elevation Target Locations



N

LEGEND

- Simulated Dry Cells
- Simulated 2024 Alluvial Aquifer Groundwater Elevation Contours
- Observed 2024 Alluvial Aquifer Groundwater Elevation Contours
- NRC License Boundary
- LTP and STP Footprints

Notes

1. Projection: North American Datum 1927 New Mexico State Plane West (Feet)

0 1,000 2,000 4,000 Feet

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Figure 3.1-9
Alluvial Aquifer Simulated vs Observed 2024 Groundwater Elevation Contours

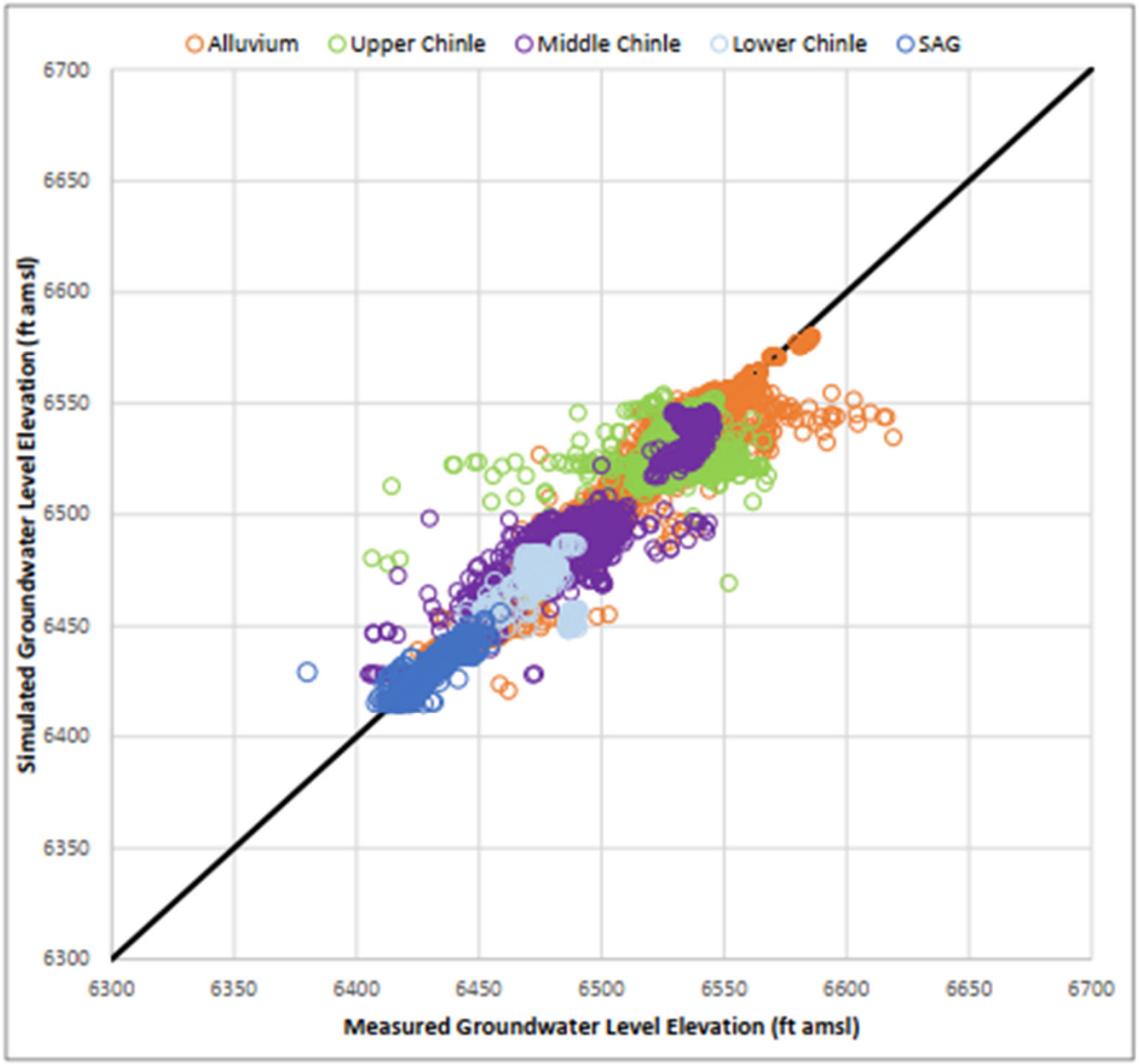

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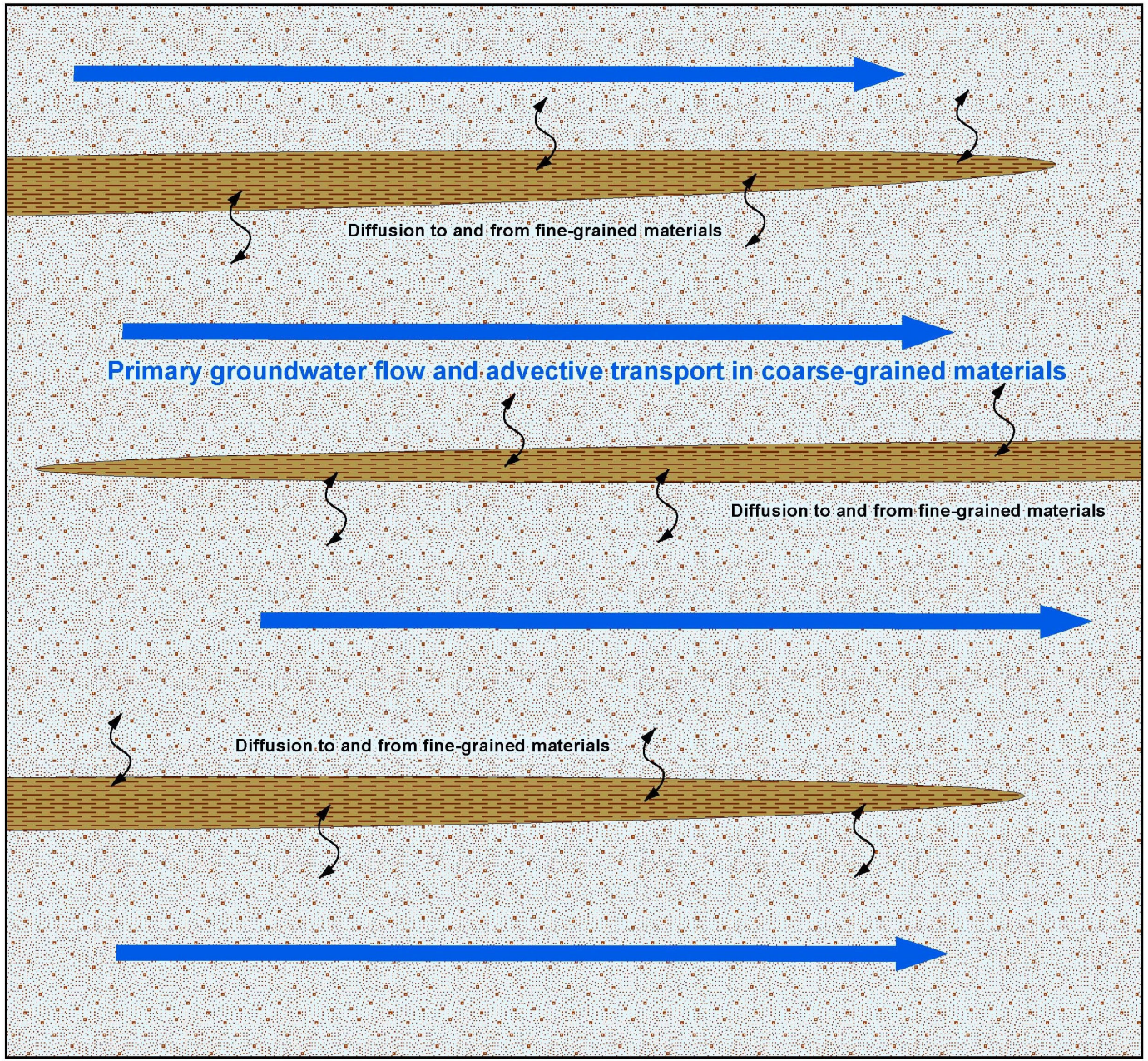
Figure 3.1-10
Simulated versus Measured
Groundwater Elevations



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Coarse-Grained Materials

Fine-Grained Materials

Notes:

Not to Scale

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Figure 3.1-11
Conceptual Dual-Porosity
Transport in Alluvium

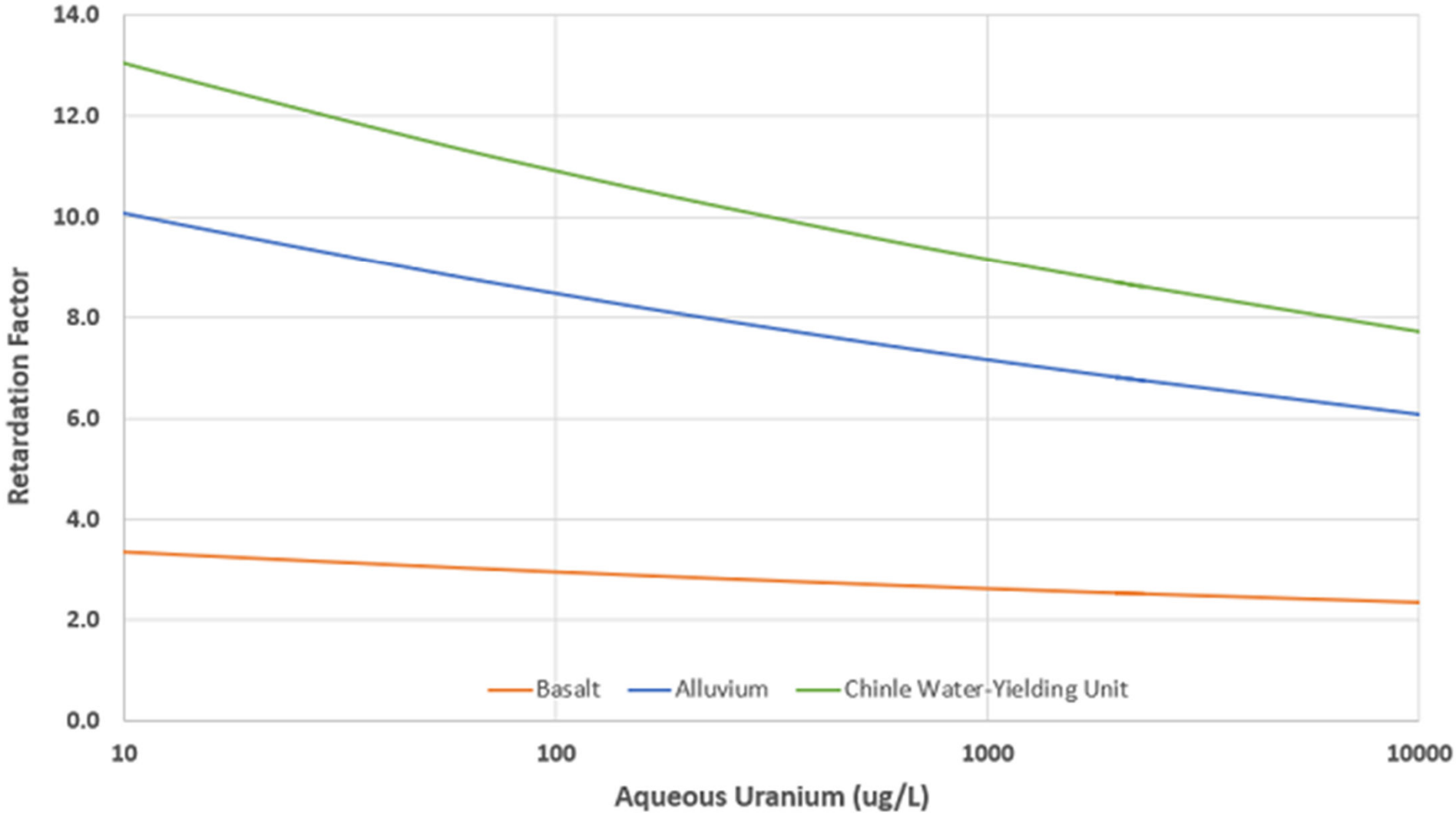

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Figure 3.1-12
Simulated Retardation and Aqueous Uranium Concentration Relationships

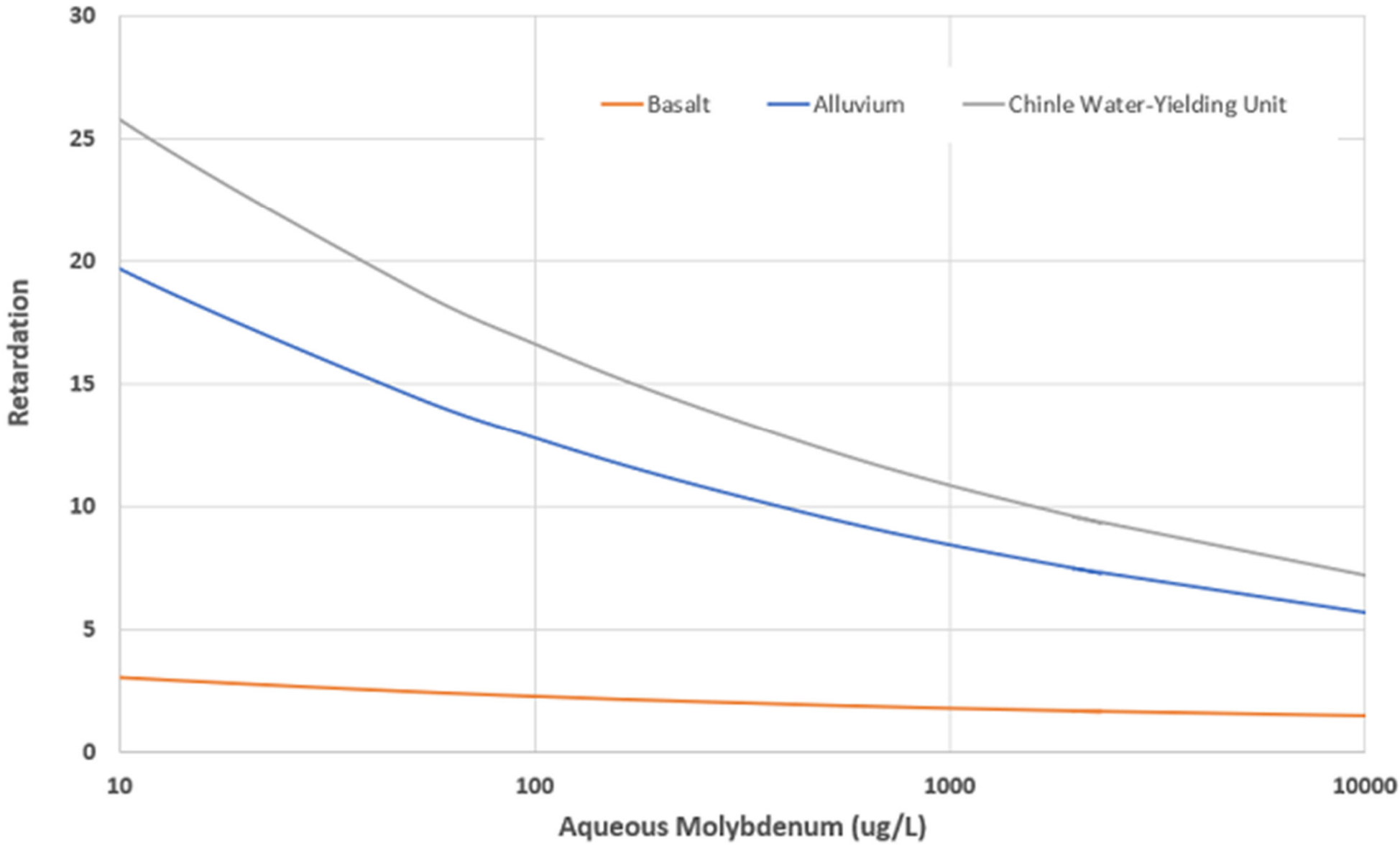

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Figure 3.1-13
Simulated Retardation and Aqueous Molybdenum Concentration Relationships

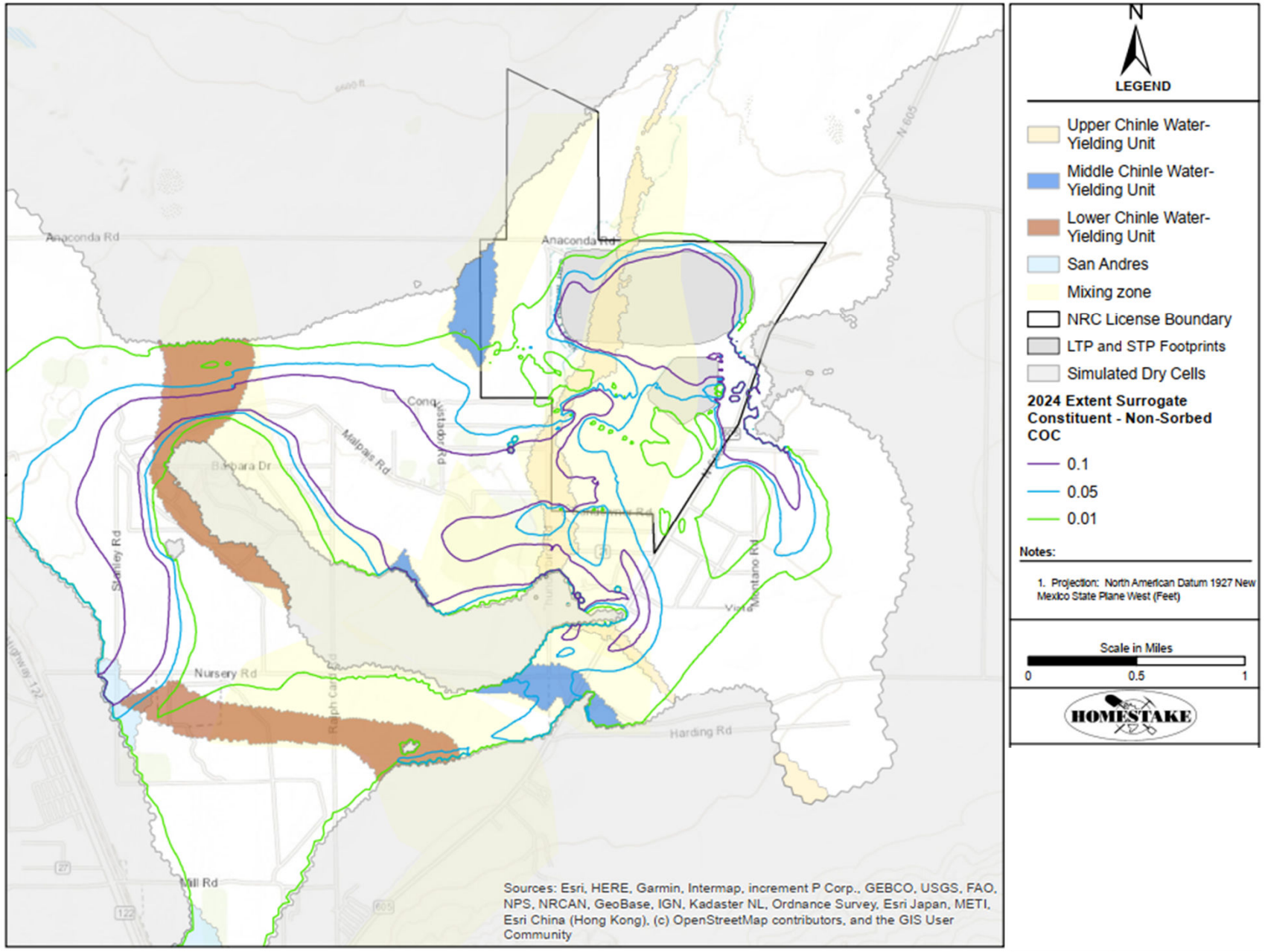

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Figure 3.2-1
Surrogate Conservative Constituent
2024 Extent Non-Sorb COC

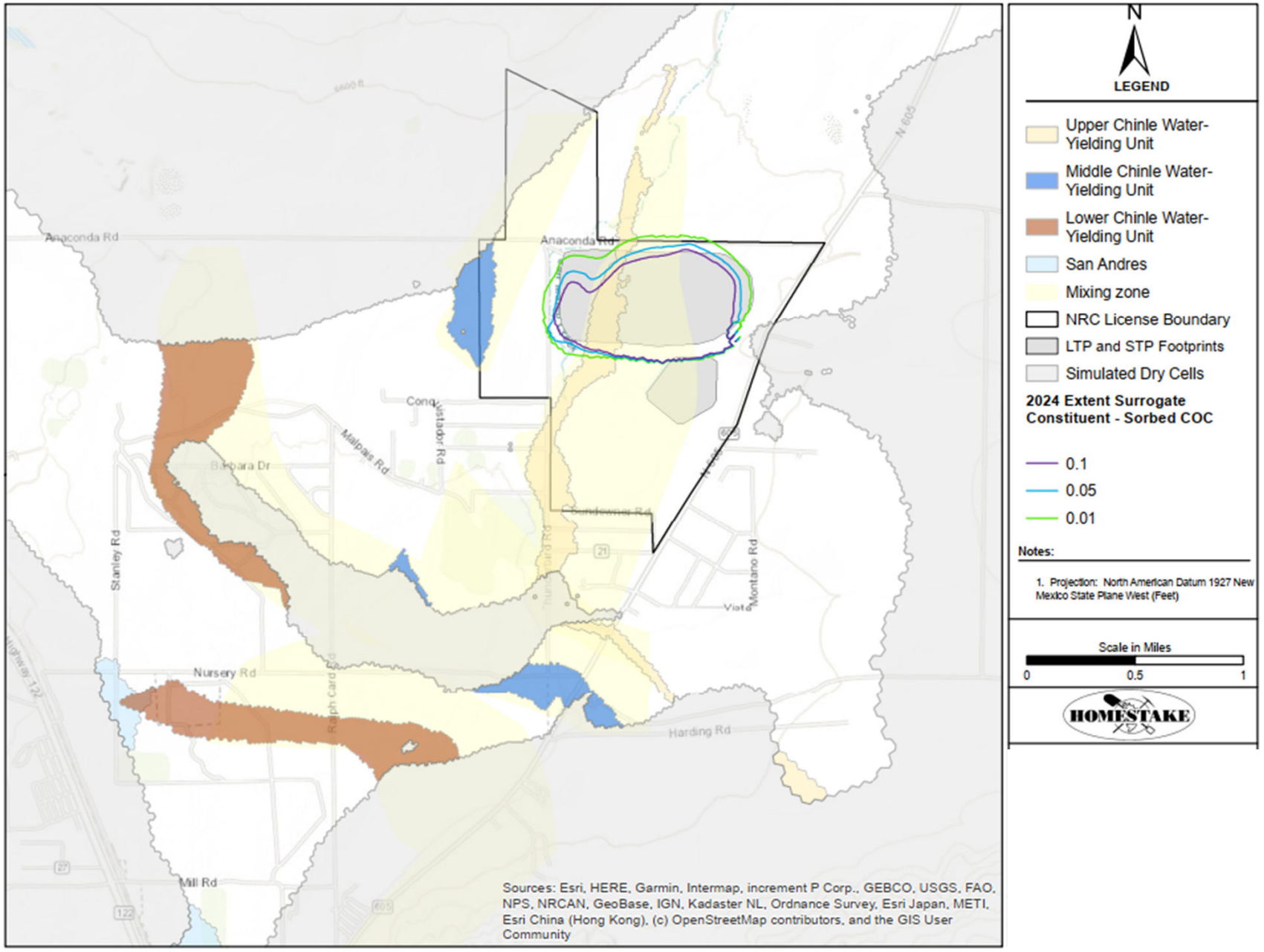

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Figure 3.2-2
Surrogate Conservative Constituent
2024 Extent - Sorb COC

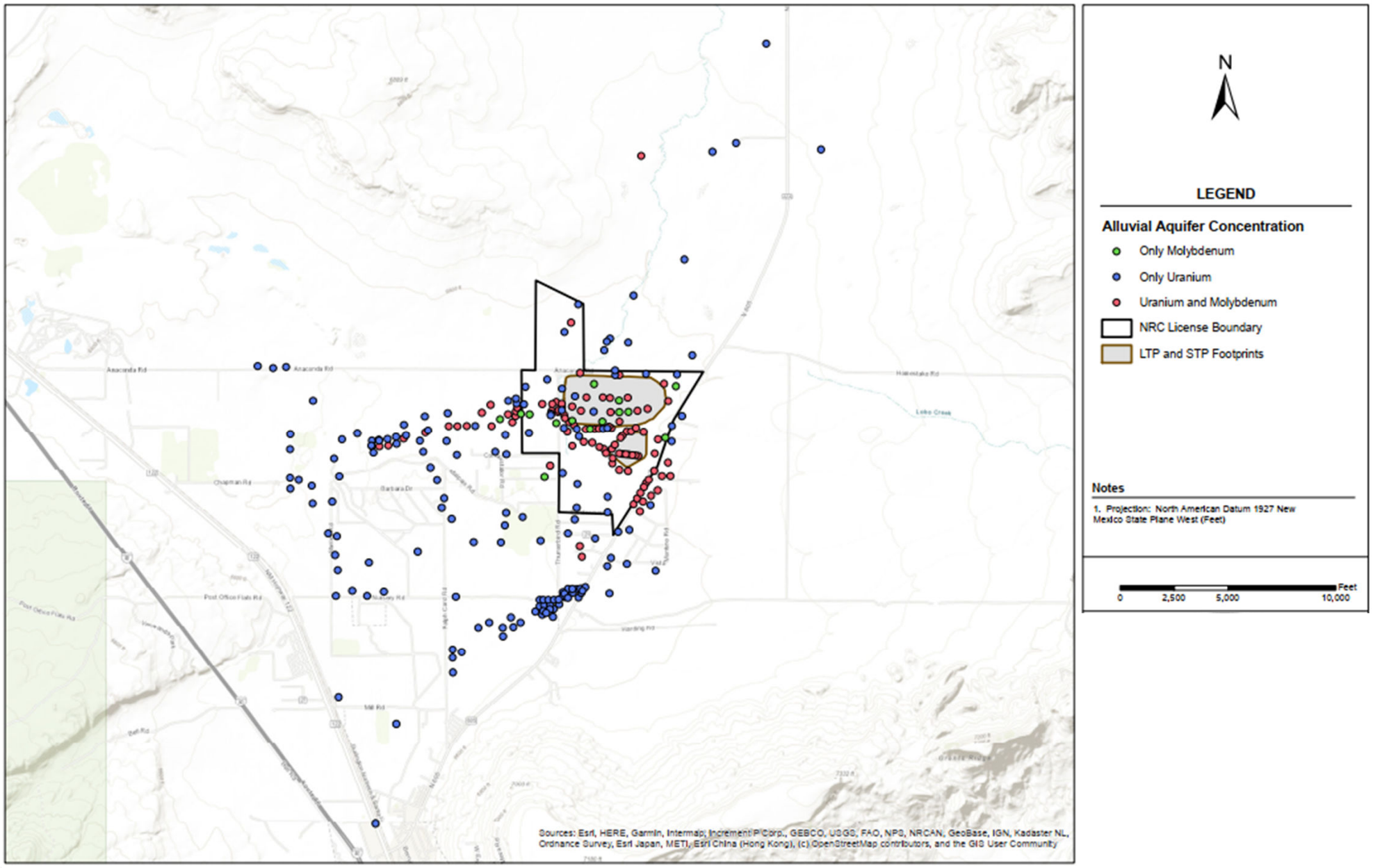

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Figure 3.3-1
Alluvial Groundwater Constituent Concentration Target Locations (Layer 1)

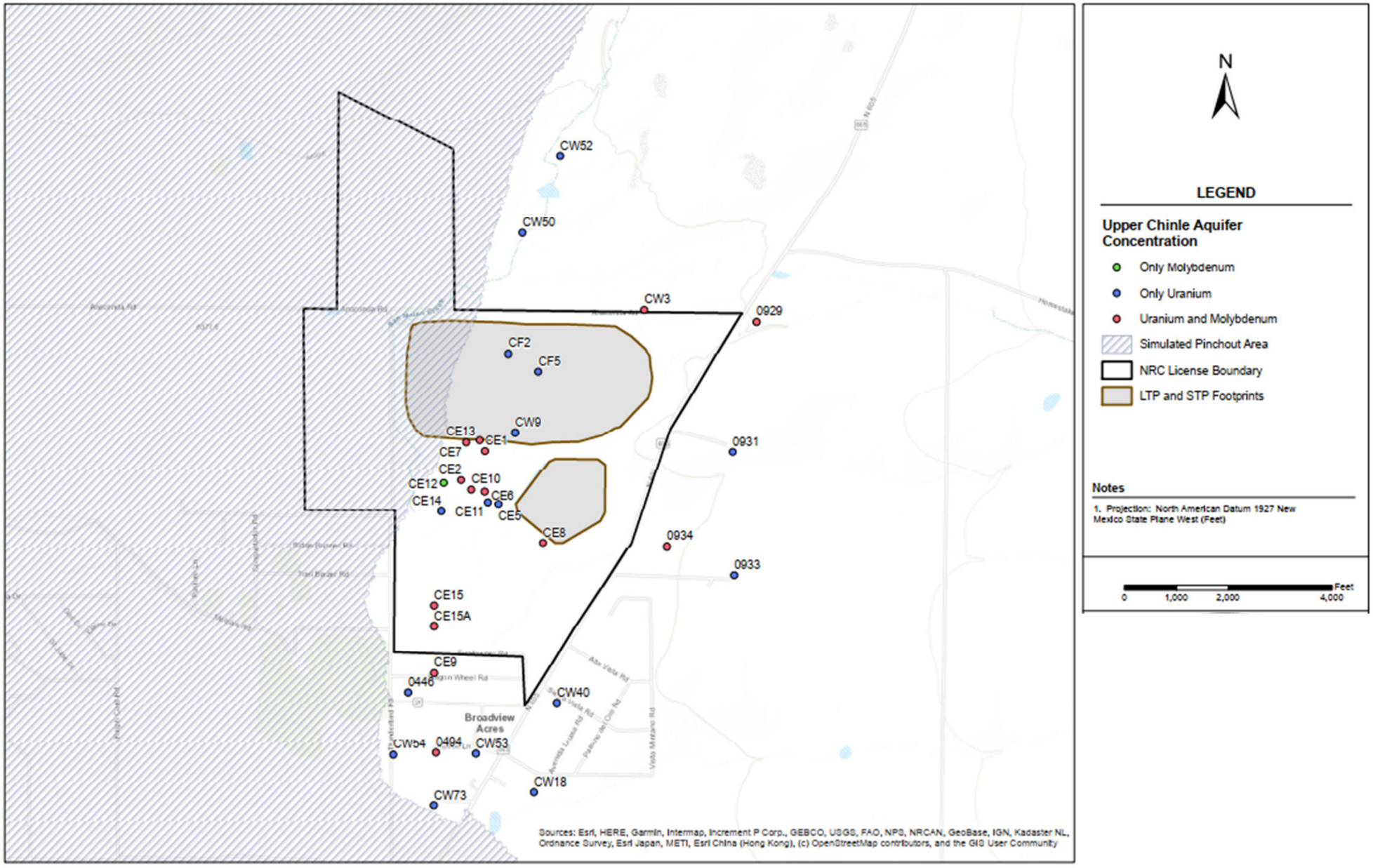

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Figure 3.3-2
Upper Chinle Groundwater Constituent Concentration Target Locations
(Layer 4)

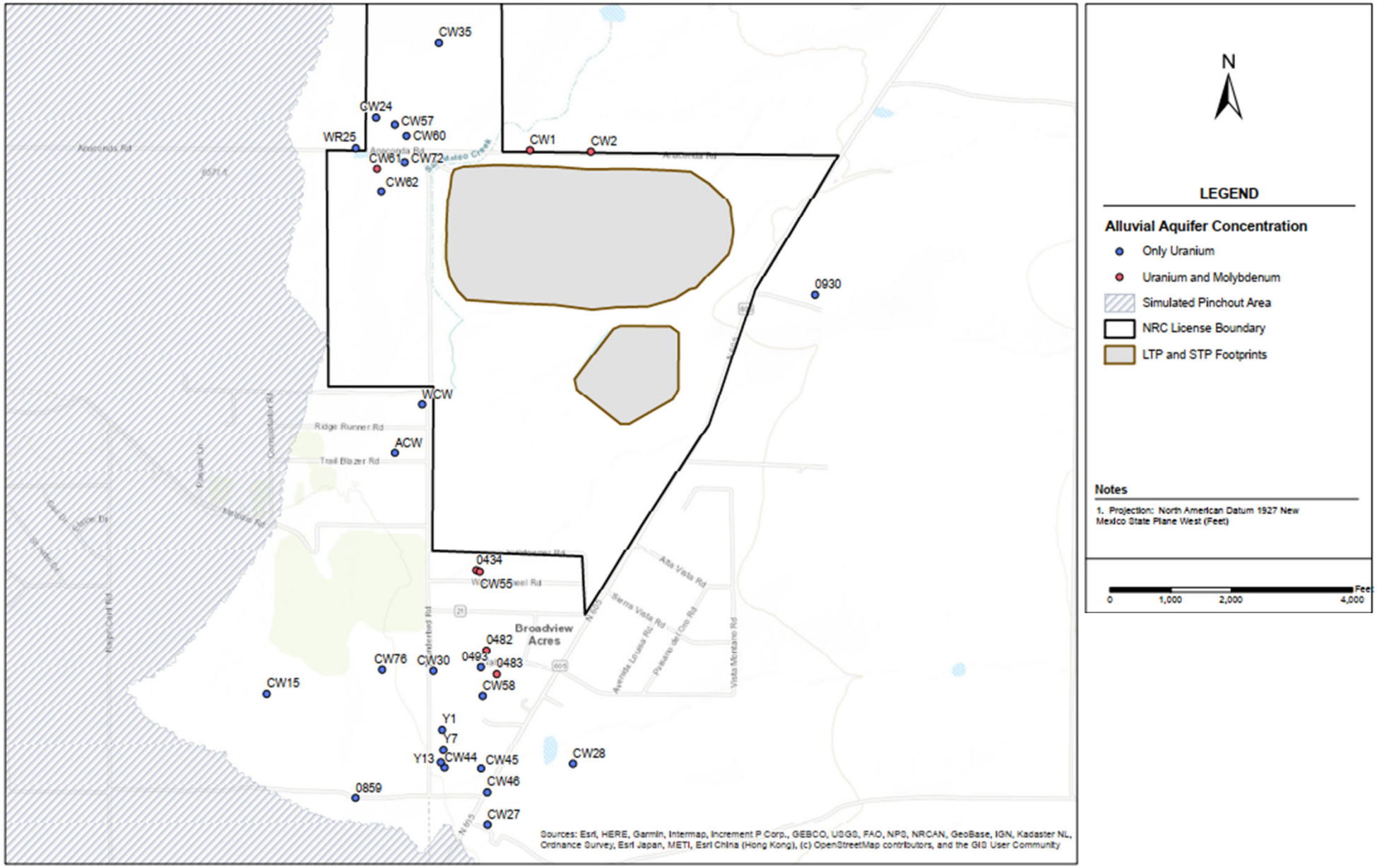

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Figure 3.3-3
Middle Chinle Groundwater Constituent Concentration Target Locations (Layer 6)

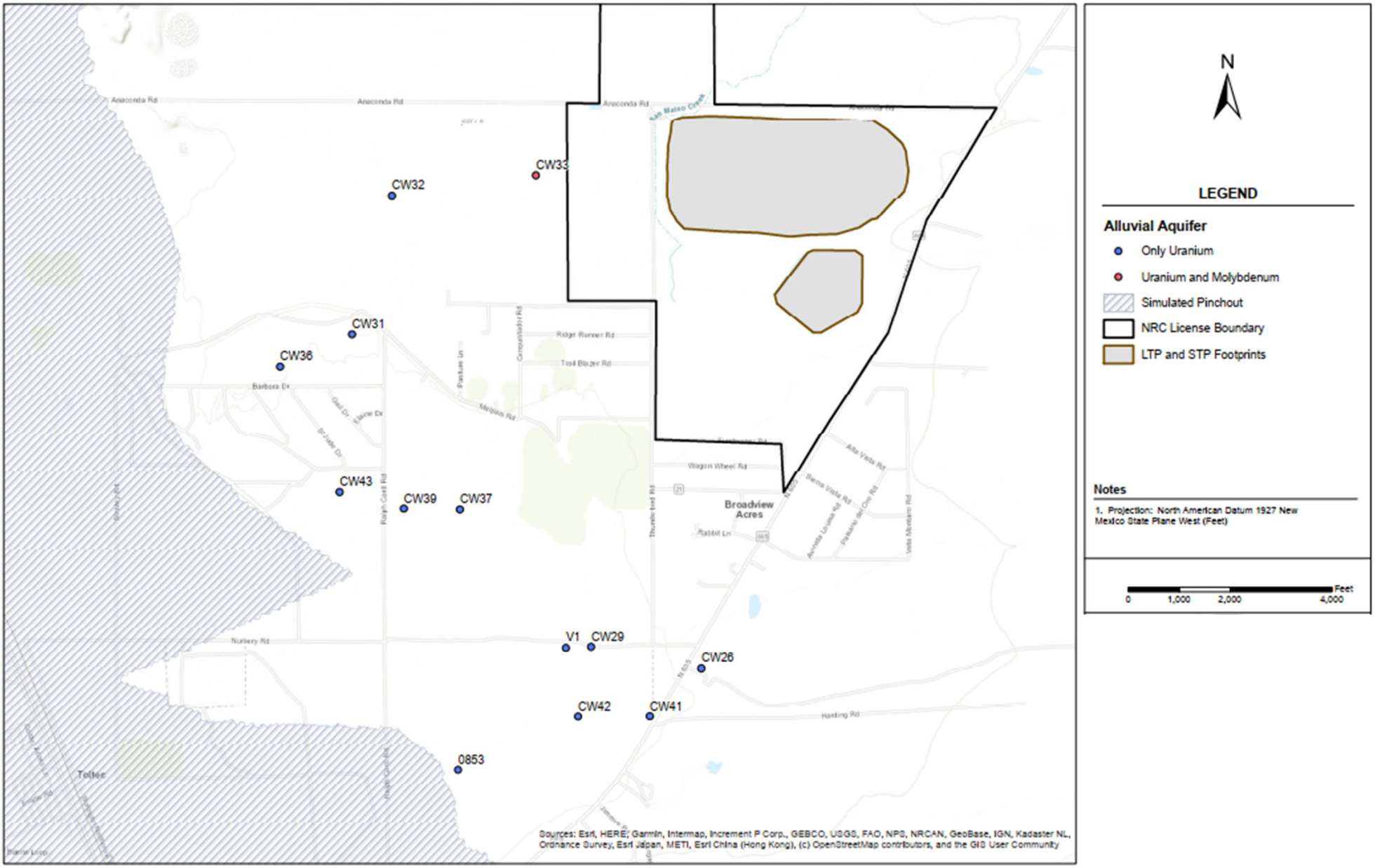

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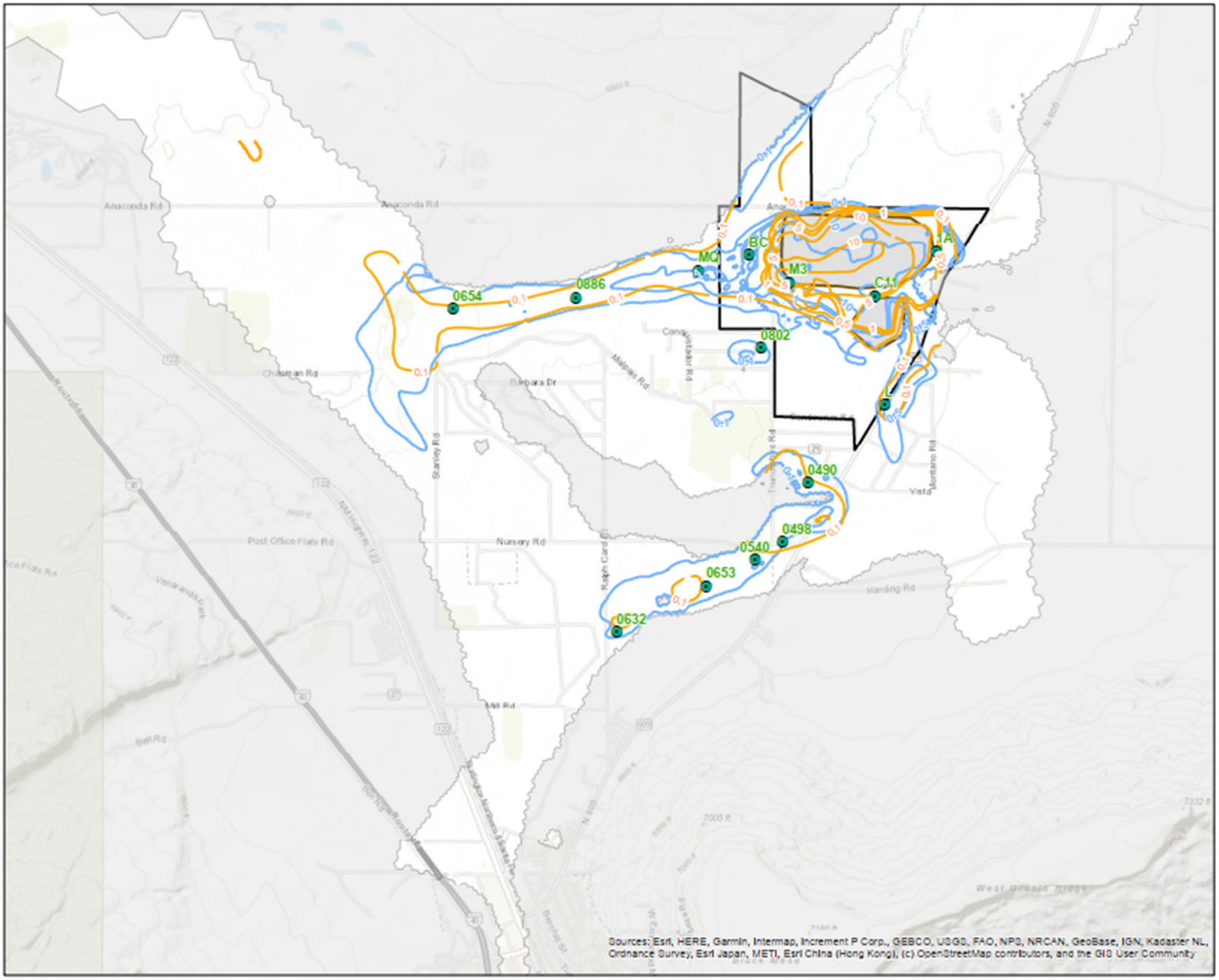
Figure 3.3-4
Lower Chinle Groundwater Constituent Concentration Target Locations
(Layer 8)



N

LEGEND

- Selected Uranium Target with Chemograph
- Observed Alluvial Aquifer U Concentration Contours - 2024 Annual Report (mg/L)
- Simulated 2024 Alluvial Aquifer U Concentration Contours (mg/L)
- Simulated Dry Cells
- NRC License Boundary
- LTP and STP Footprints

Notes

1. Projection: North American Datum 1927 New Mexico State Plane West (Feet)

Feet
0 1,000 2,000 4,000

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Figure 3.3-5
Alluvial Aquifer Simulated versus Observed 2024 Groundwater Uranium Concentrations

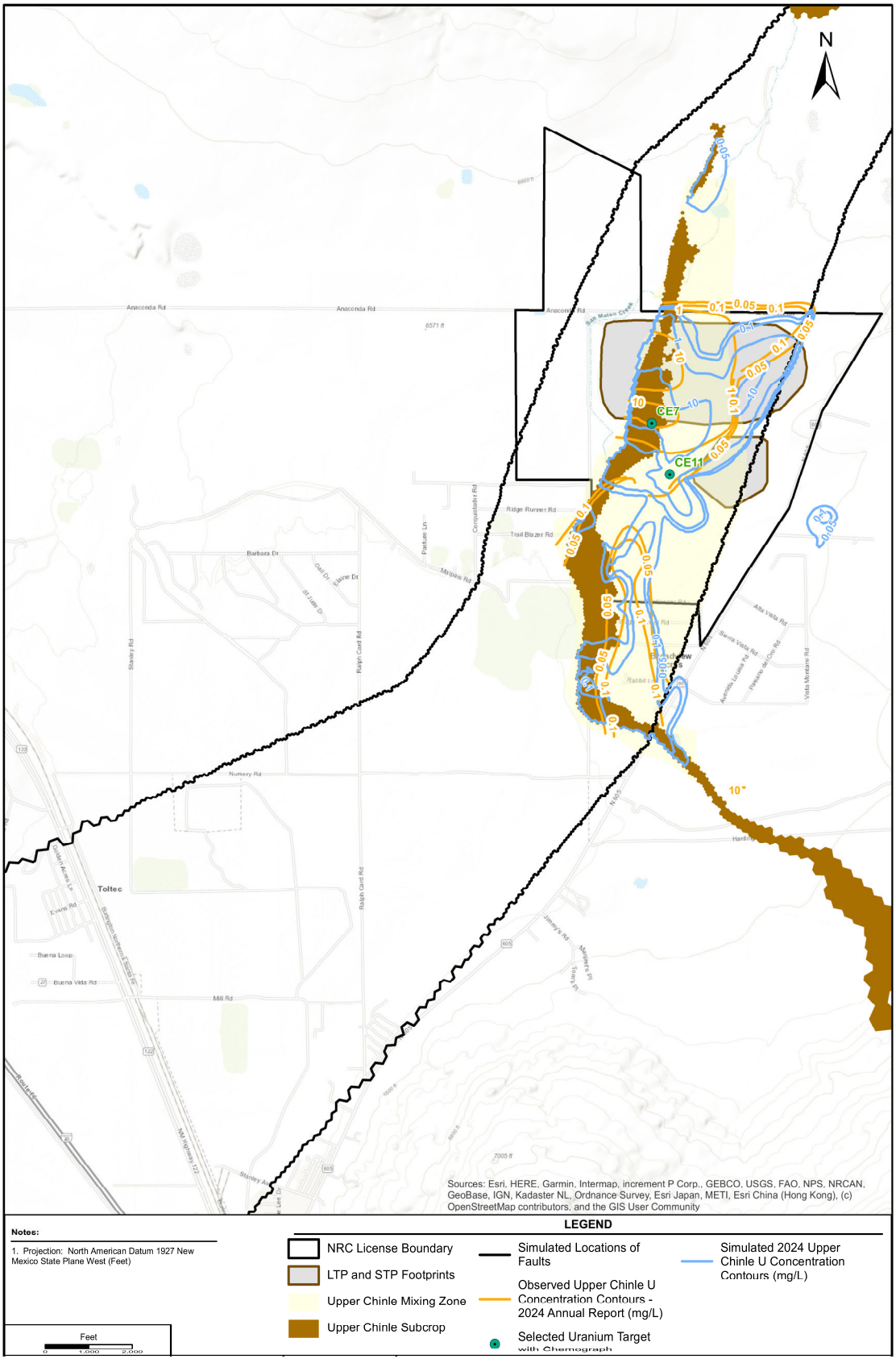

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Figure 3.3-6
Upper Chinle Simulated versus Observed
2024 Groundwater Uranium Concentrations

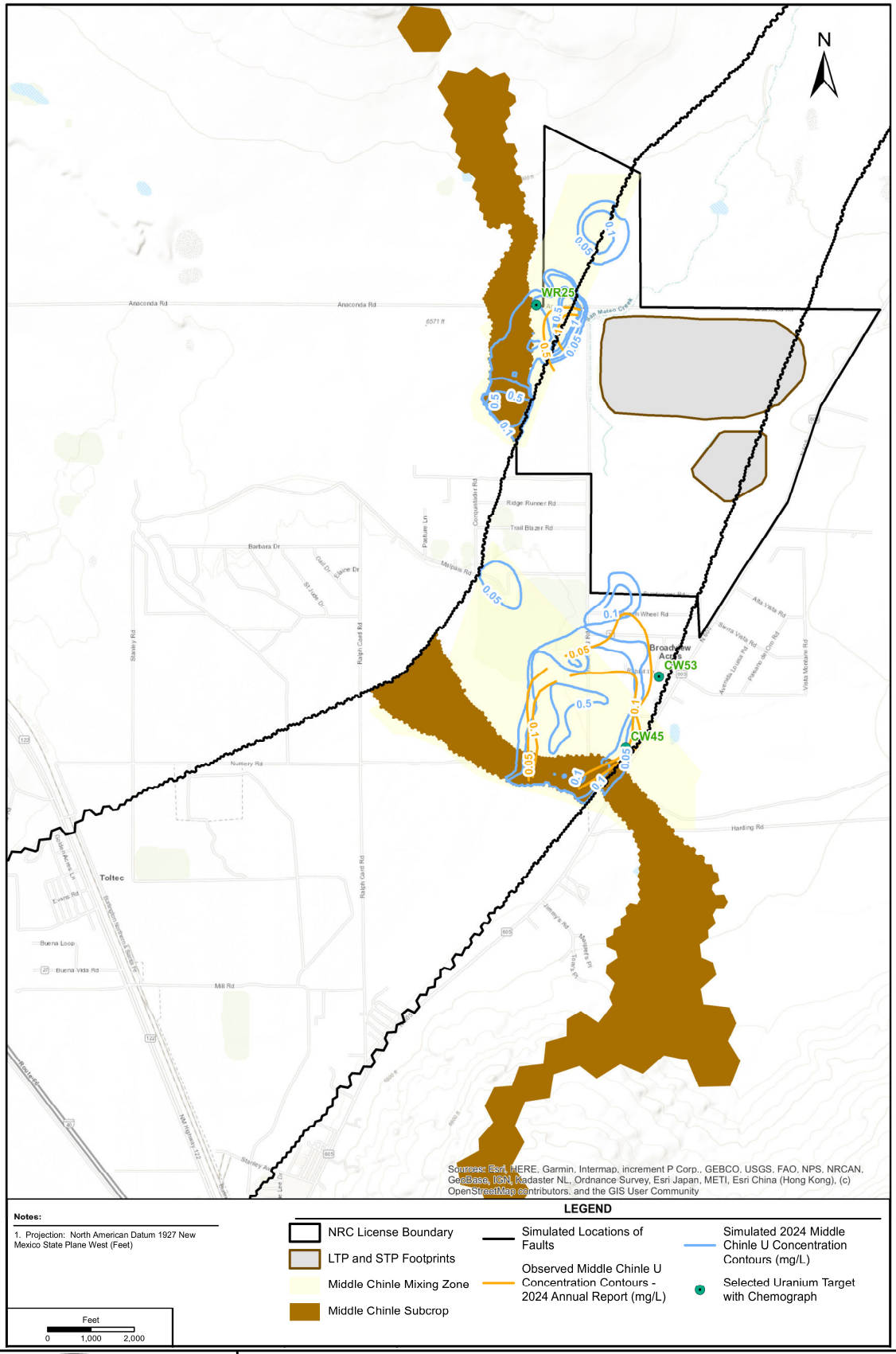

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Figure 3.3-7
Middle Chinle Simulated versus Observed
2024 Groundwater Uranium Concentrations

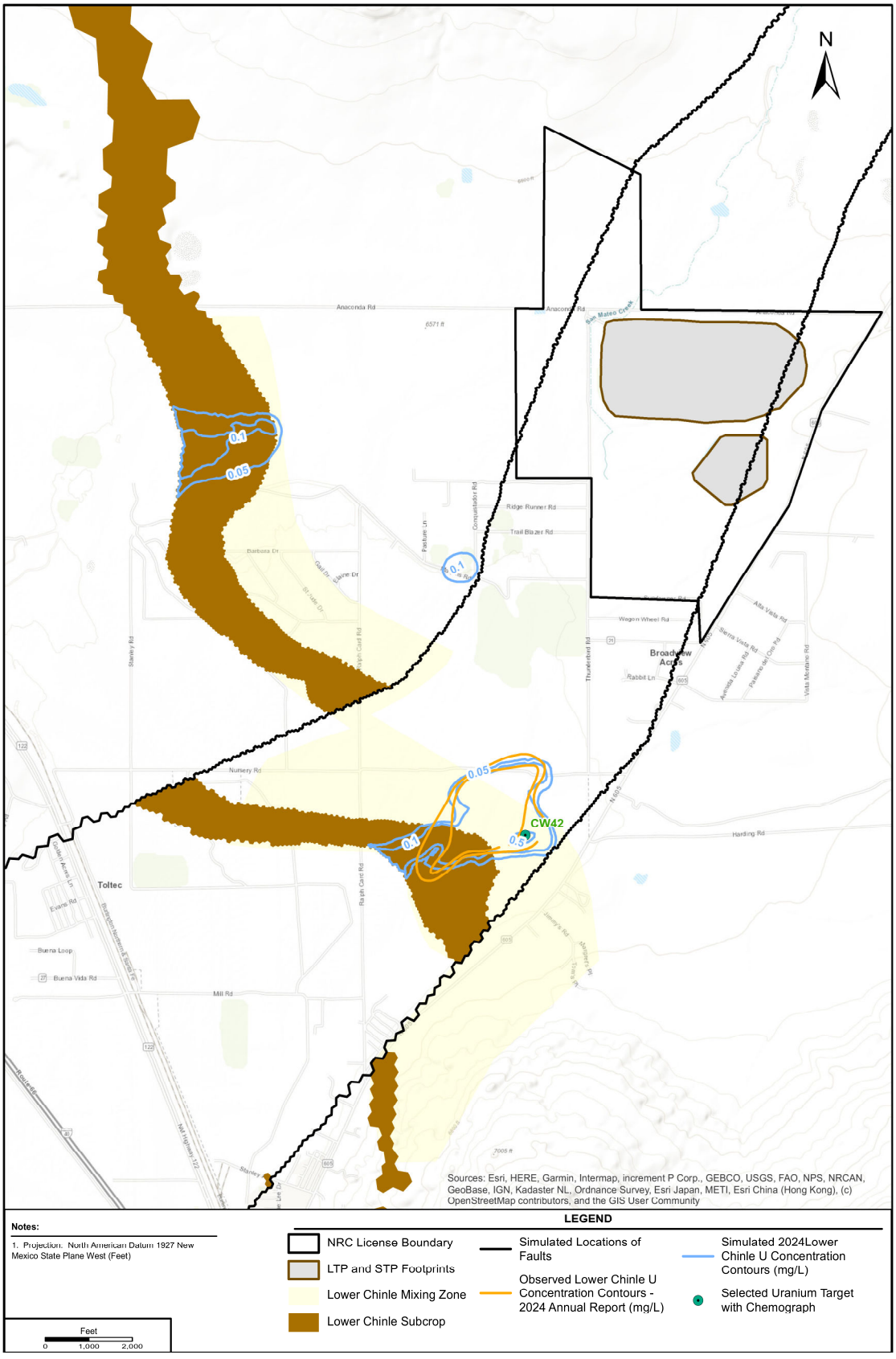

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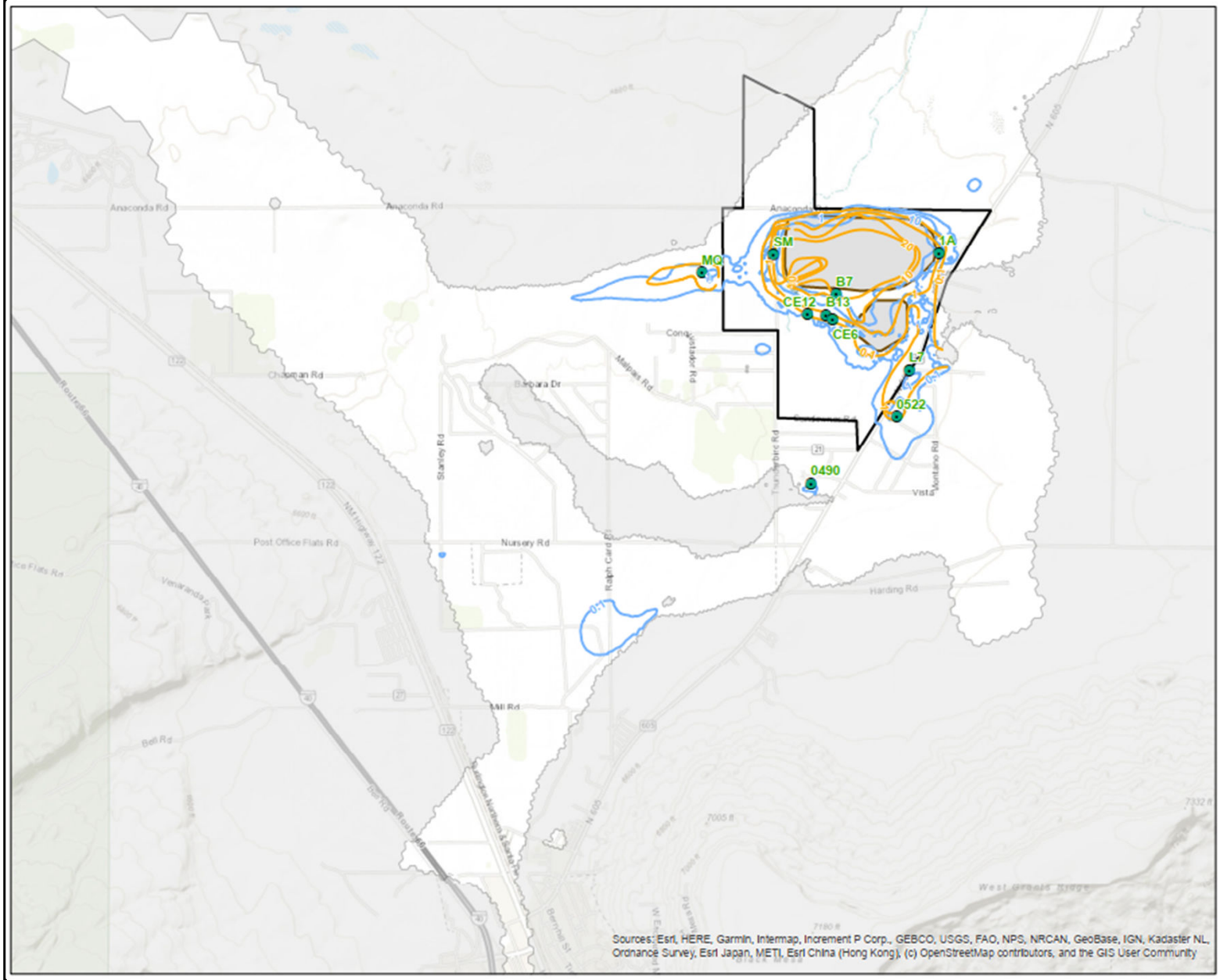
Figure 3.3-8
Lower Chinle Simulated versus Observed
2024 Groundwater Uranium Concentrations



N

LEGEND

- Selected Molybdenum Target with Chemograph
- Observed Alluvial Aquifer Mo Concentration Contours - 2024 Annual Report (mg/L)
- Simulated 2024 Alluvial Aquifer Mo Concentration Contours (mg/L)
- Simulated Dry Cells
- NRC License Boundary
- LTP and STP Footprints

Notes

1. Projection: North American Datum 1927 New Mexico State Plane West (Feet)

0 1,000 2,000 4,000 Feet

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Figure 3.3-9
Alluvial Aquifer
Simulated versus Observed 2024
Groundwater Molybdenum Concentrations

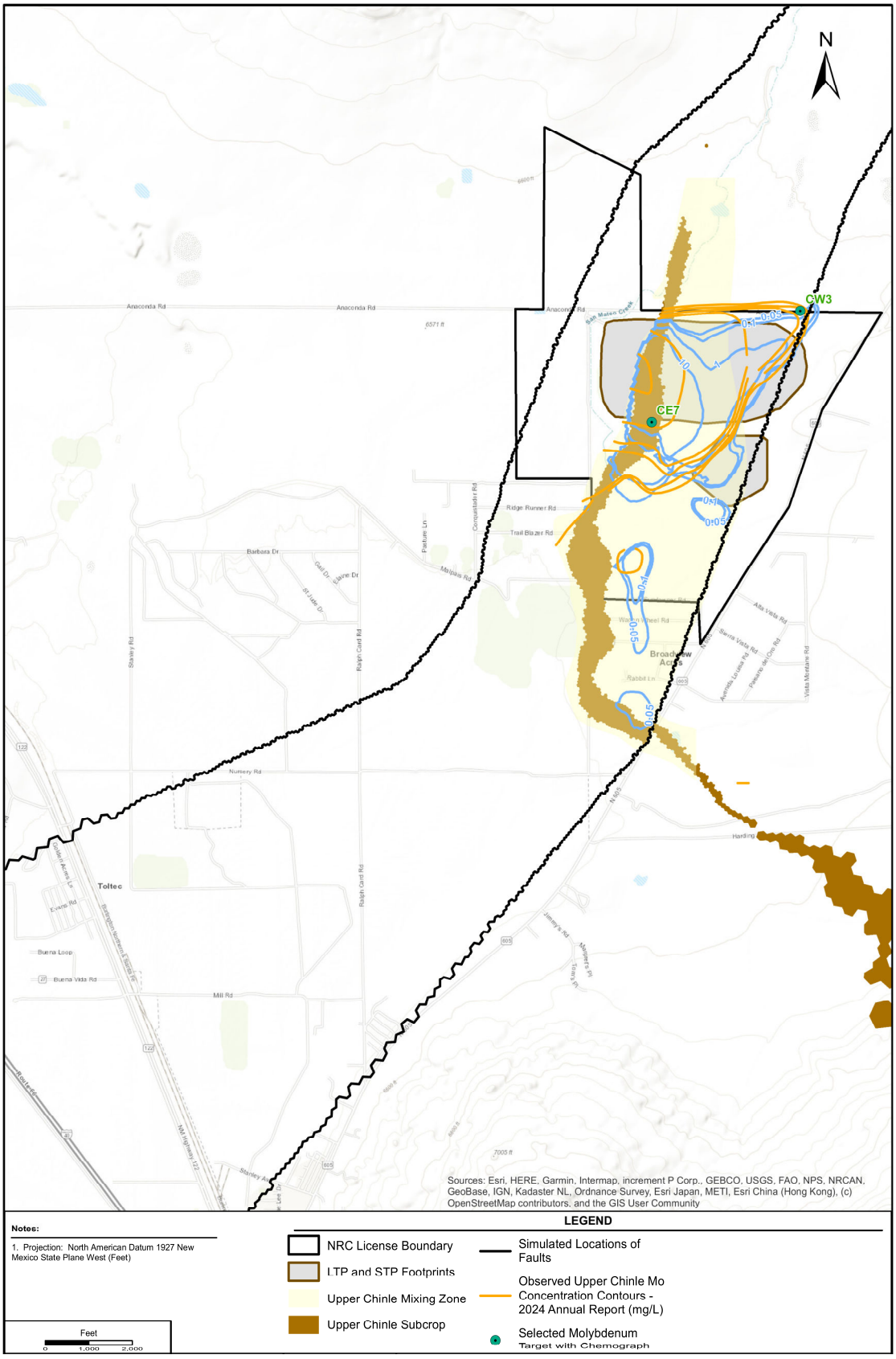

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Figure 3.3-10
Upper Chinle Simulated versus Observed
2024 Groundwater Molybdenum Concentrations

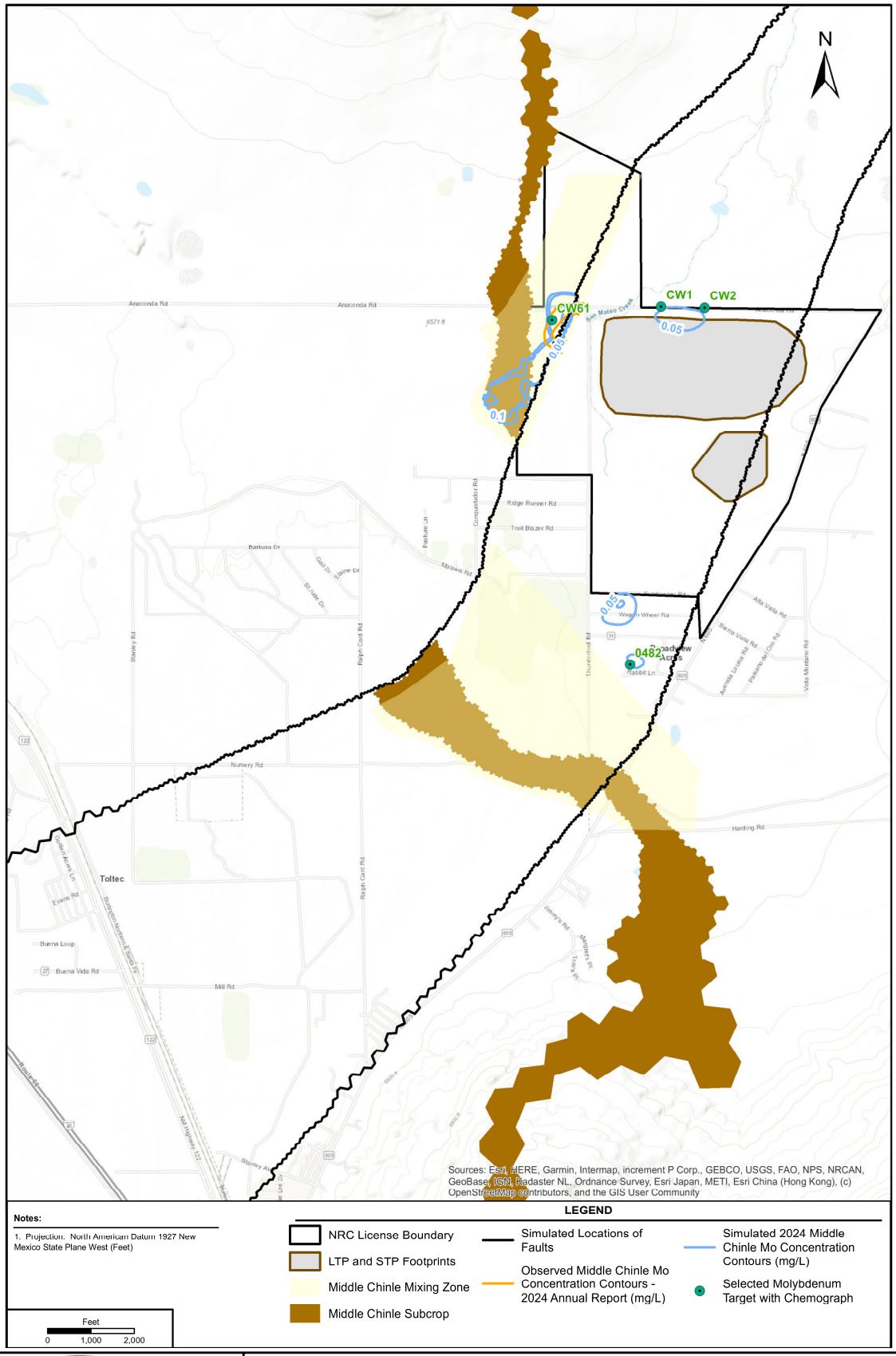

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Figure 3.3-11
Middle Chinle Simulated versus Observed
2024 Groundwater Molybdenum Concentrations

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Figure 3.3-12
Simulated versus Estimated Uranium Mass Removal By Year

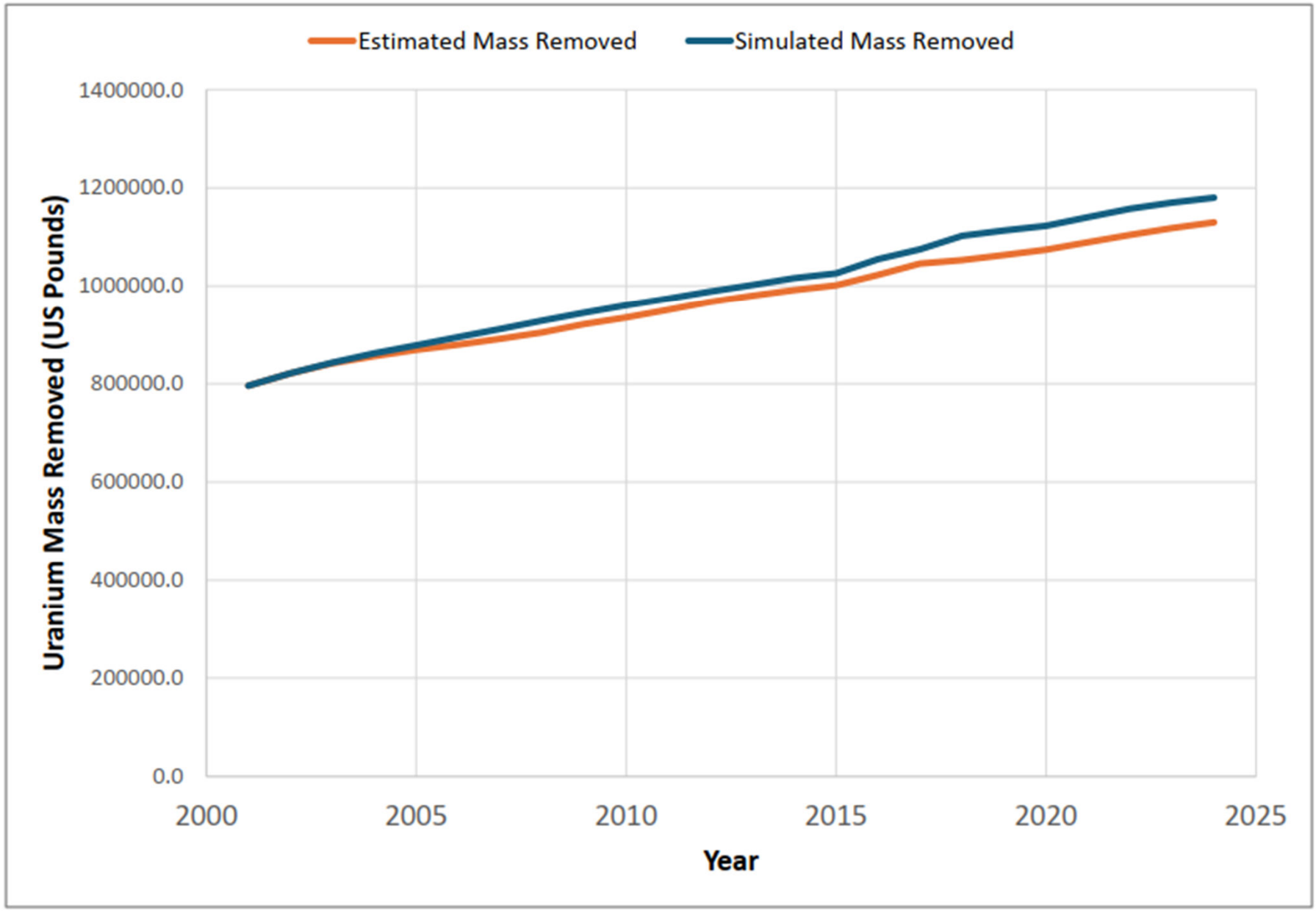

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Figure 3.3-13
Cumulative Simulated versus Estimated Uranium Mass Removal

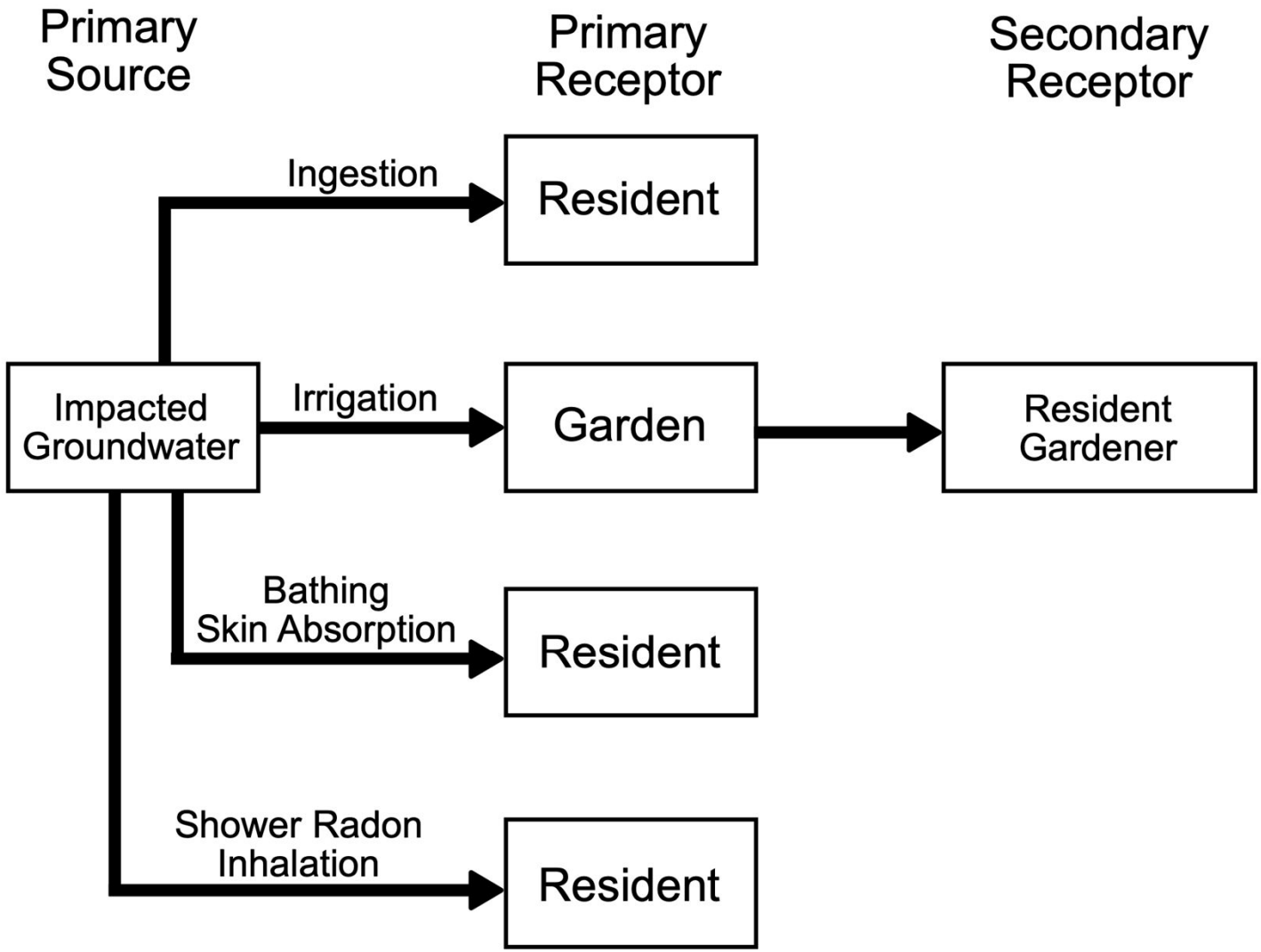

Figure 3.4-1
Conceptual Site Model for Resident Gardener at Point of Exposure

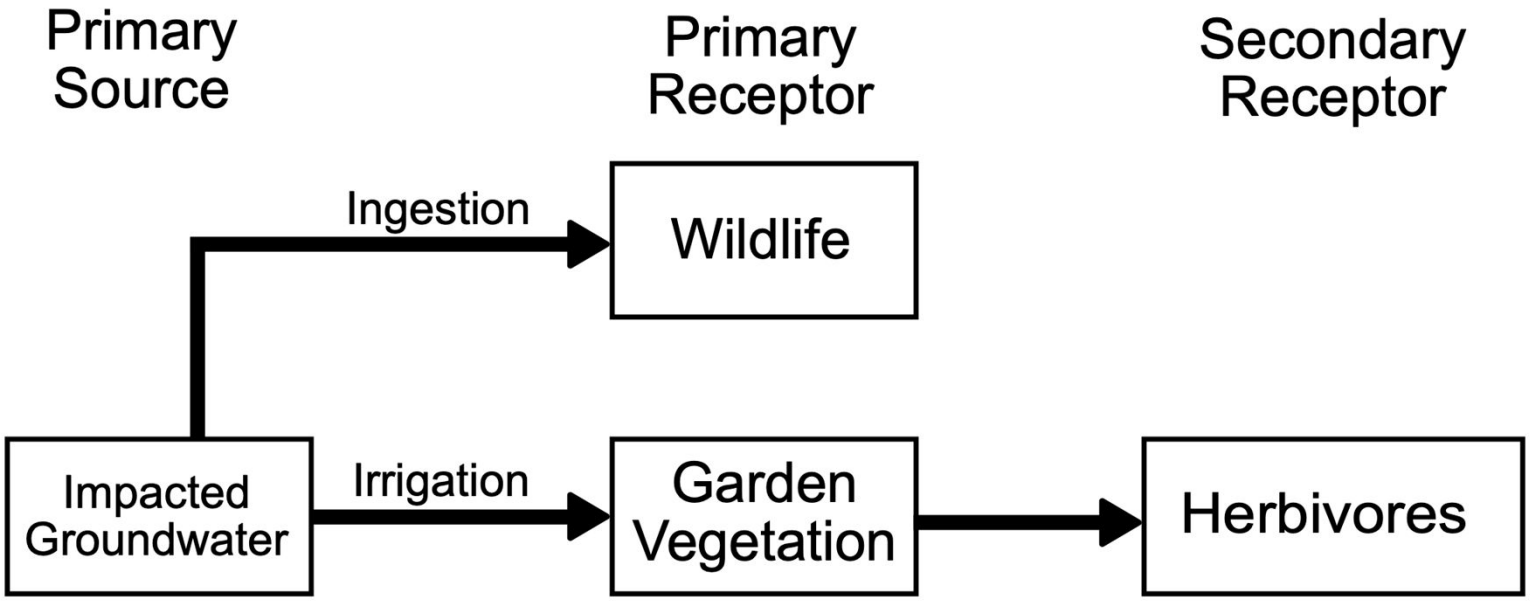

Figure 3.6-1
Conceptual Site Model for
Wildlife at Point of Exposure

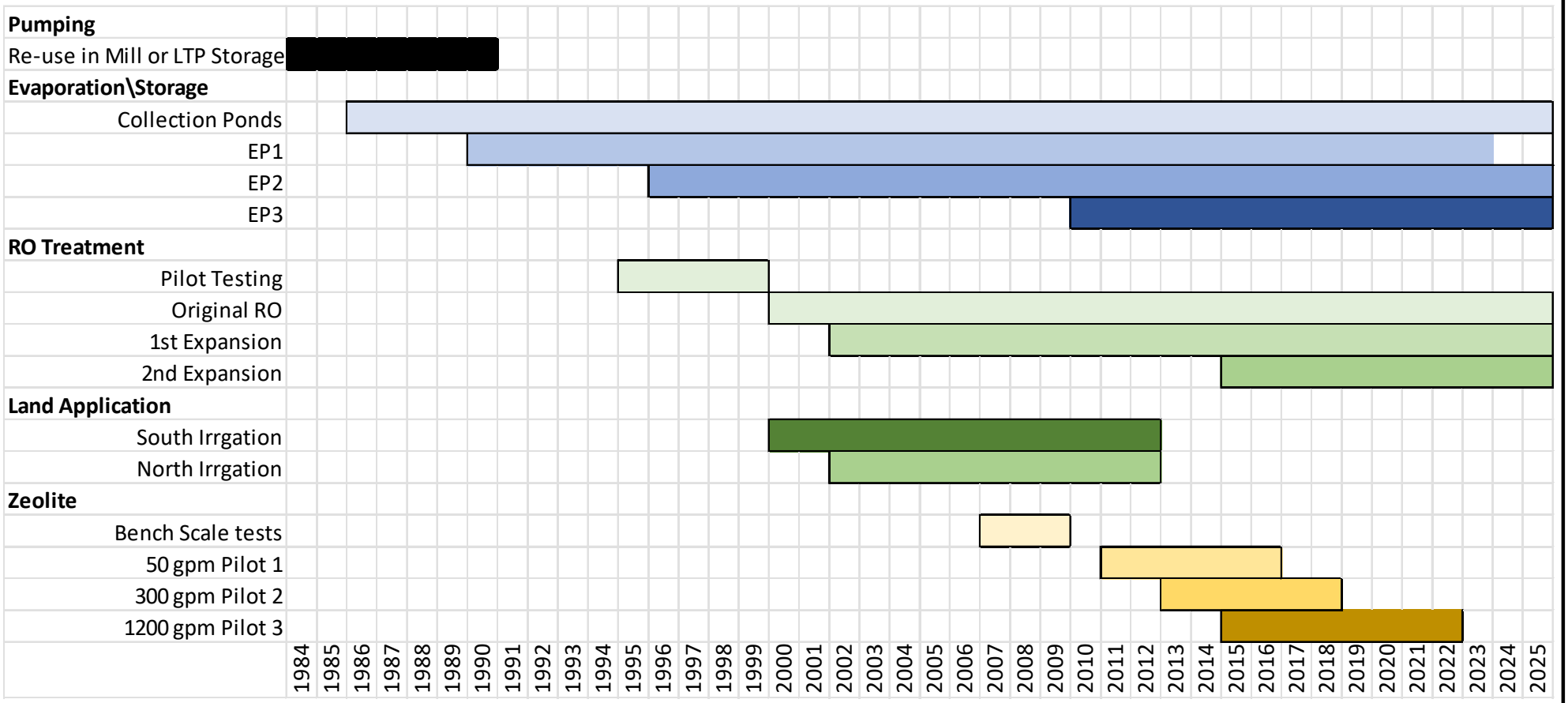

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Figure 4.1-1
Summary Timeline of
Groundwater Corrective Action Systems

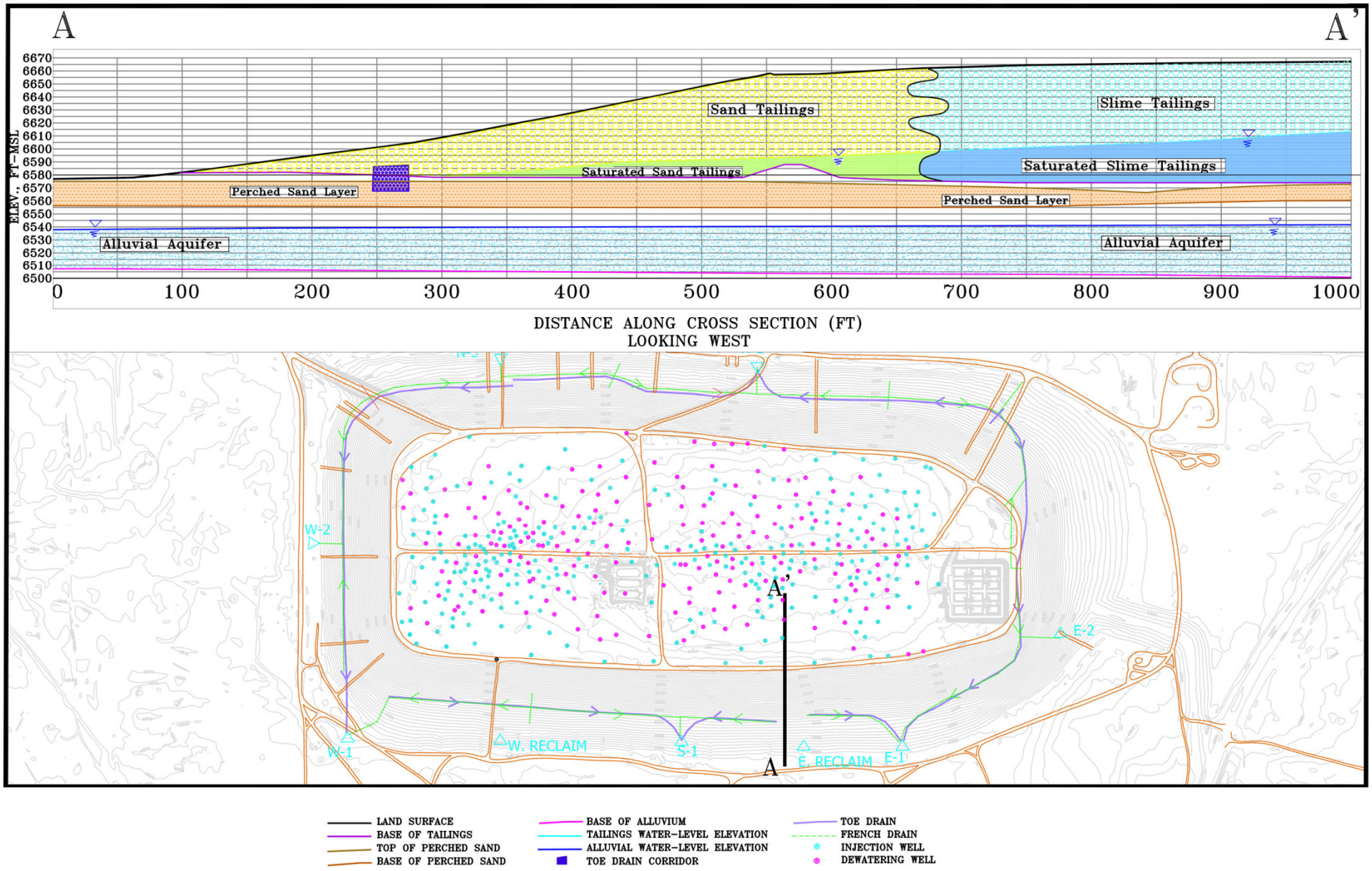

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Figure 4.1-2
Locations of Large Tailings Pile Toe Drains, Dewatering Wells and Injection Wells

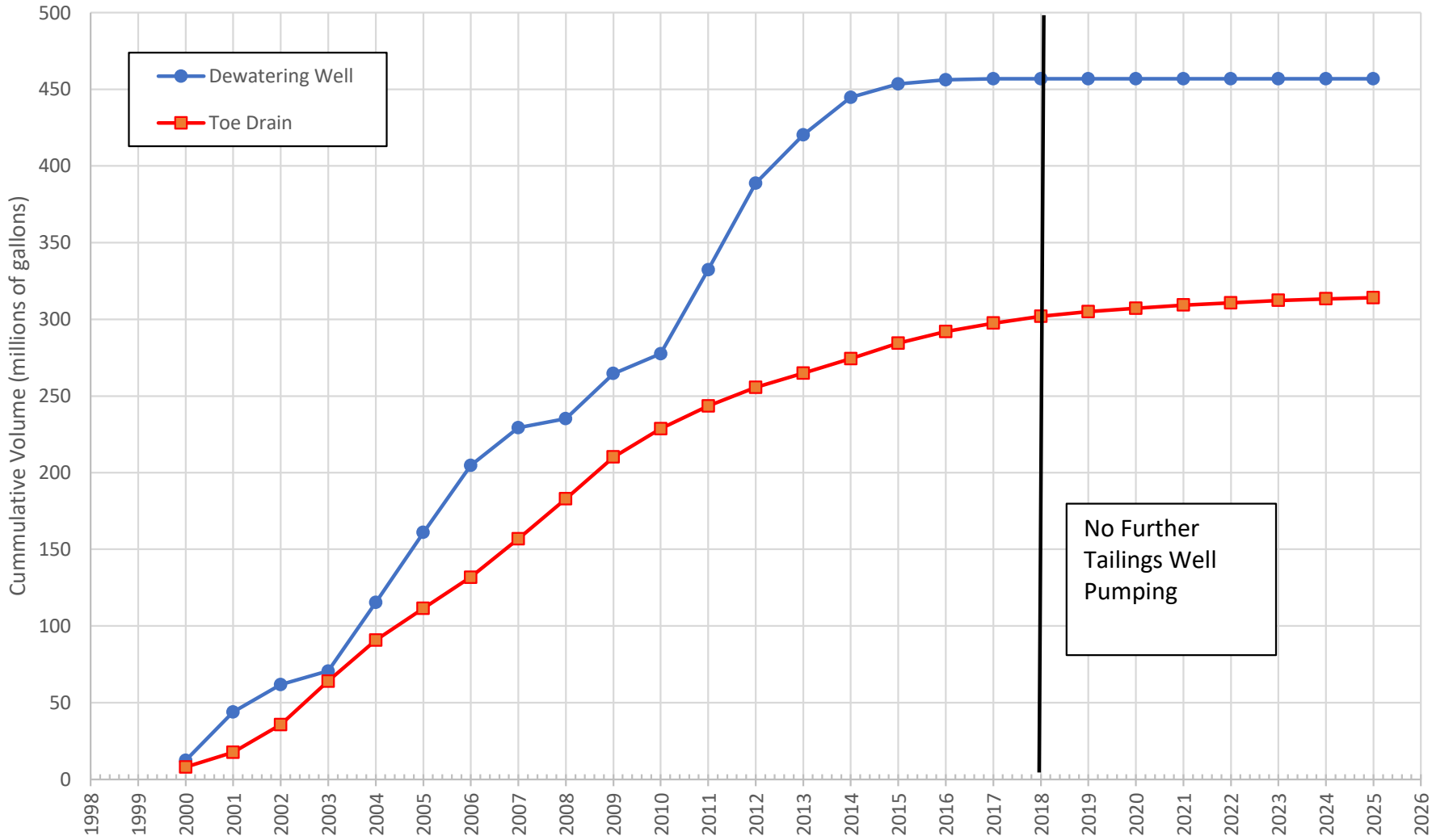

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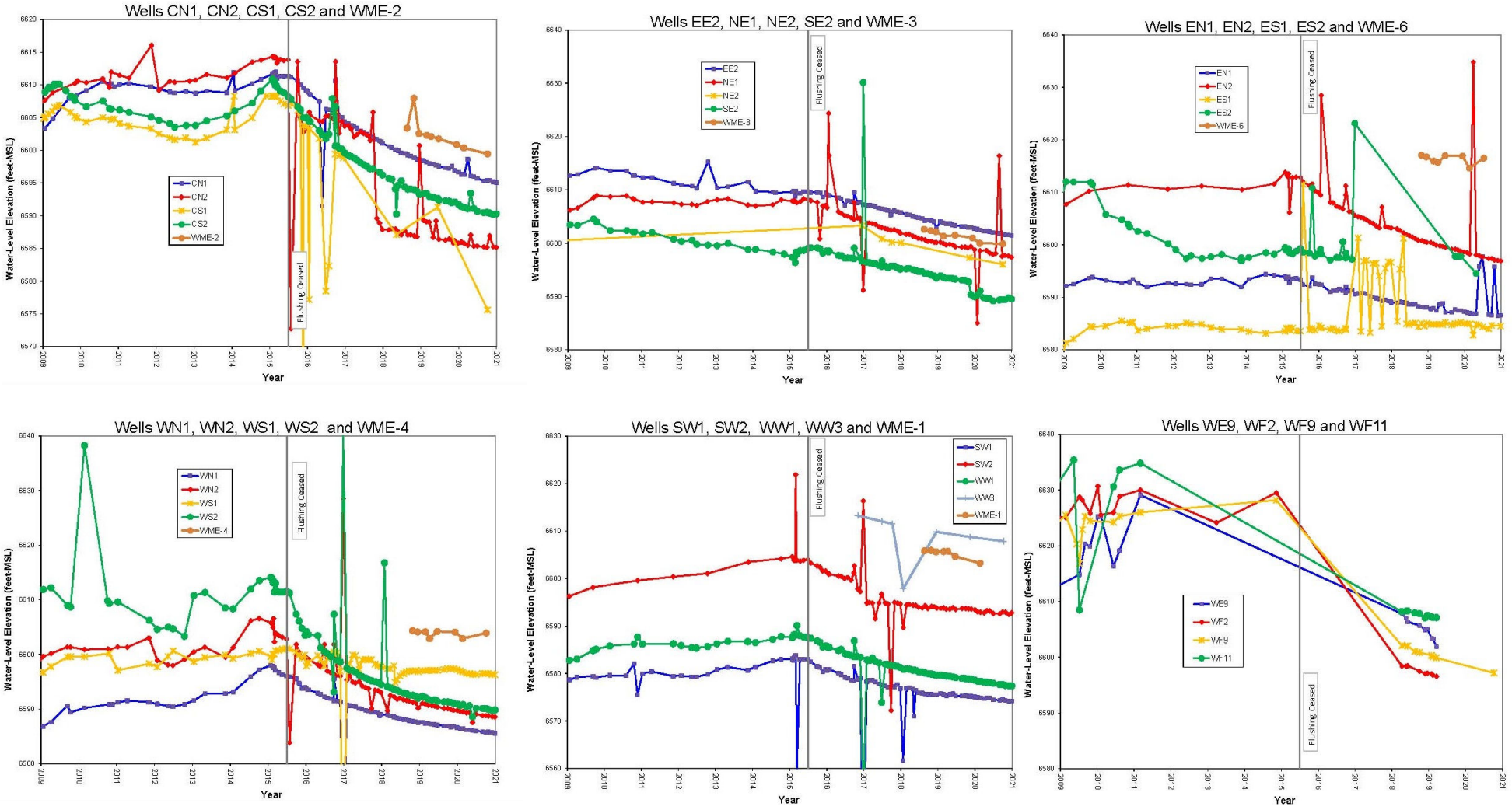
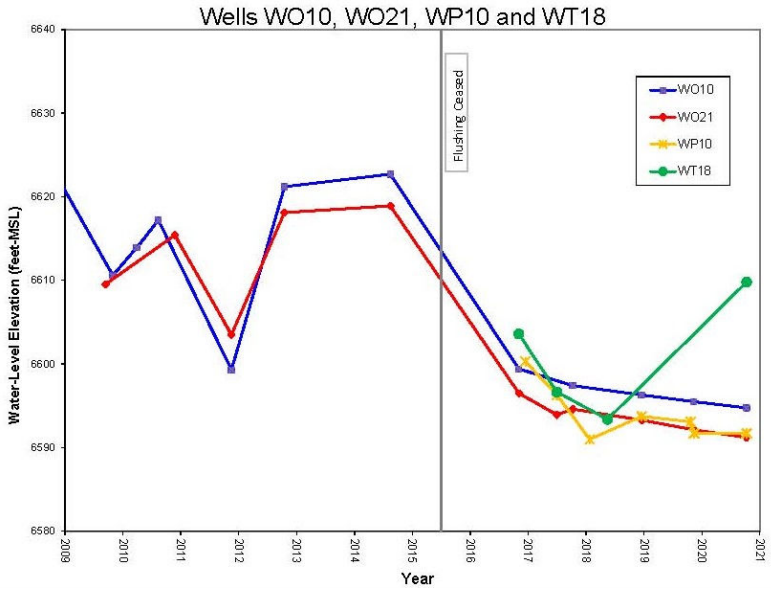
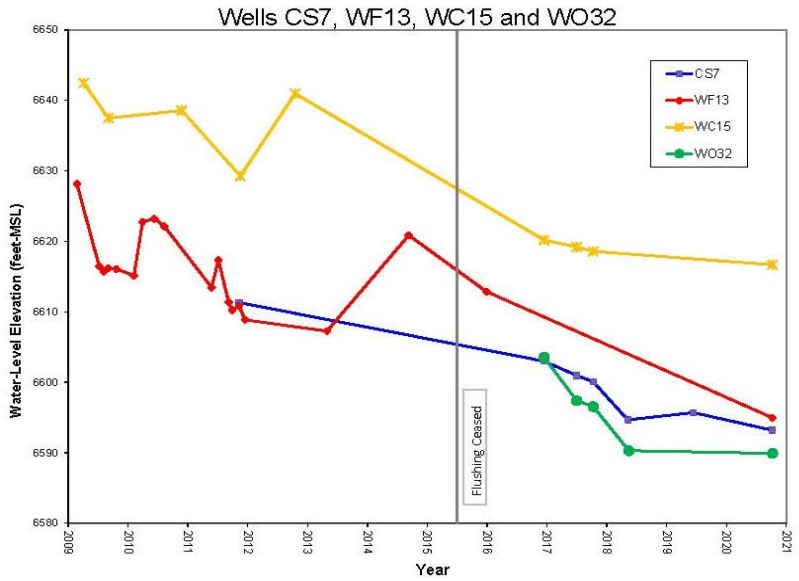
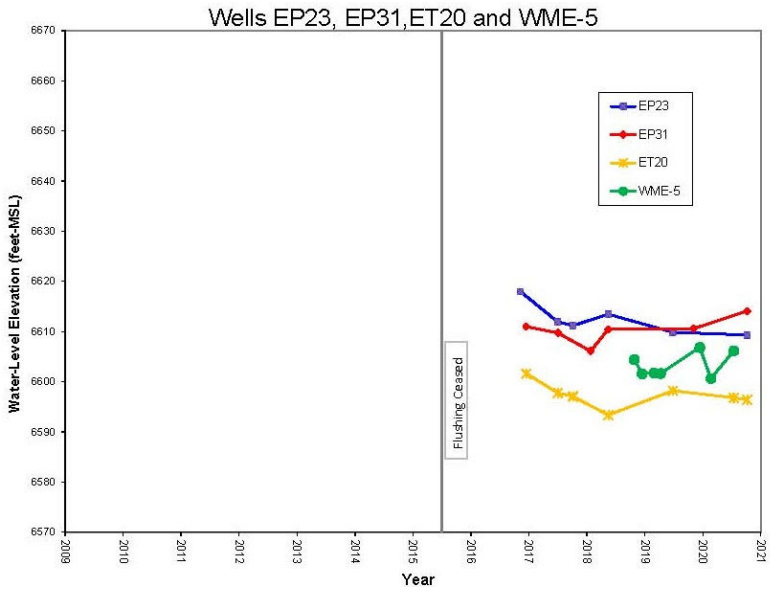
Figure 4.1-3
Cumulative Volume of Collection Water from Tailings Dewatering Wells and Toe Drains

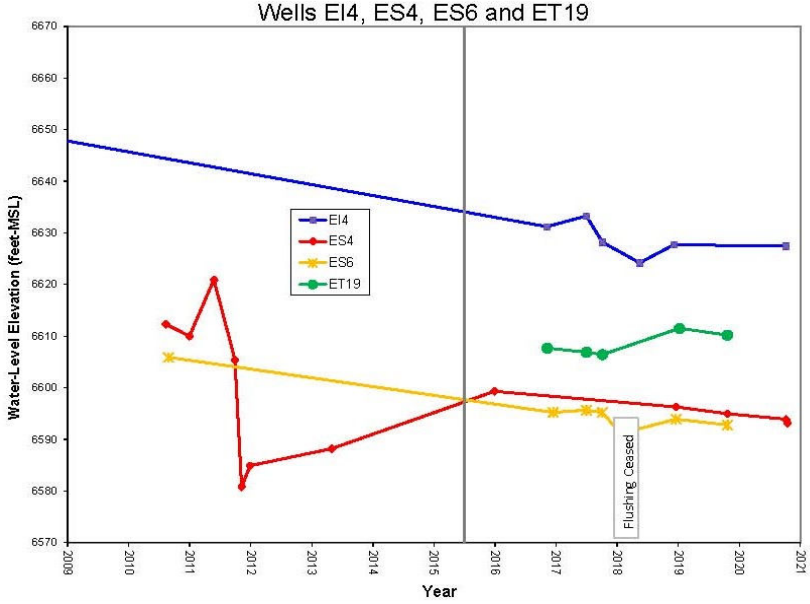


Base of Tailings is approximately 6575 feet above mean sea level.









Base of Tailings is approximately 6575 feet above mean sea level.

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Figure 4.1-5
Water Levels in the Large Tailings Pile
2009 Through 2020

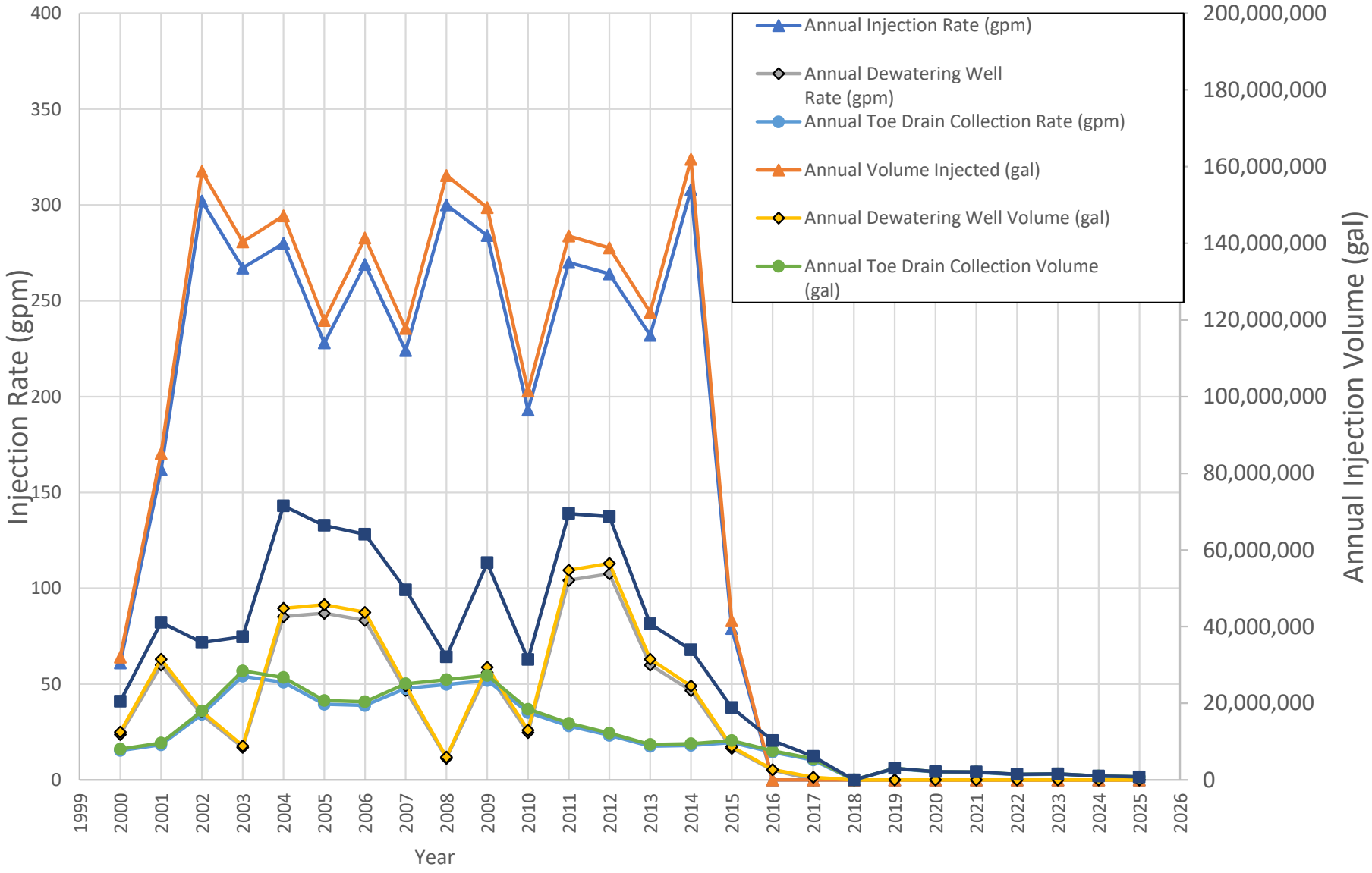

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Figure 4.1-6
Tailings Flushing Injection and Tailings Dewatering

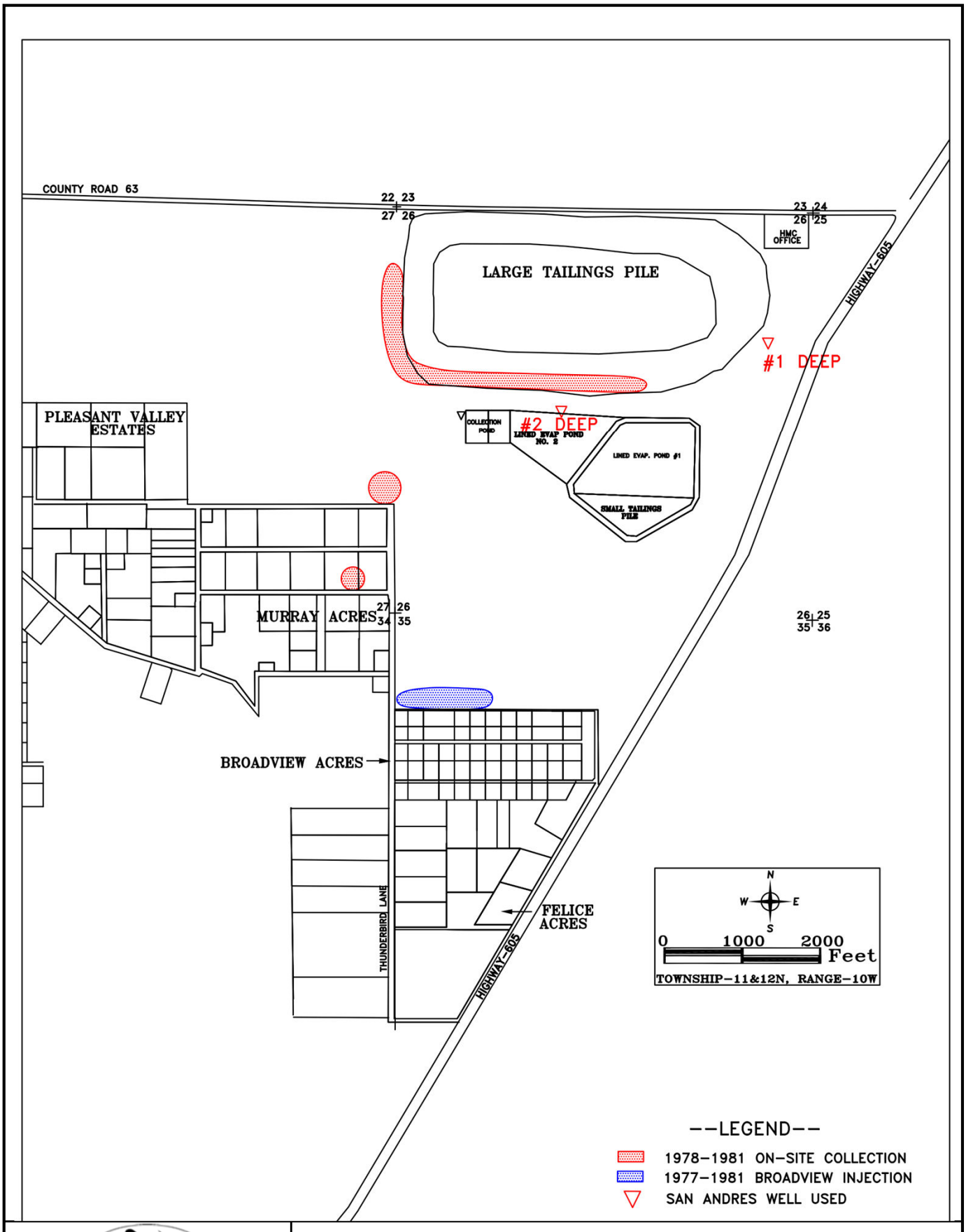

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Figure 4.1-7
Alluvial Operation Locations 1977-1981

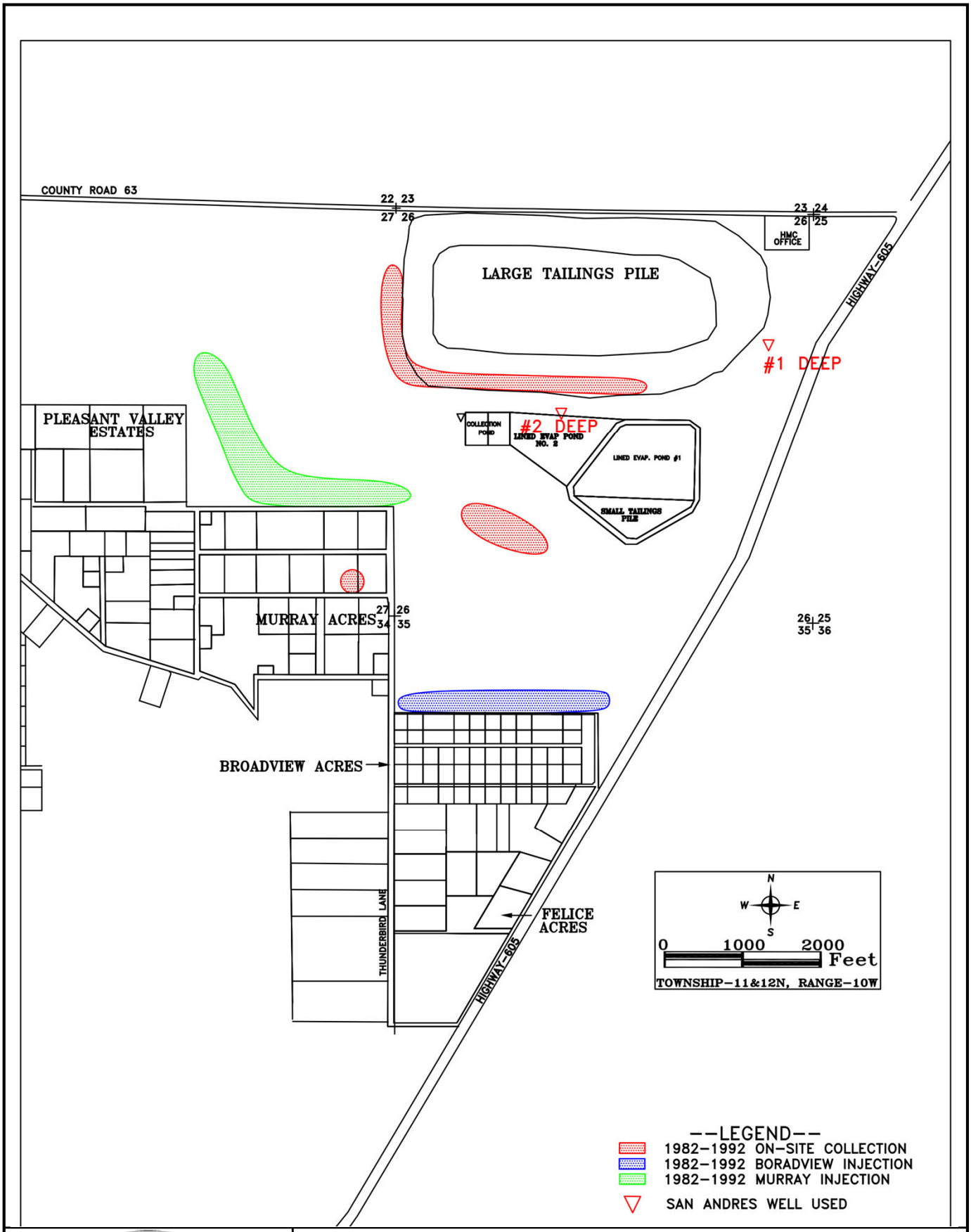

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Figure 4.1-8
Alluvial Operation Locations 1982-1992

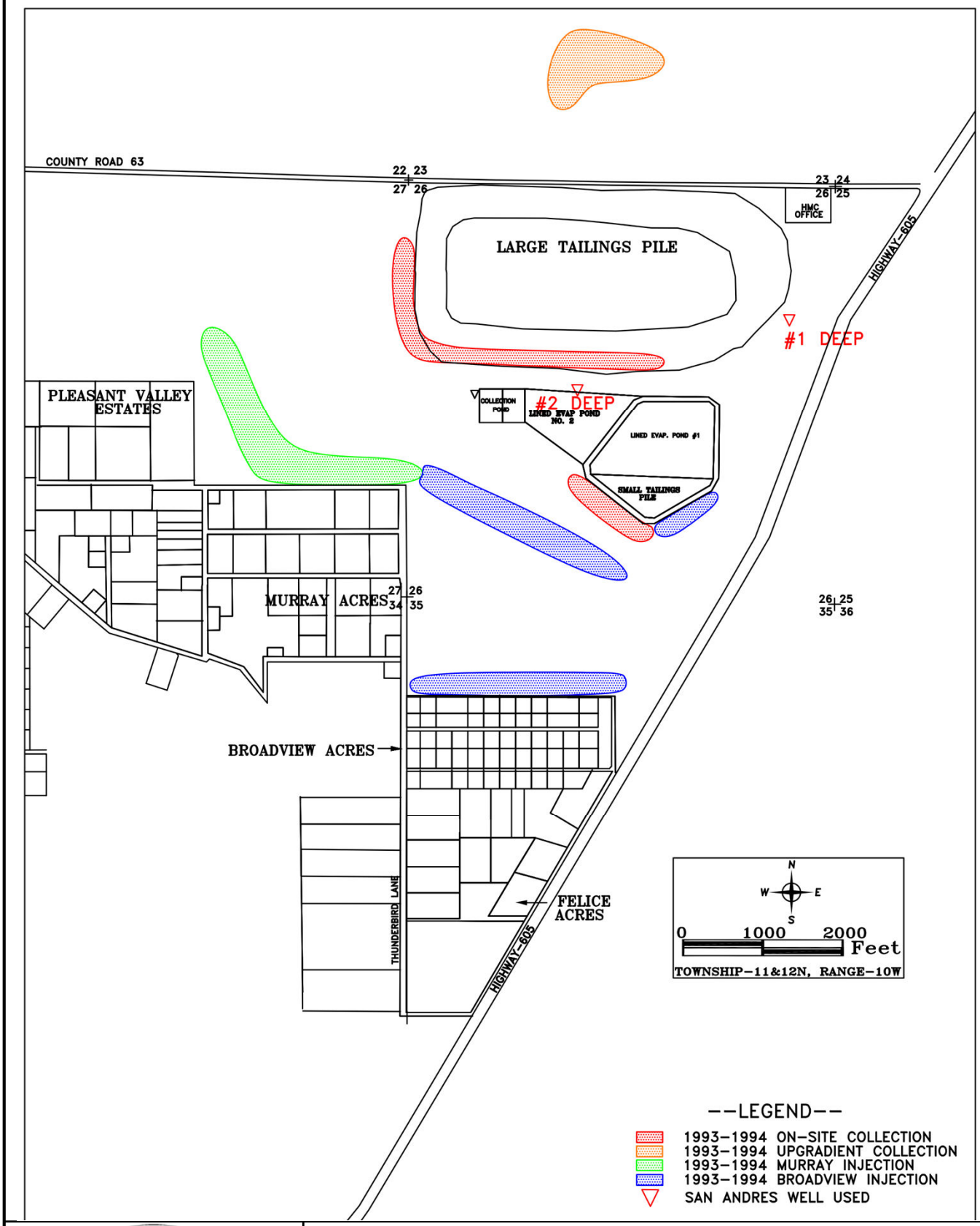

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Figure 4.1-9
Alluvial Operation Locations 1993-1994

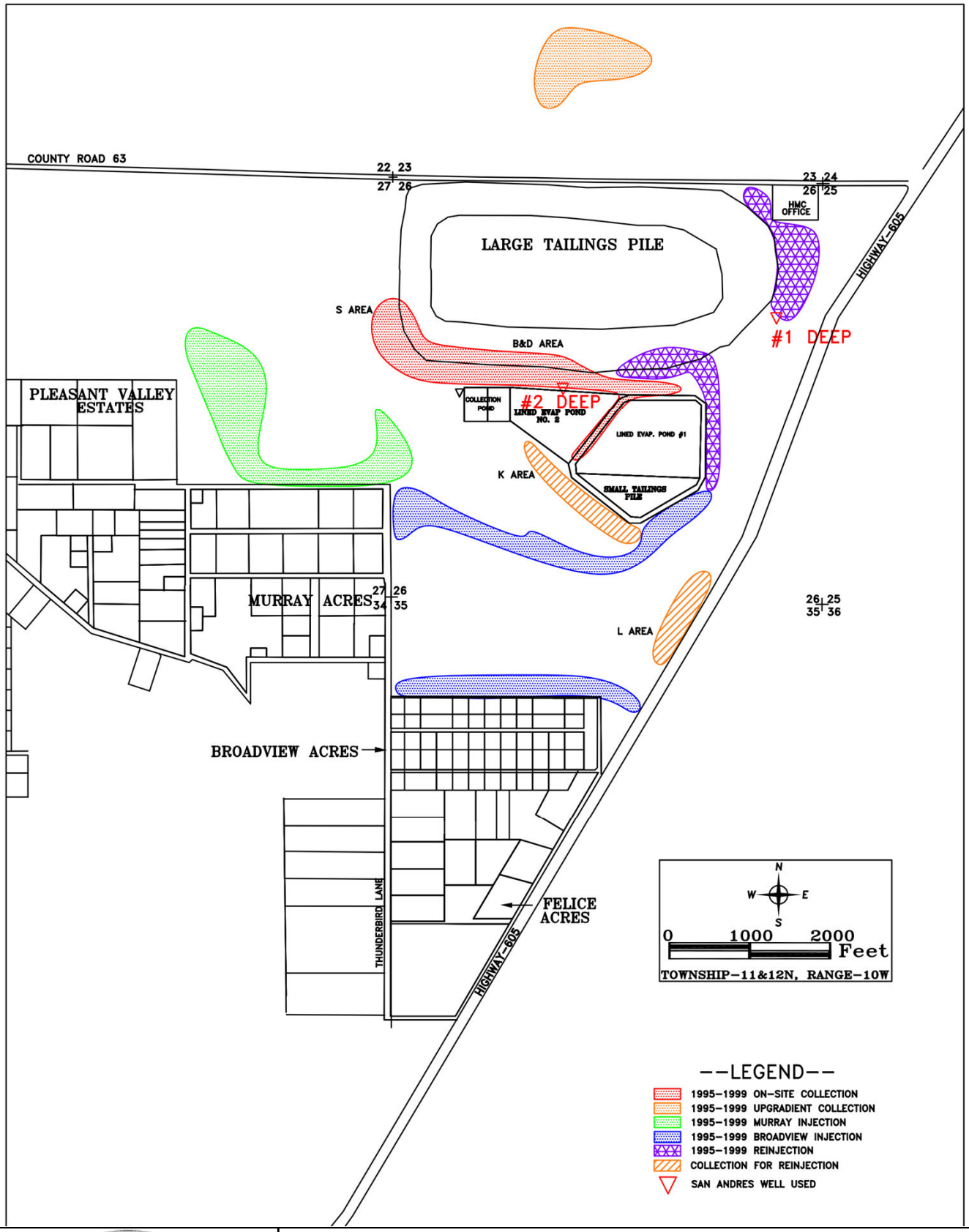

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Figure 4.1-10
Alluvial Operation Locations 1995-1999

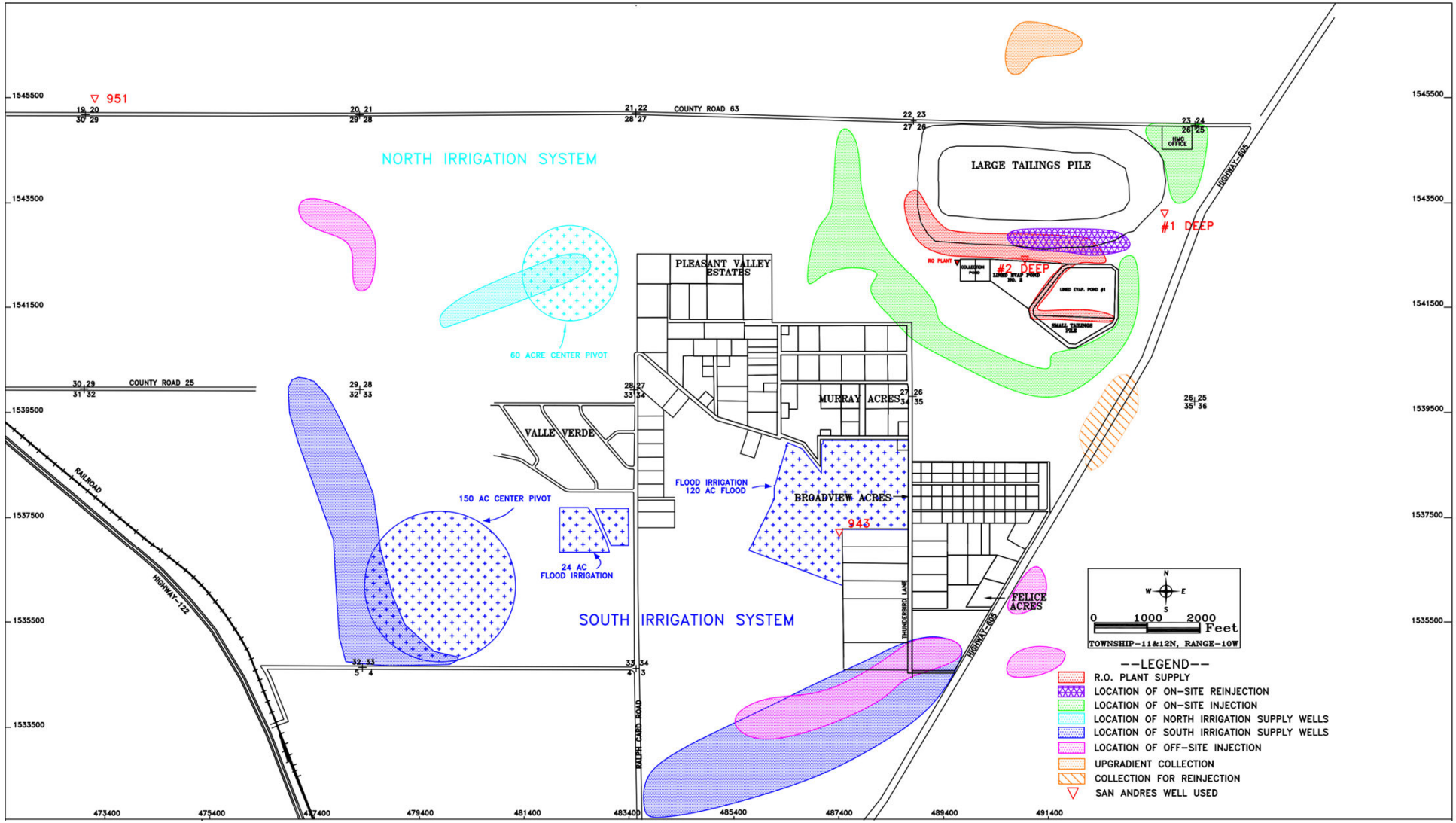

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Figure 4.1-11
Alluvial Operation Locations 2000-2004

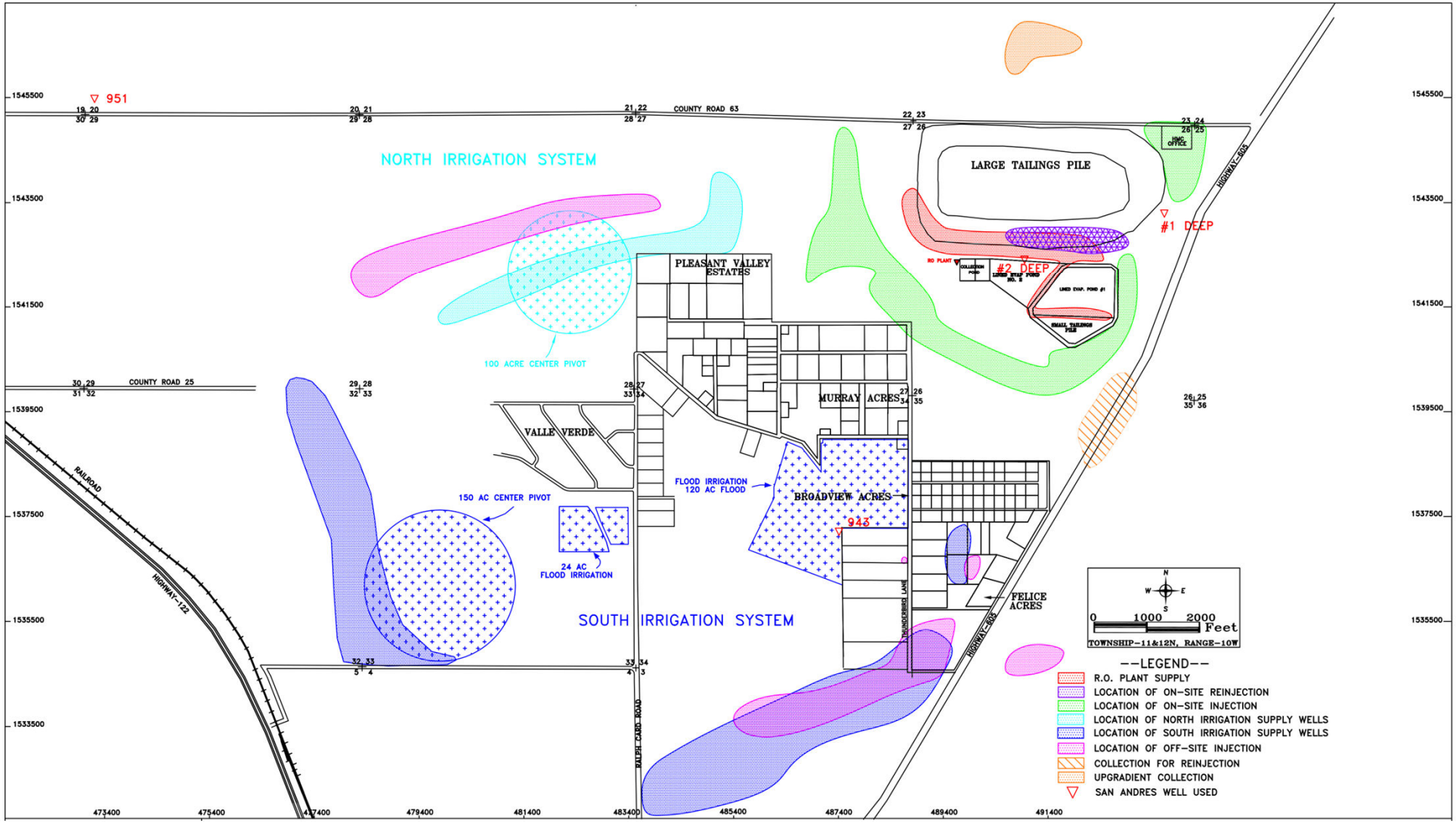

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Figure 4.1-12
Alluvial Operation Locations 2005-2009

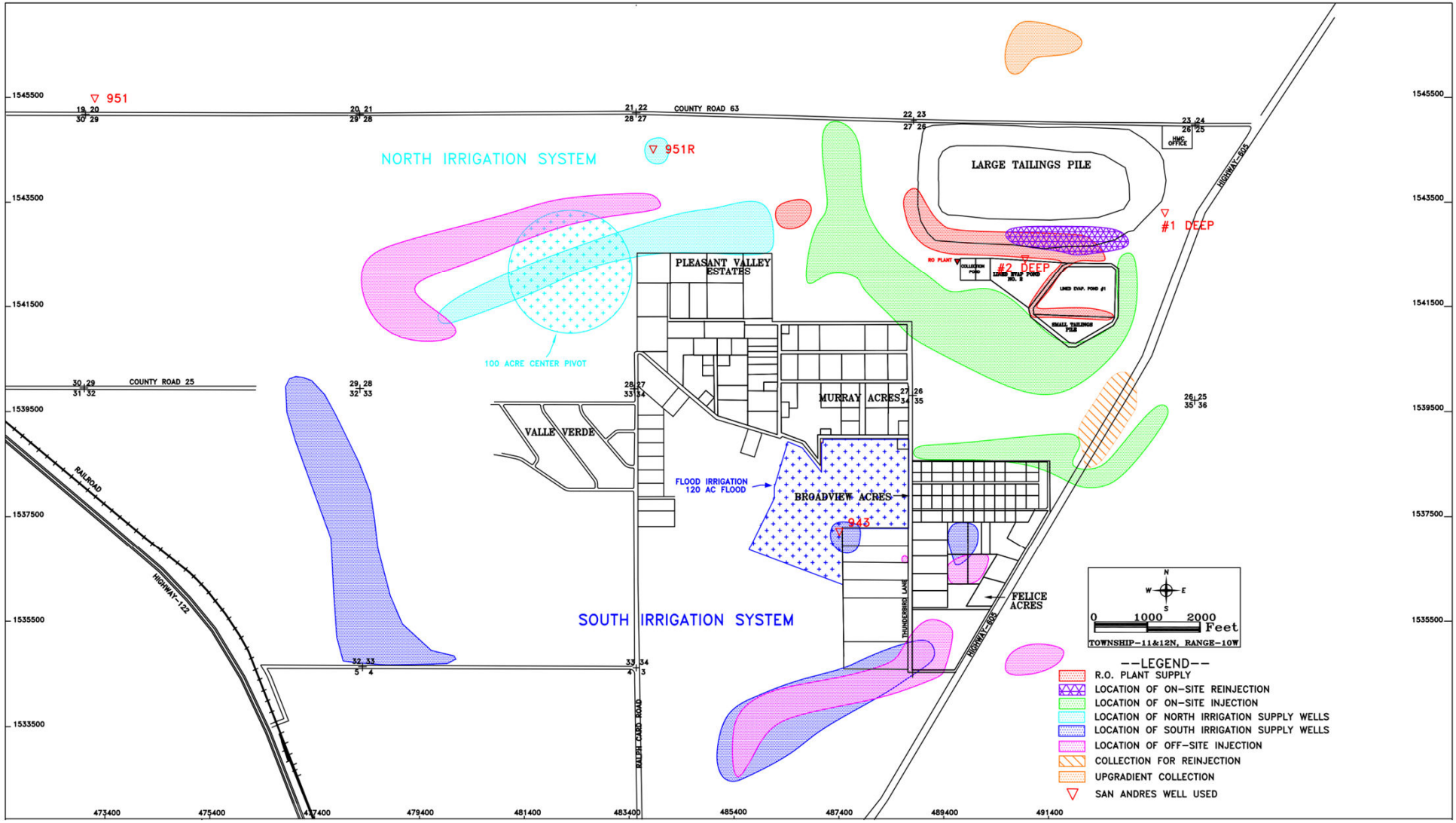

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Figure 4.1-13
Alluvial Operation Locations 2010-2012

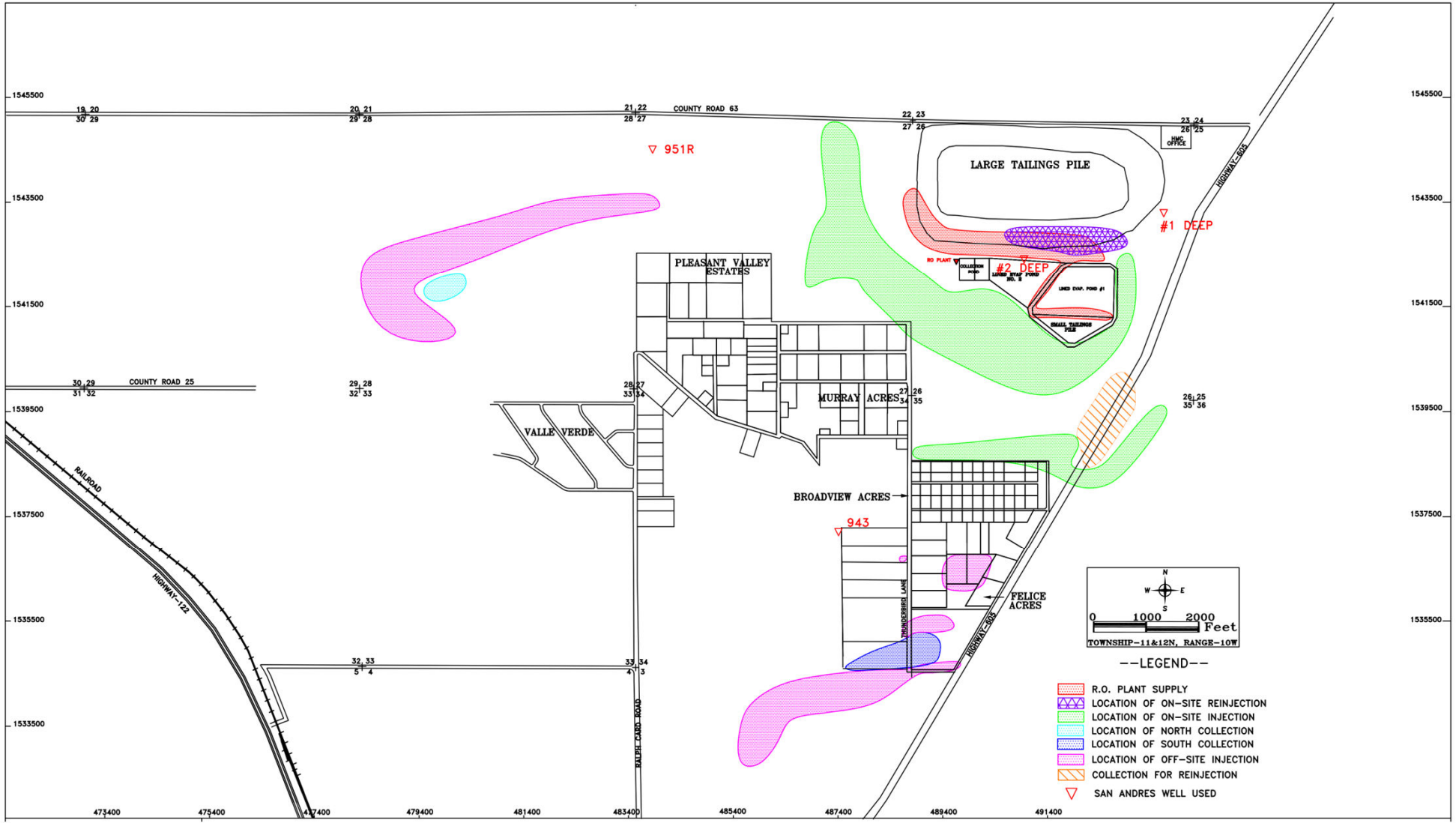

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Figure 4.1-14
Alluvial Operation Locations 2013-2015

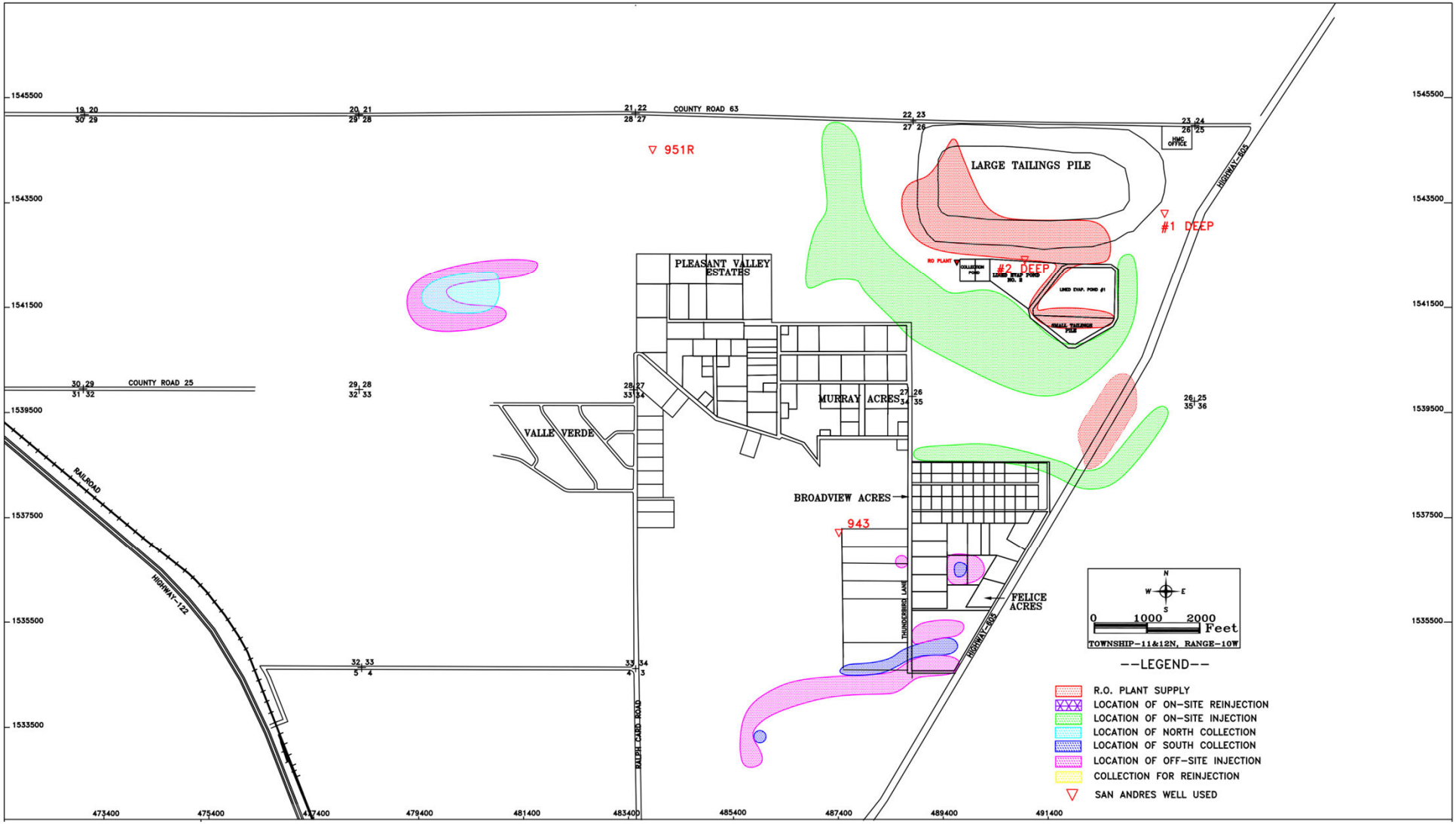

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Figure 4.1-15
Alluvial Operation Locations 2016-2023

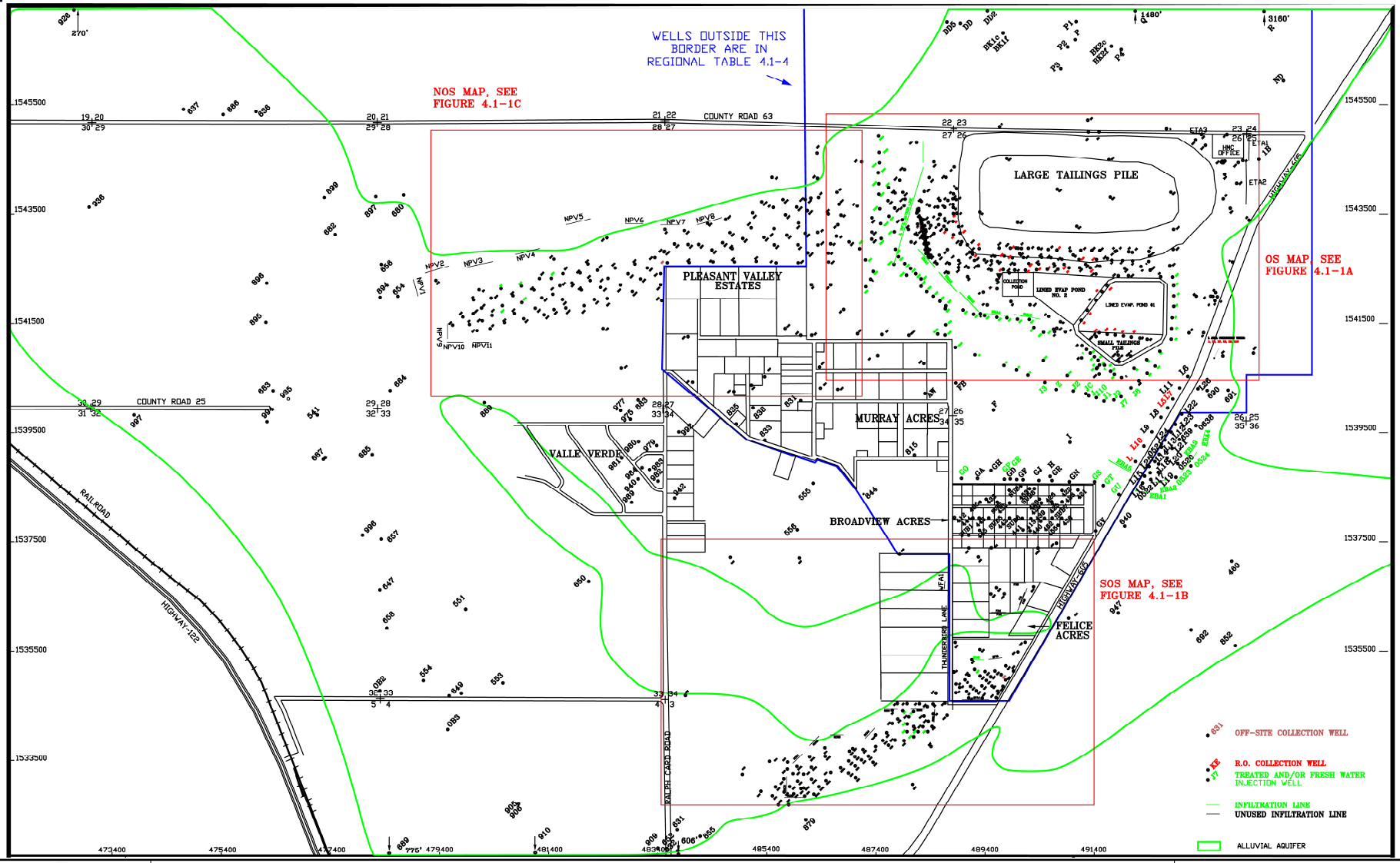

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Figure 4.1-16
Current Alluvial Operations

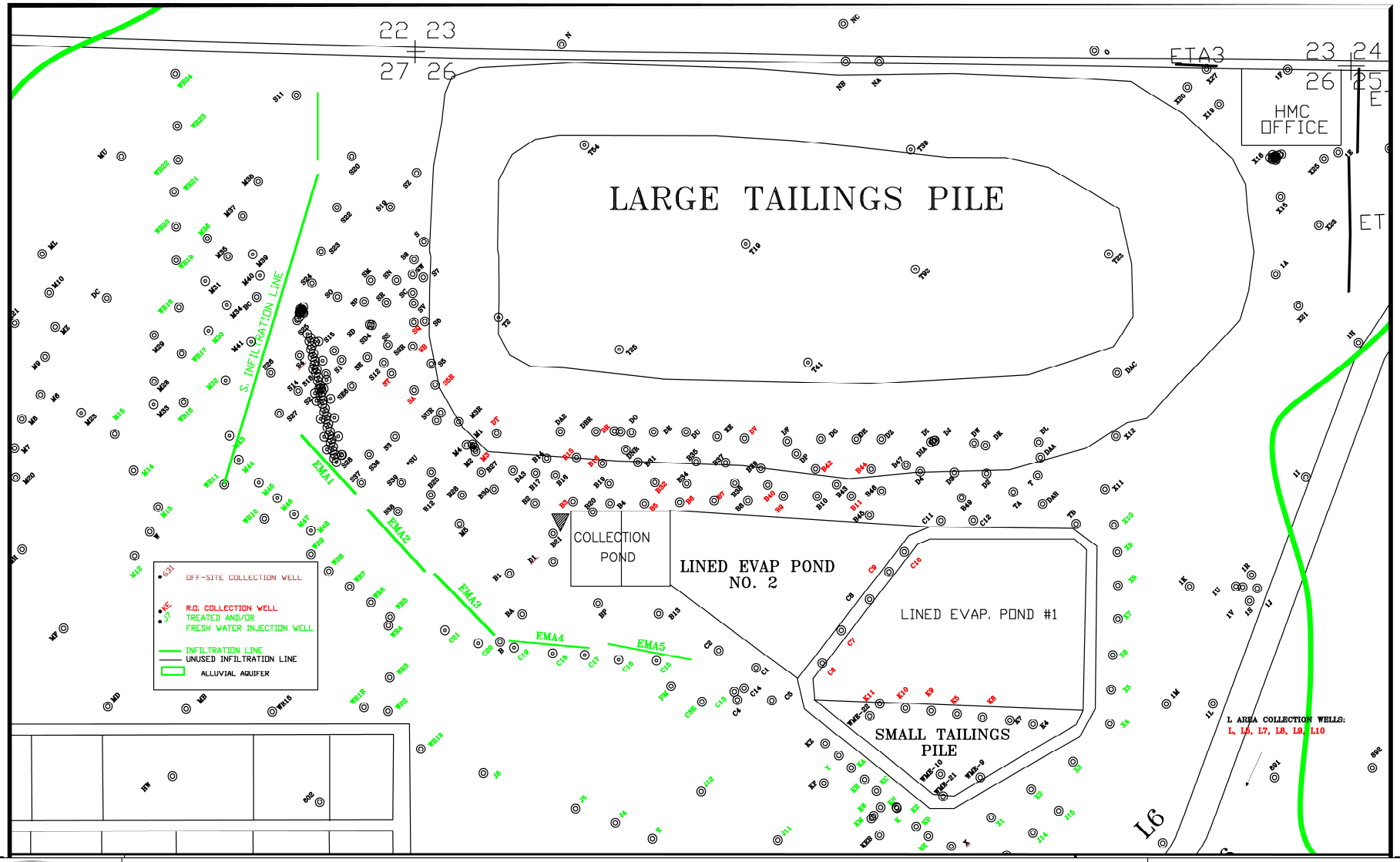

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Figure 4.1-17
Current Alluvial Operations
On-Site

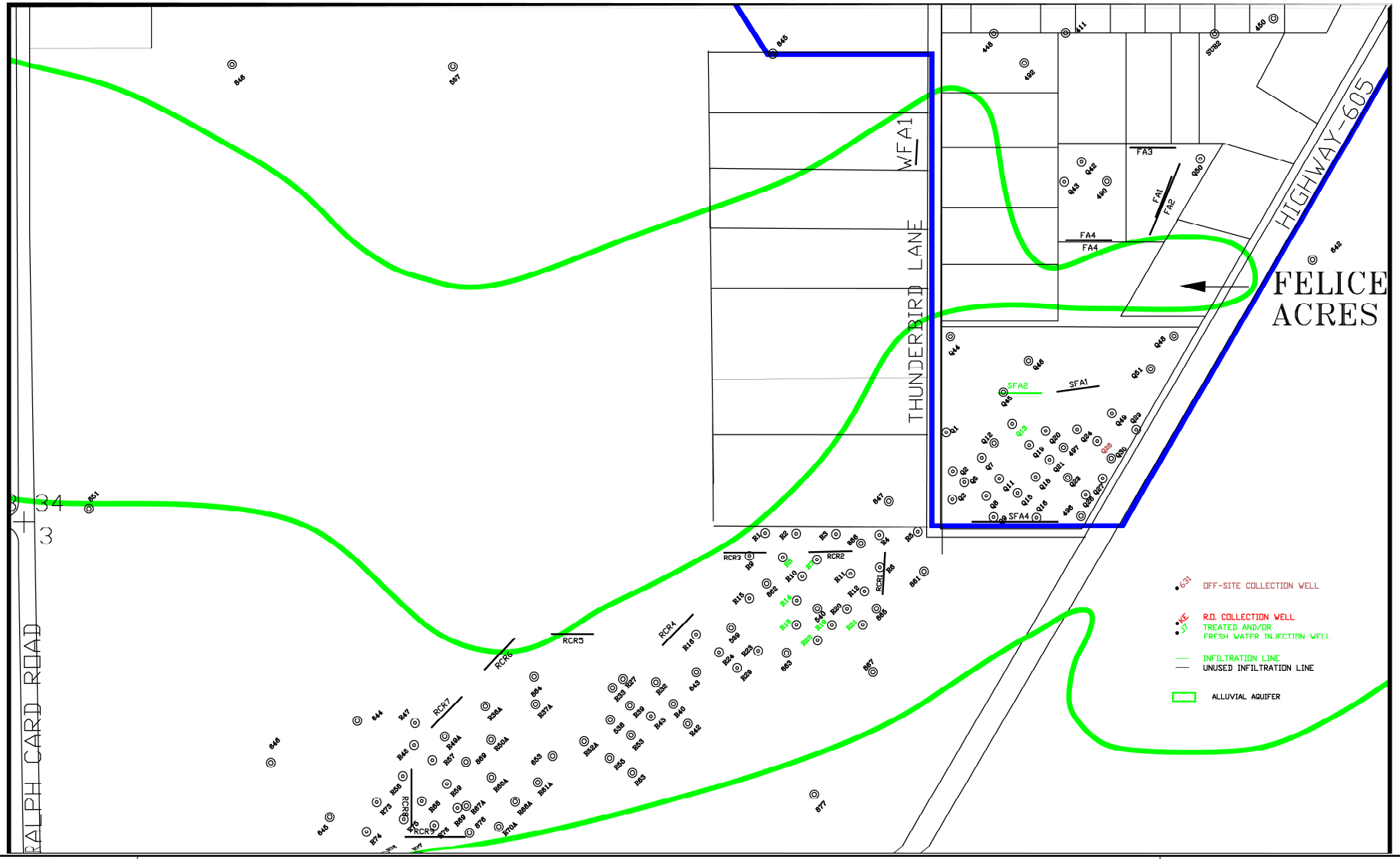

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Figure 4.1-18
Current Alluvial Operations
South Off-Site

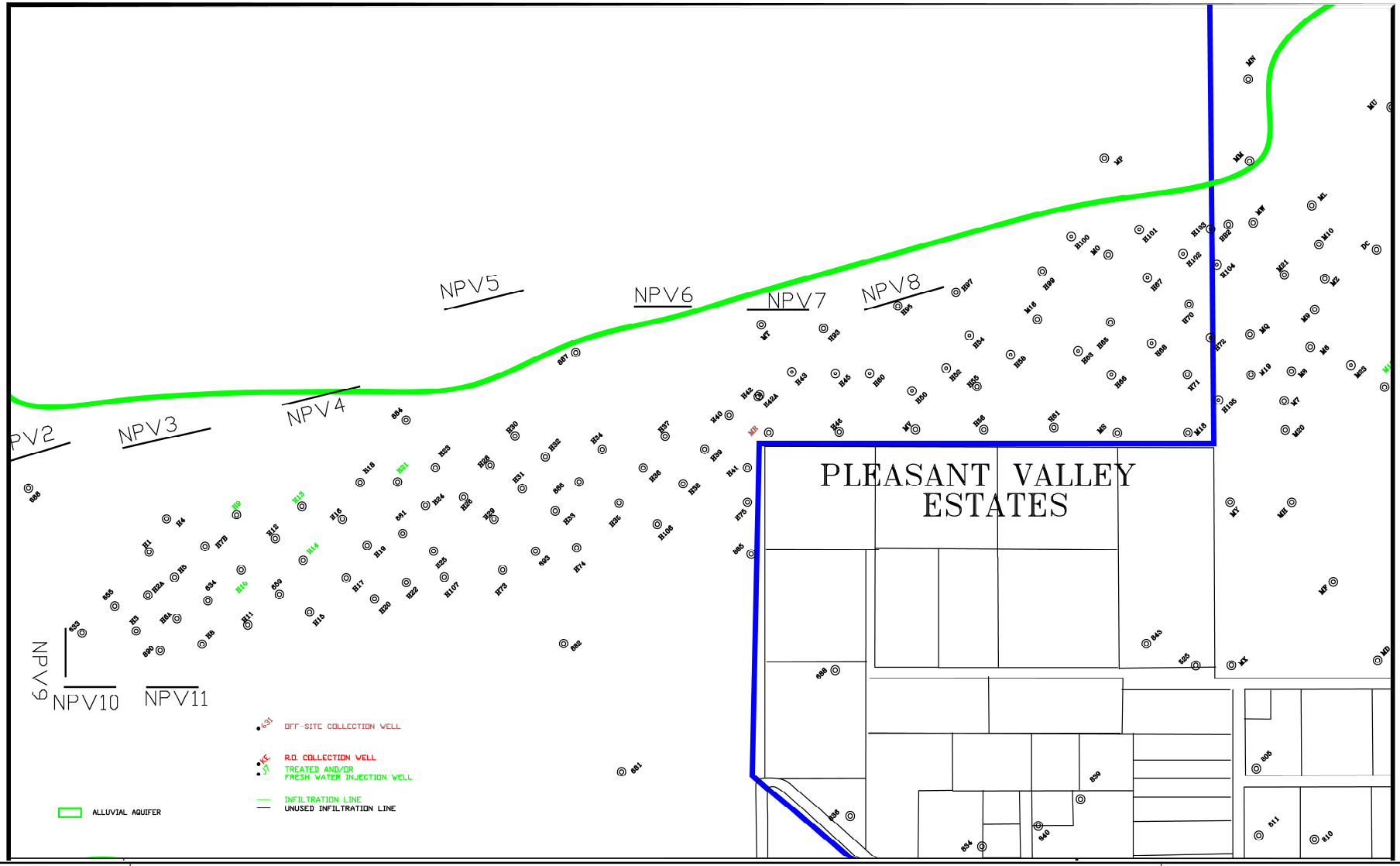

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Figure 4.1-19
Current Alluvial Operations
North Off-Site

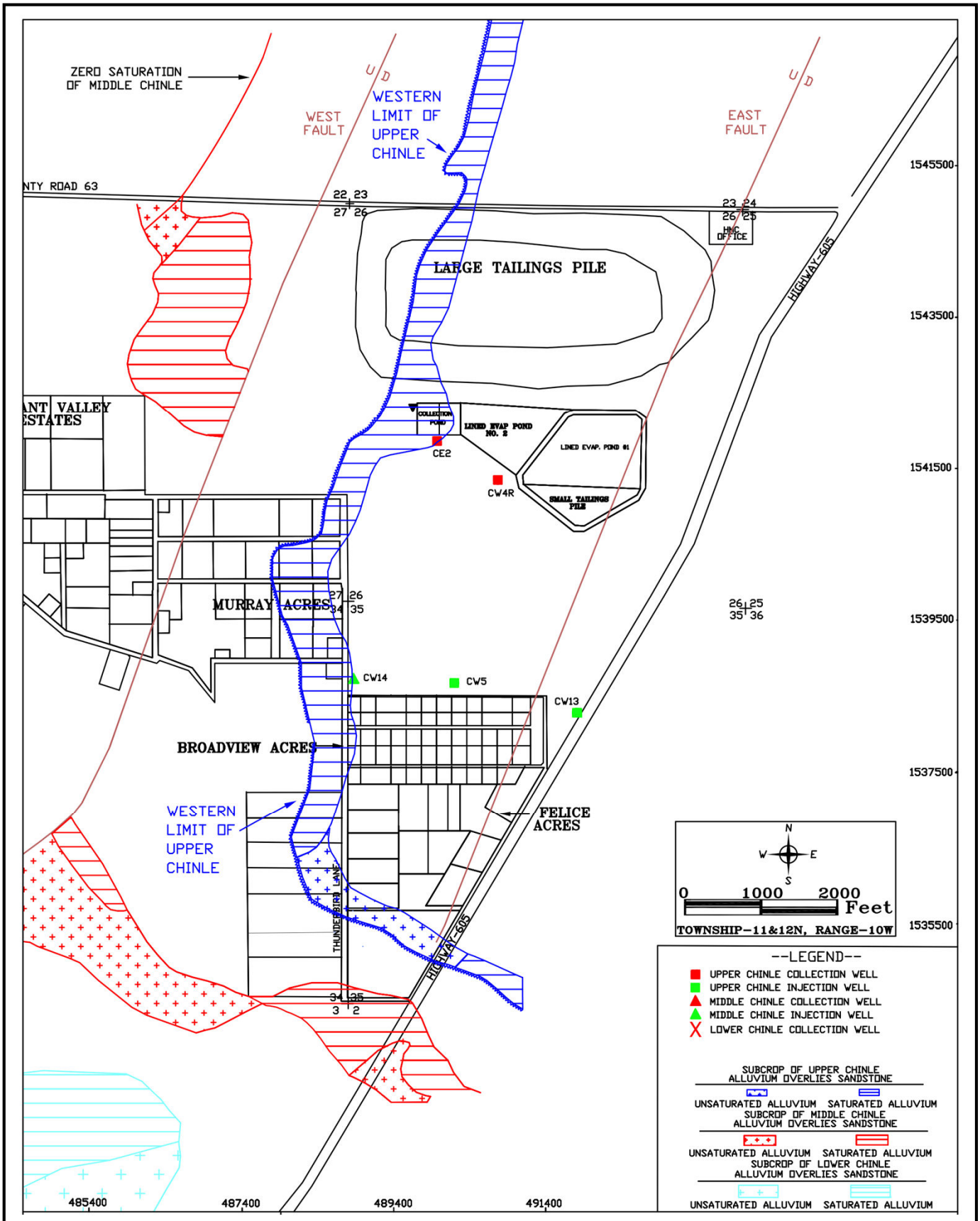

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Figure 4.1-20
Chinle Operation Locations 1984-1999

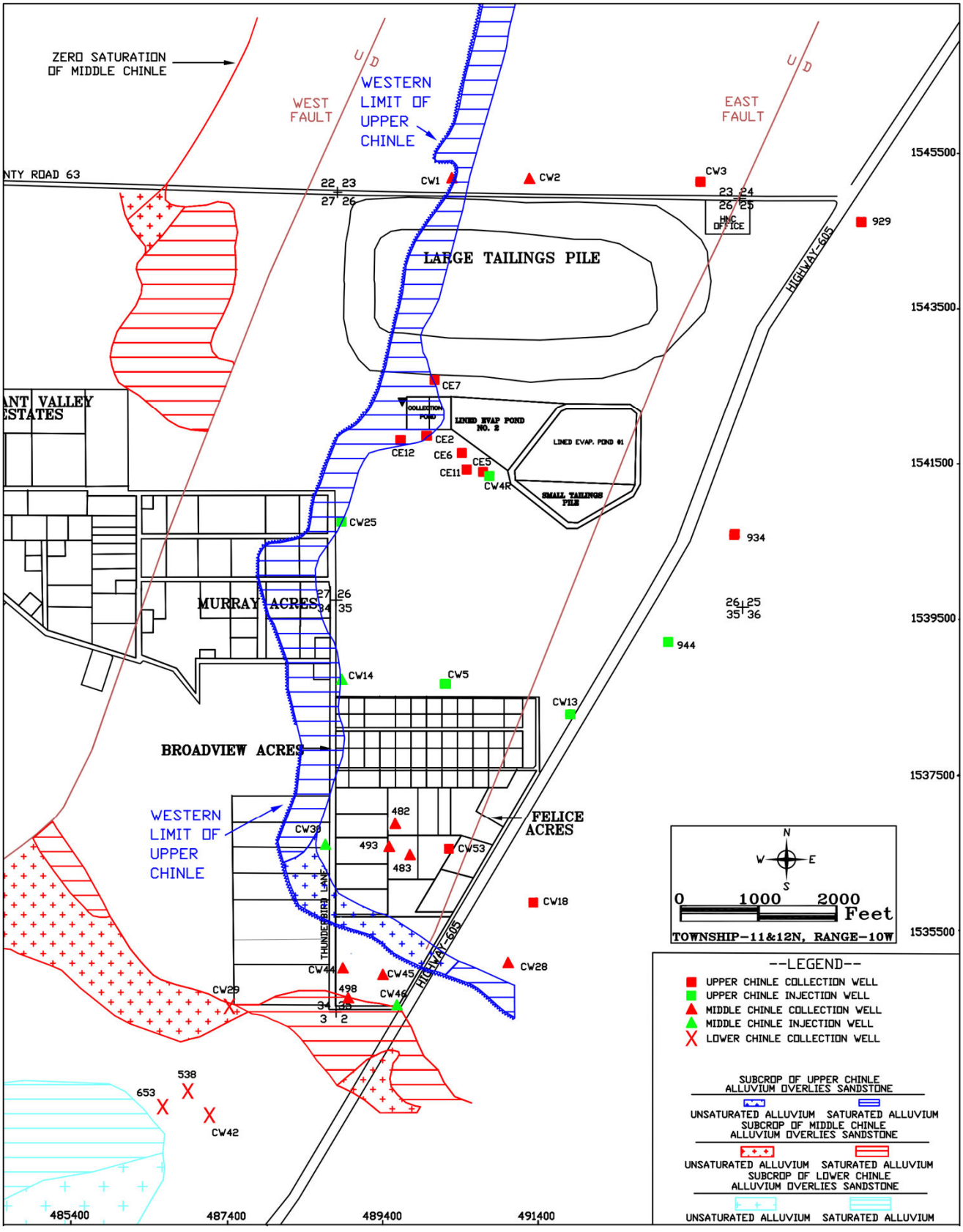

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Figure 4.1-21
Chinle Operation Locations 2000-2012

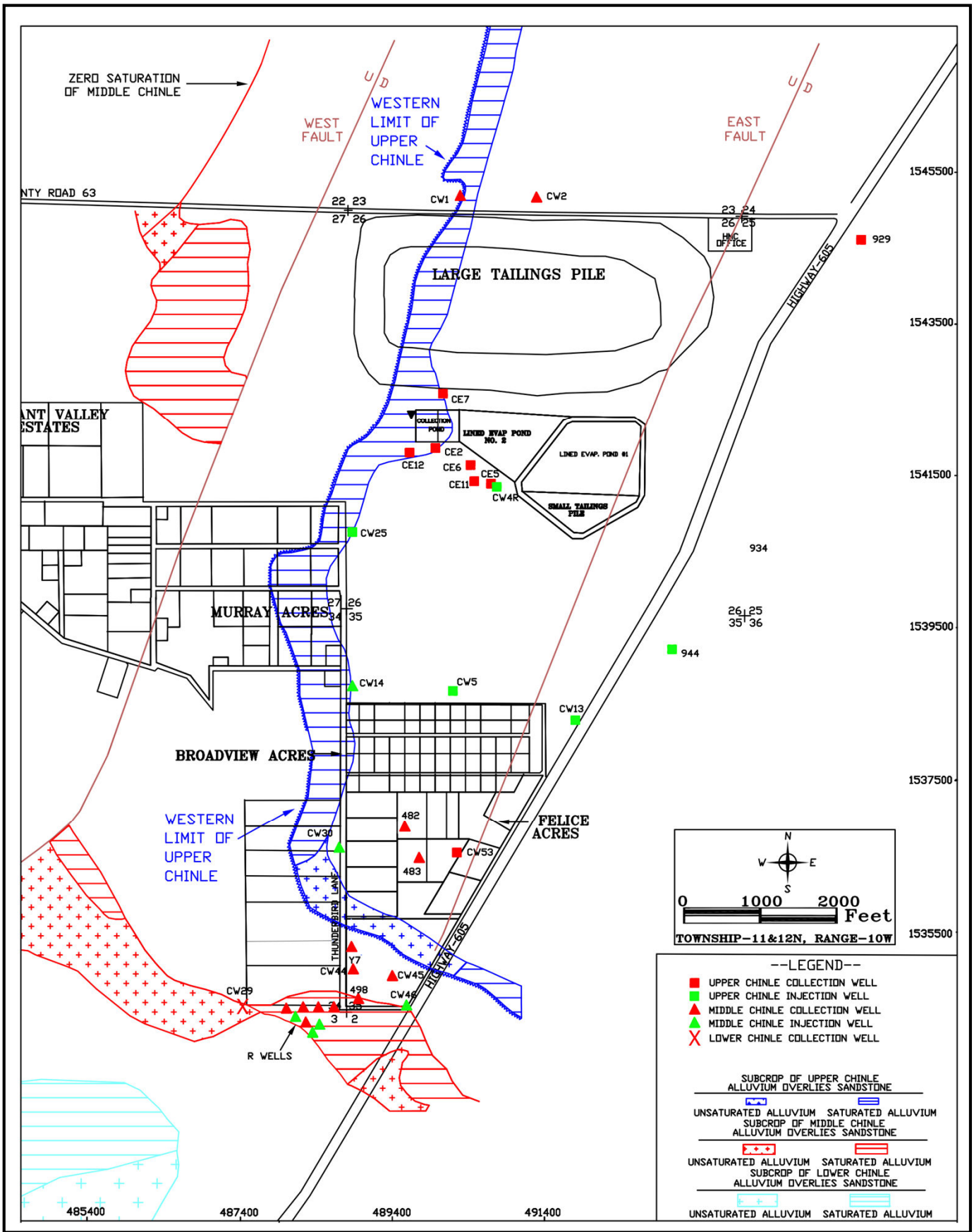

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Figure 4.1-22
Chinle Operation Locations 2013-2015

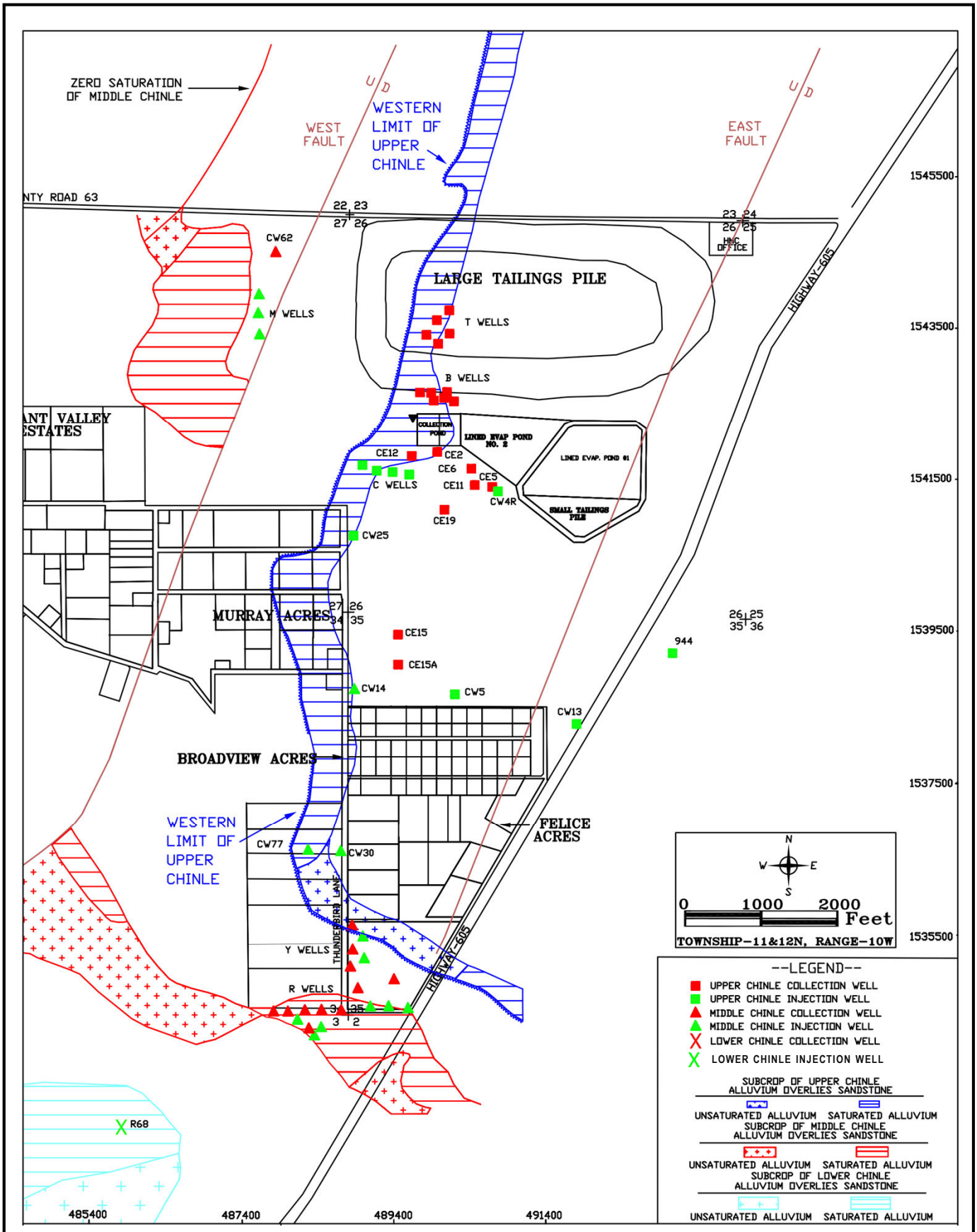

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Figure 4.1-23
Chinle Operation Locations 2016-2019

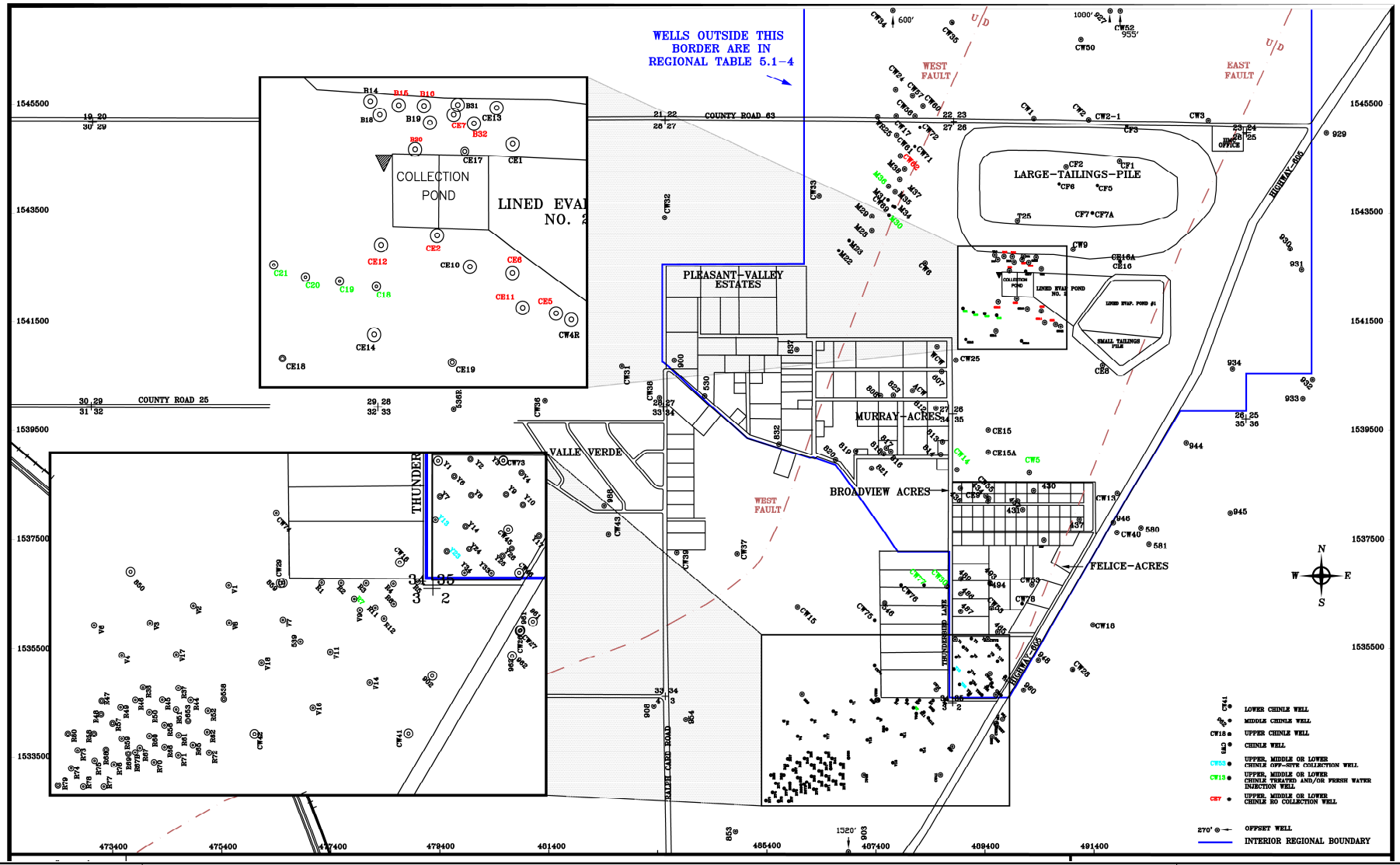

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Figure 4.1-24
Chinle Corrective Action Wells

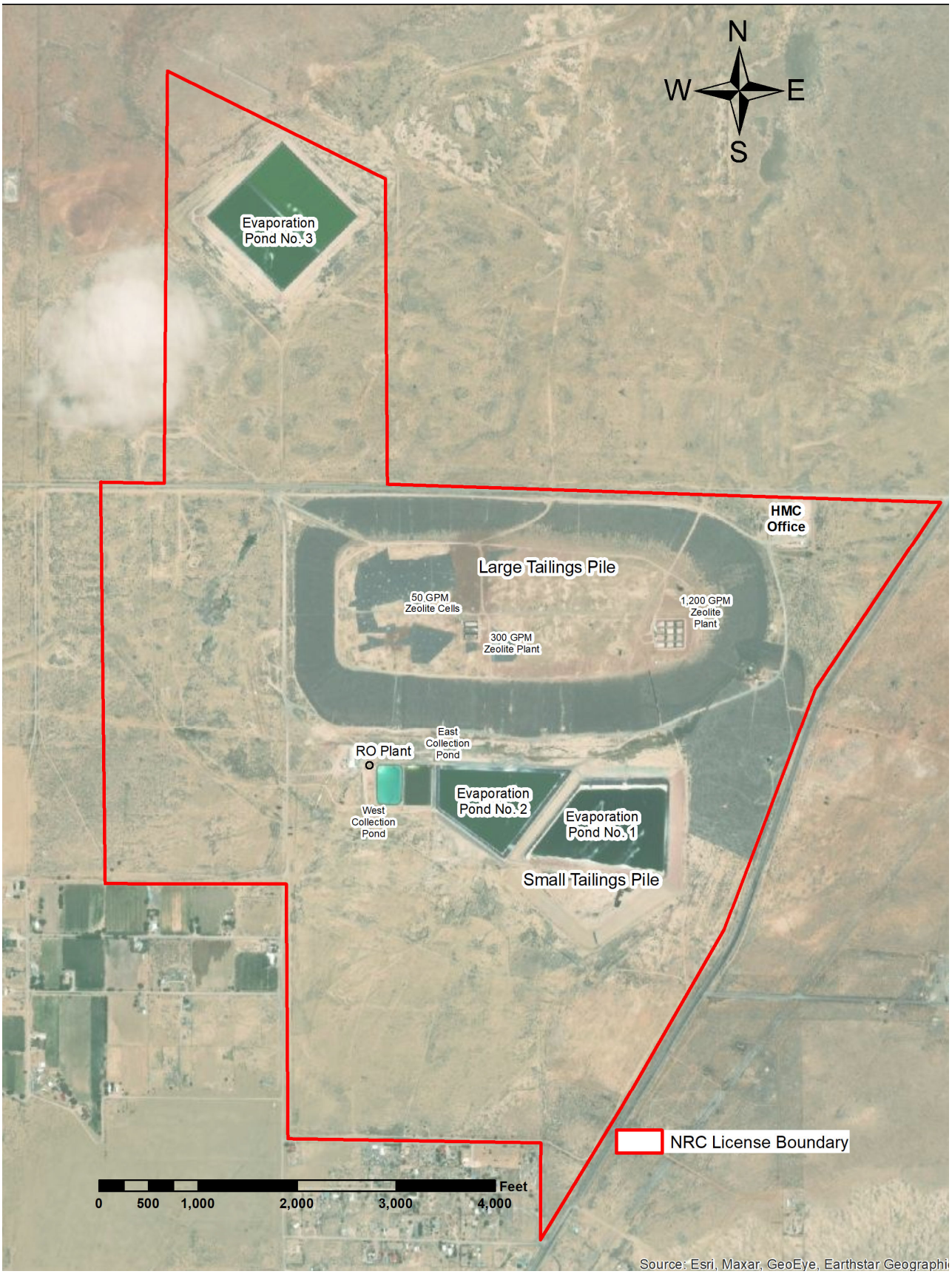

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Figure 4.1-25
Locations of GRP Evaporation Ponds, RO Plant, And Zeolite Cells

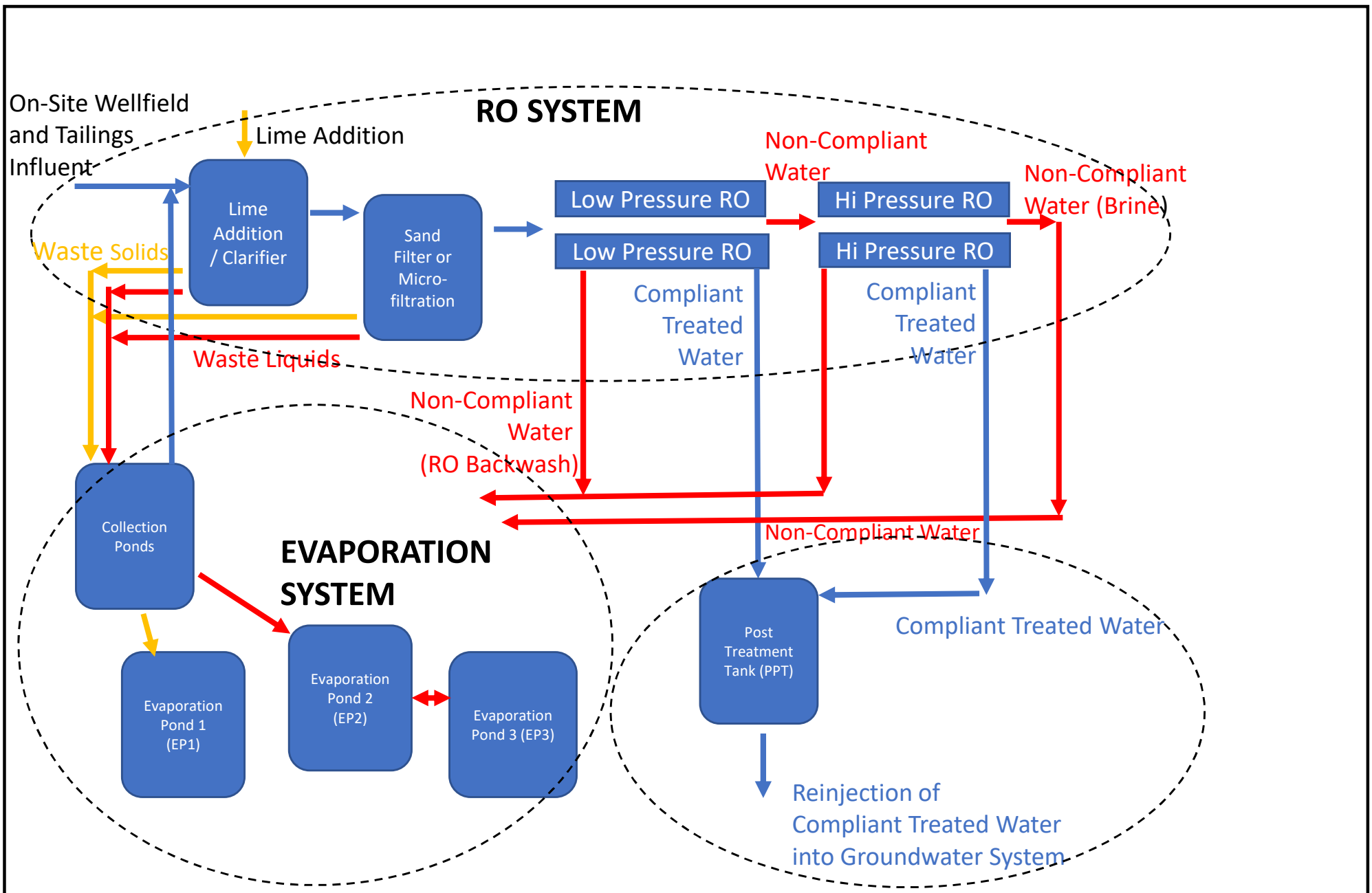

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Figure 4.1-26
Conceptual Flow Diagram
Groundwater Corrective Treatment Systems

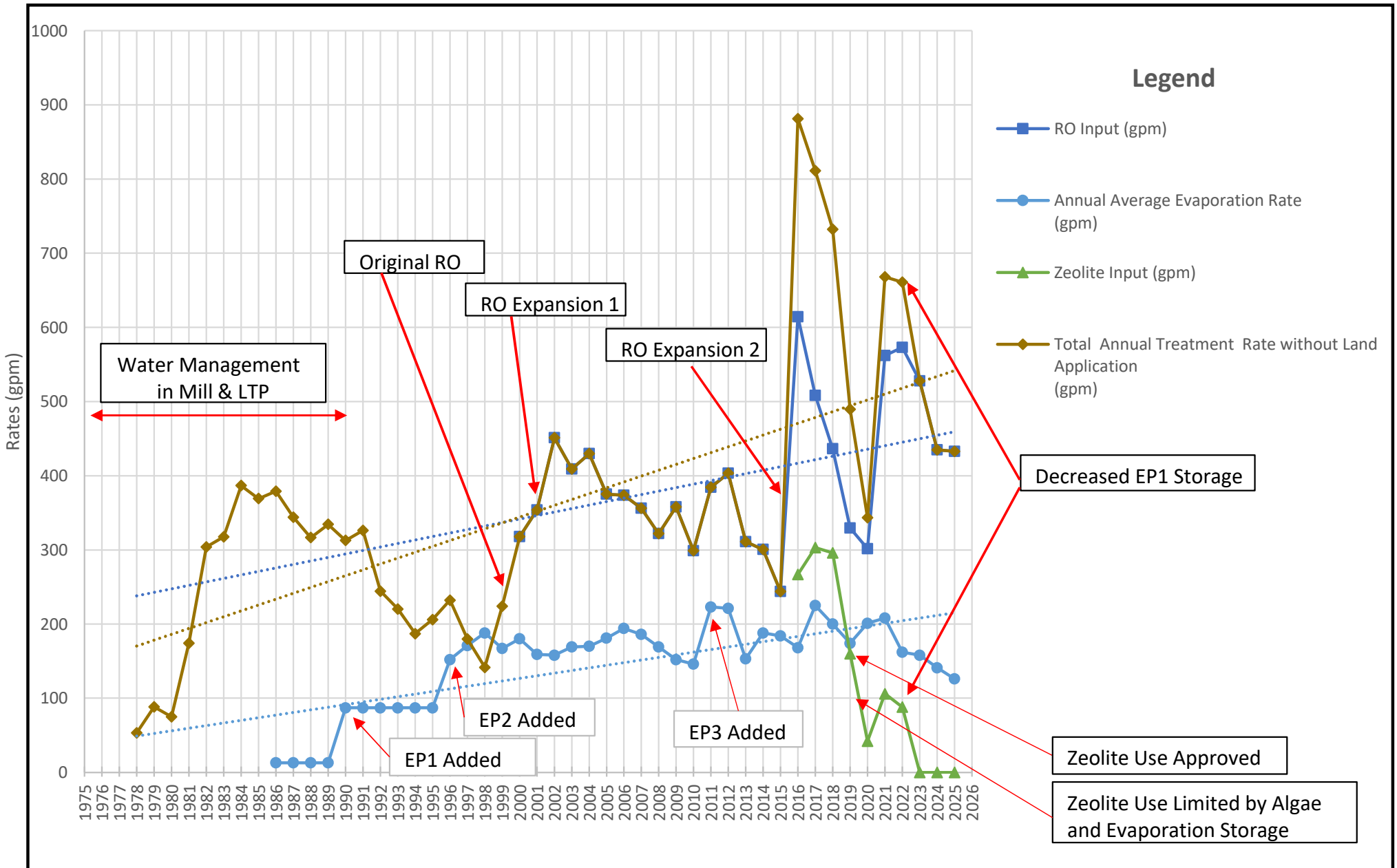

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Figure 4.1-27
Summary of Water Management System Performance

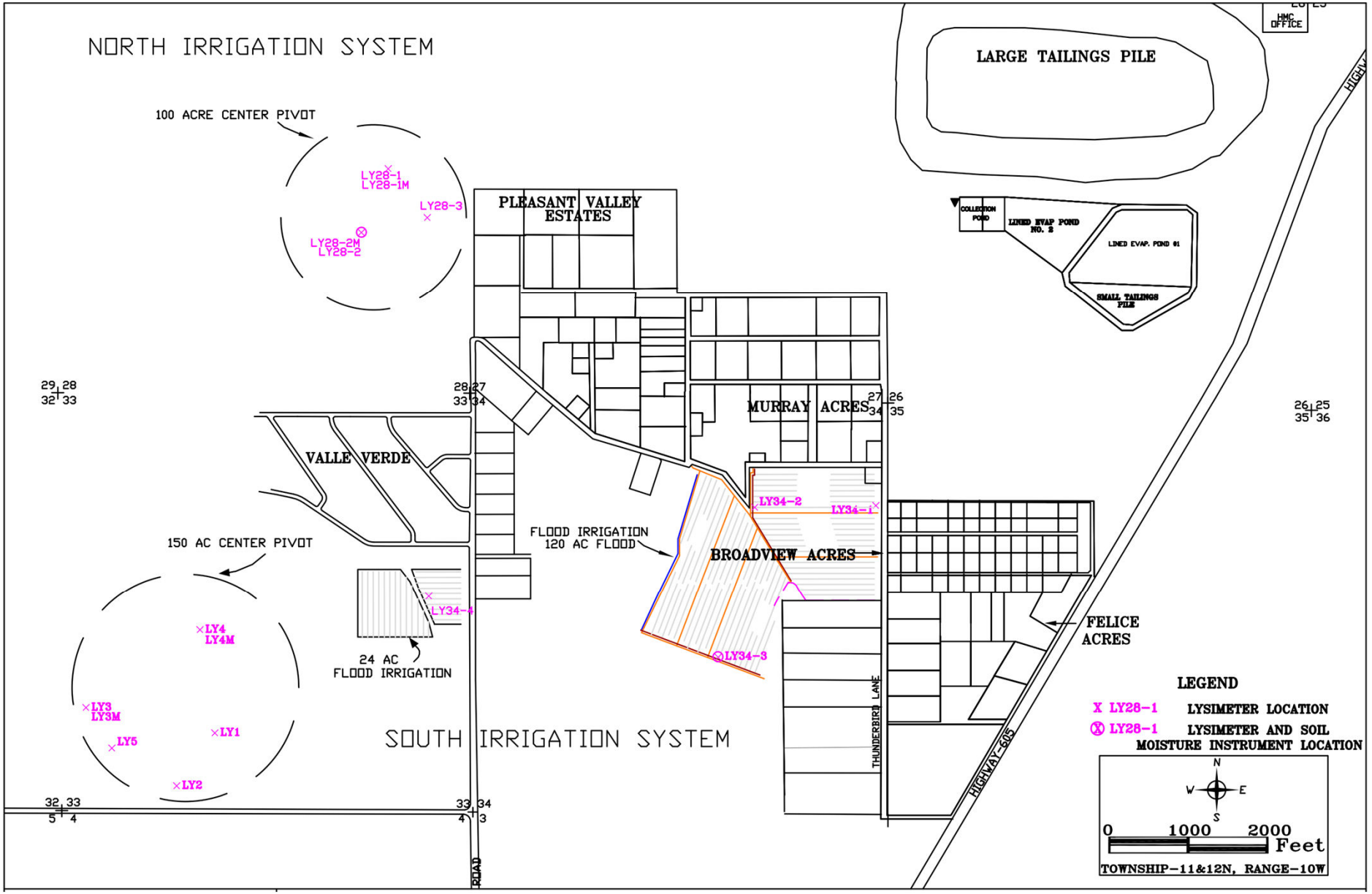
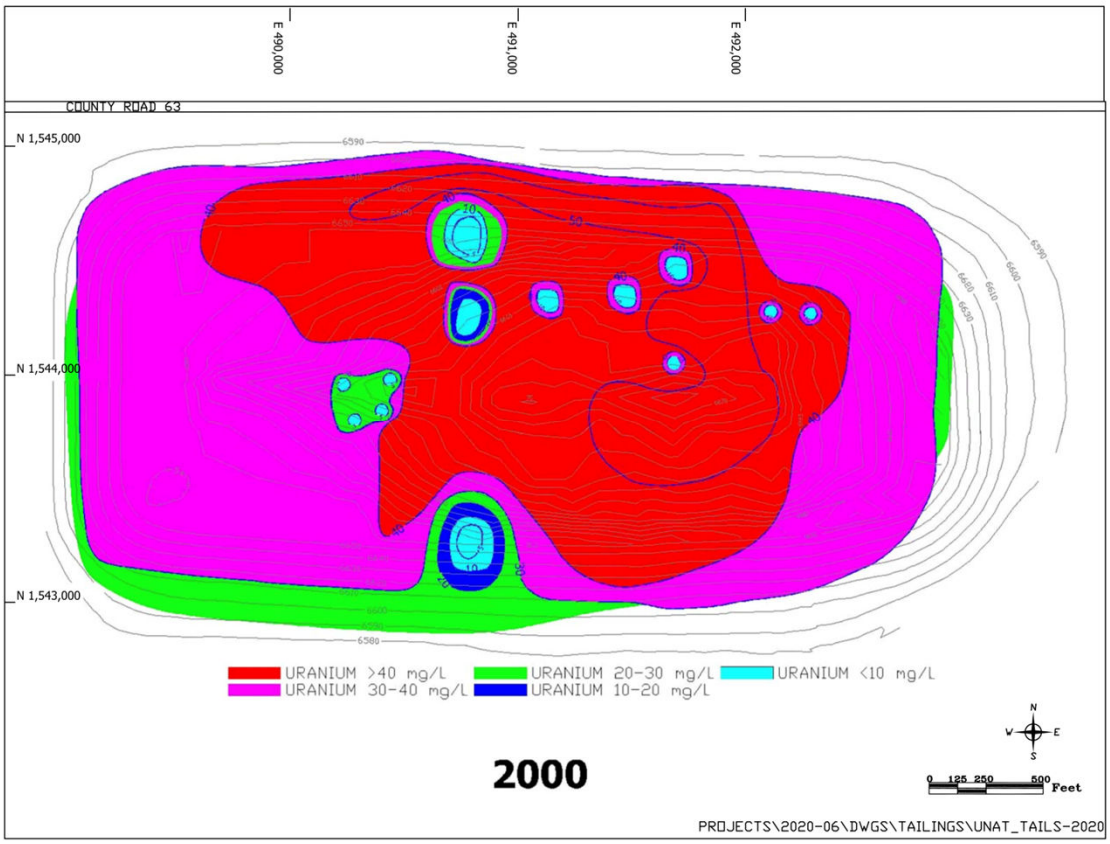


Figure 4.1-28
Land Application Irrigated
Areas and Instrumentation Locations



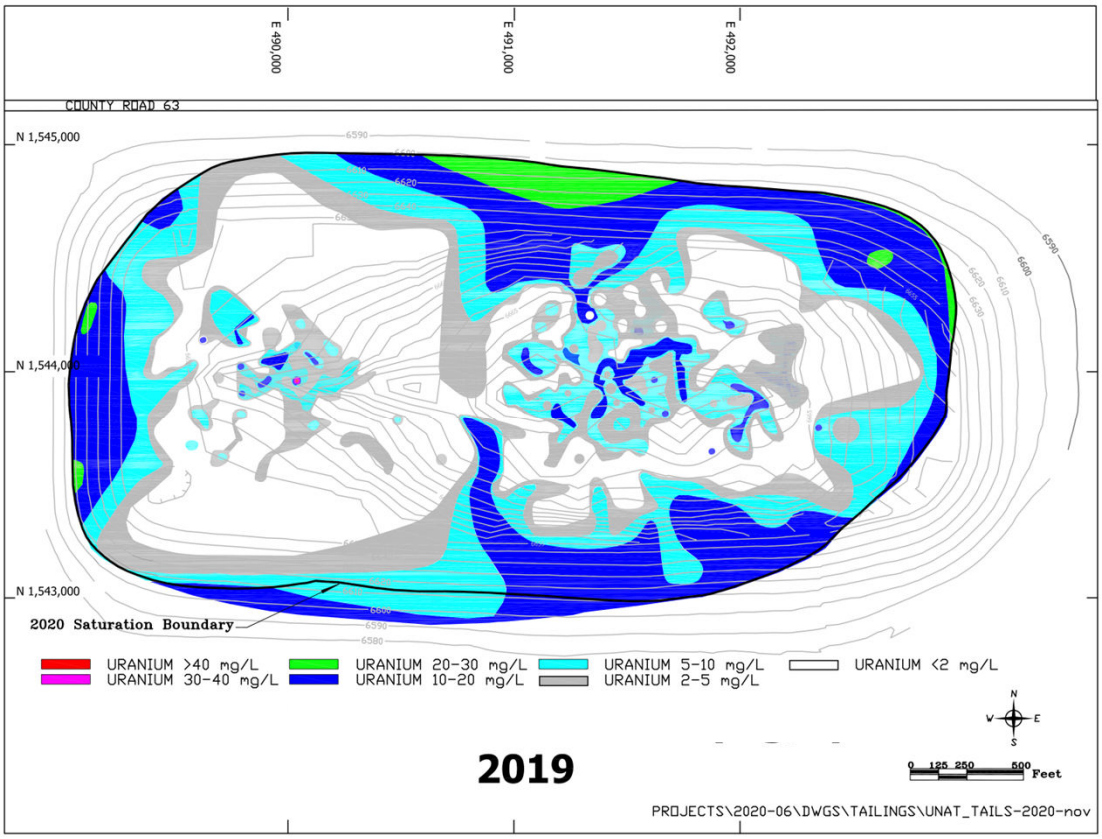


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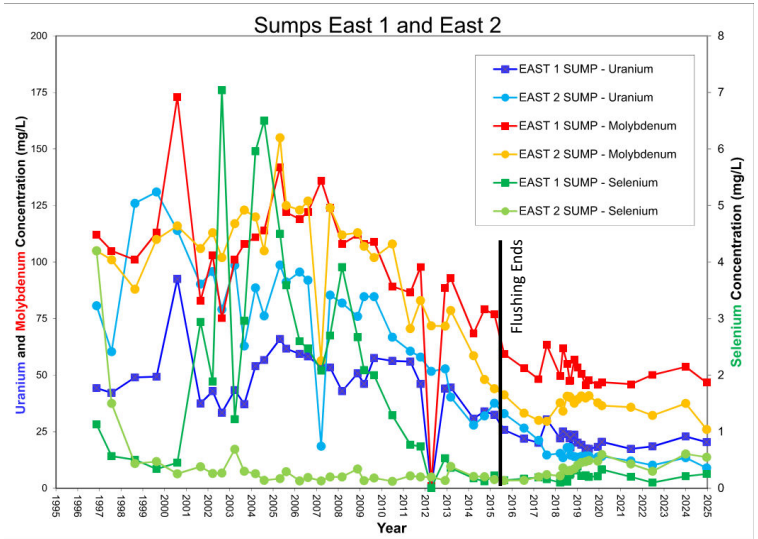
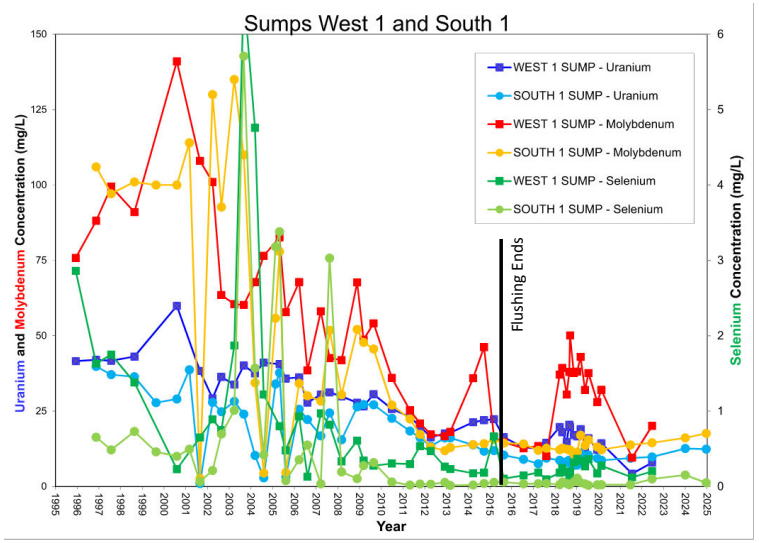
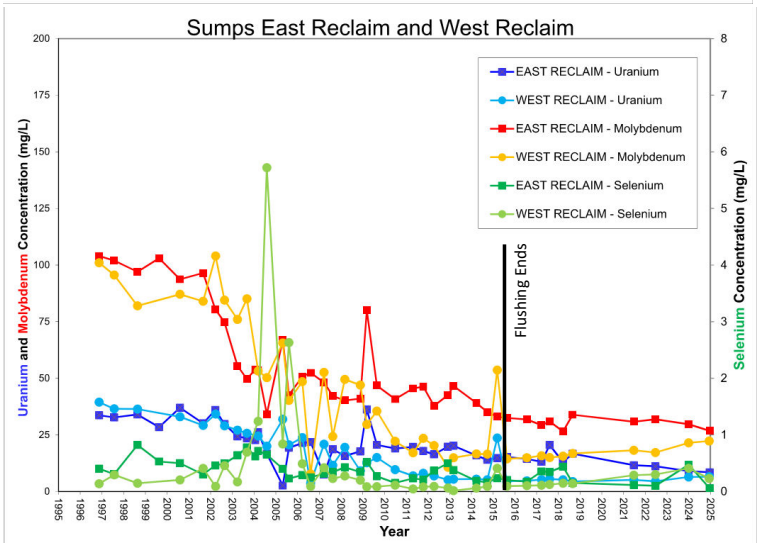
Figure 4.1-29
Pre- and Post- Flushing Uranium Concentrations in the Large Tailings Pile







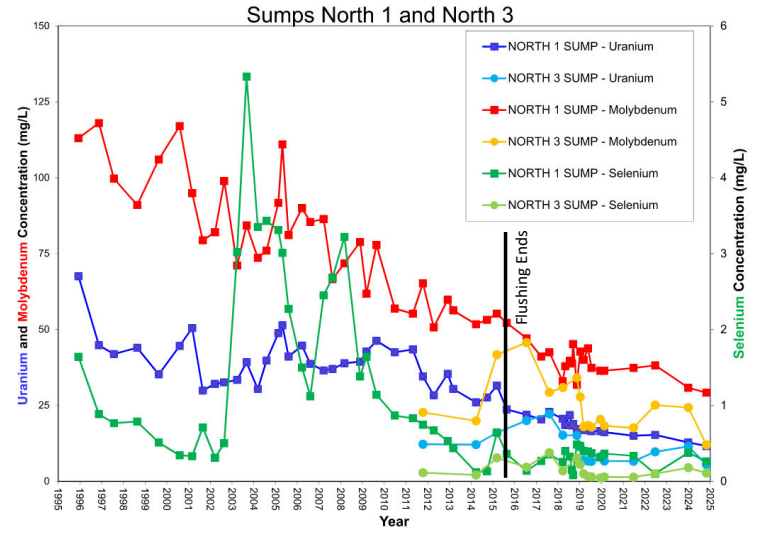


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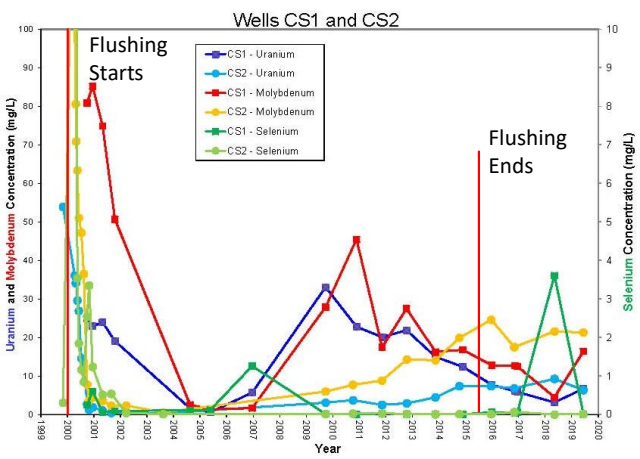
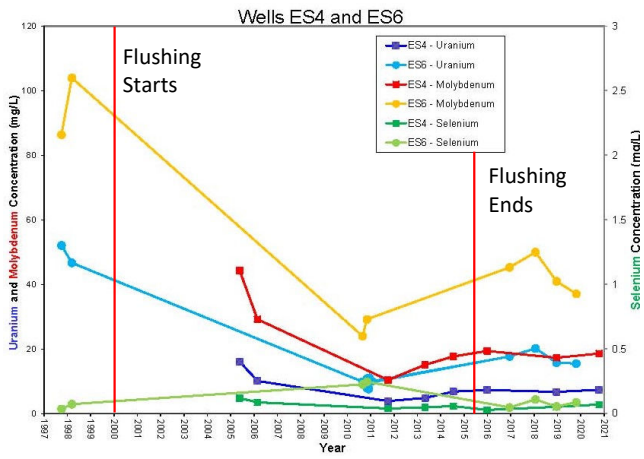
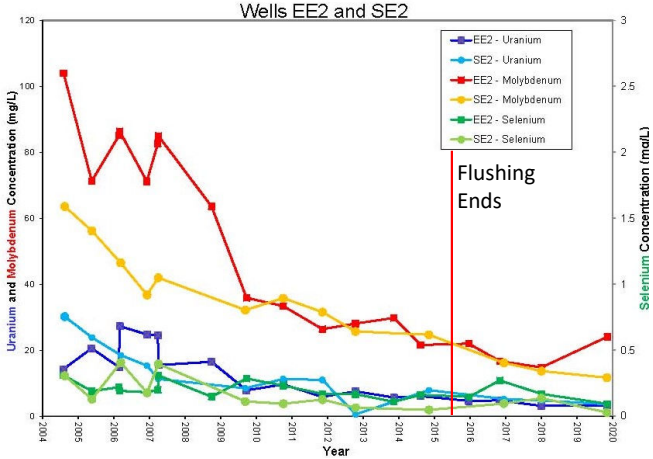
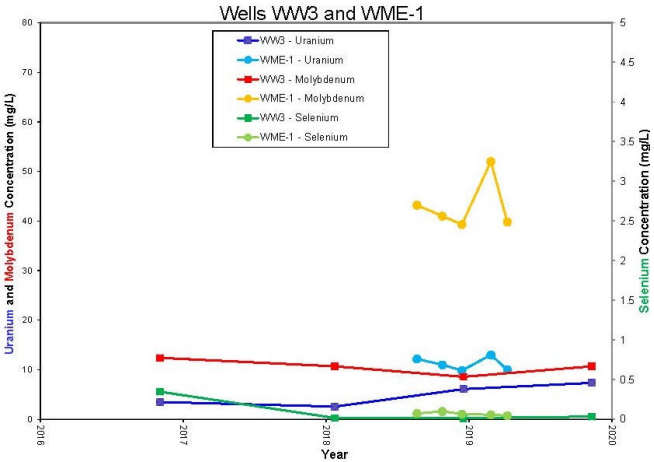
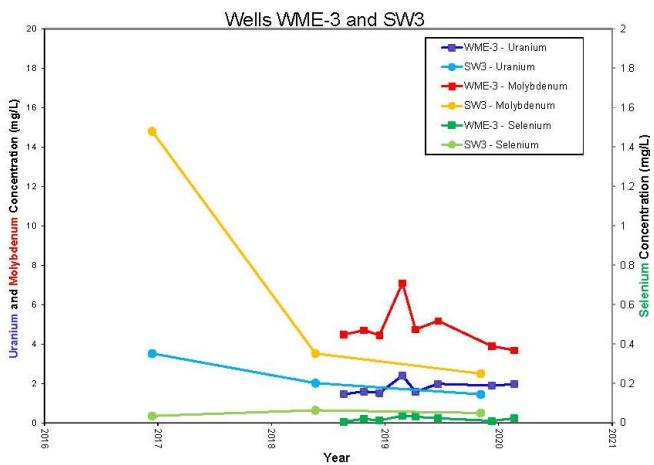
Figure 4.1-30
Large Tailings Pile Toe Drain
Sump Concentrations











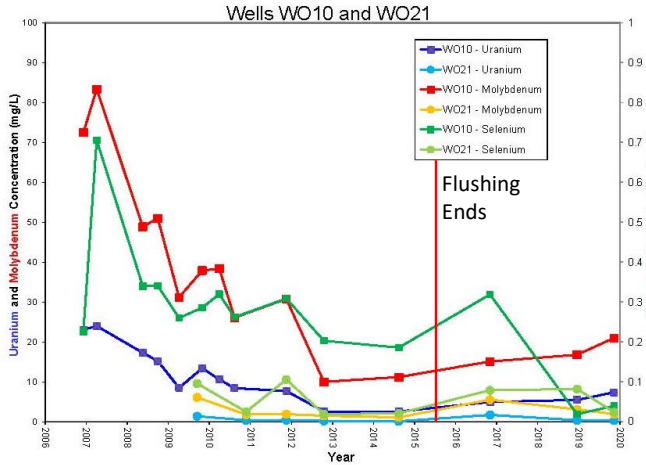


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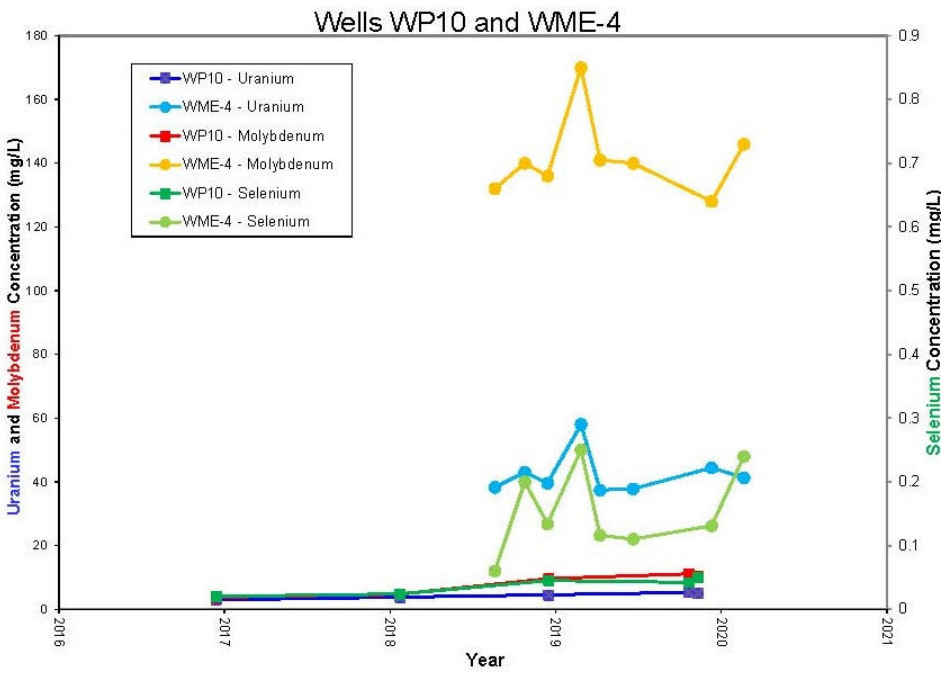
Figure 4.1-31
Large Tailings Pile Well Concentrations for Uranium, Molybdenum, and Selenium



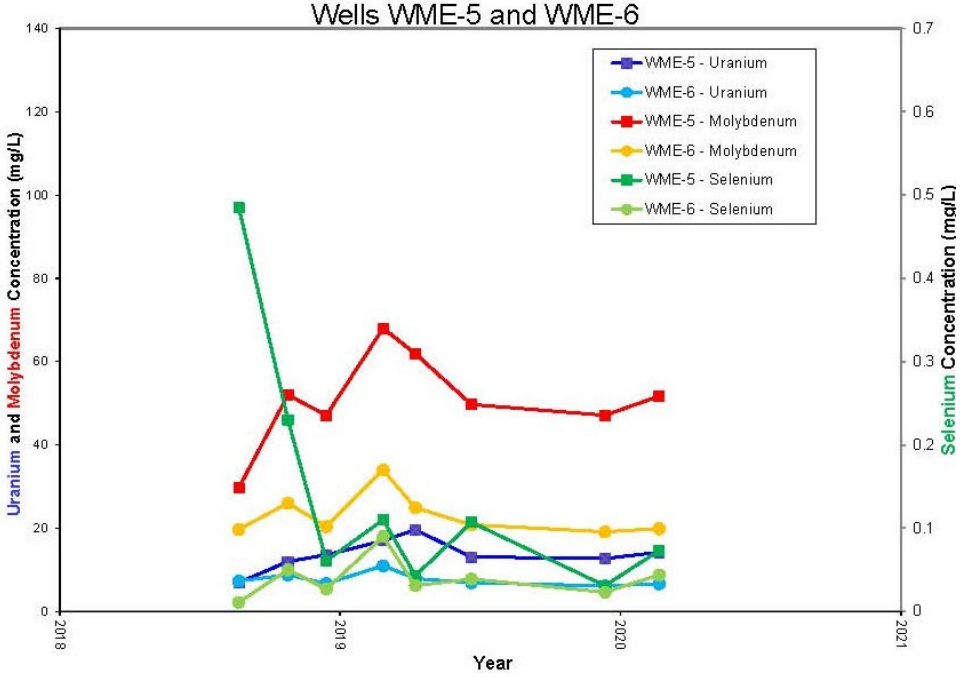


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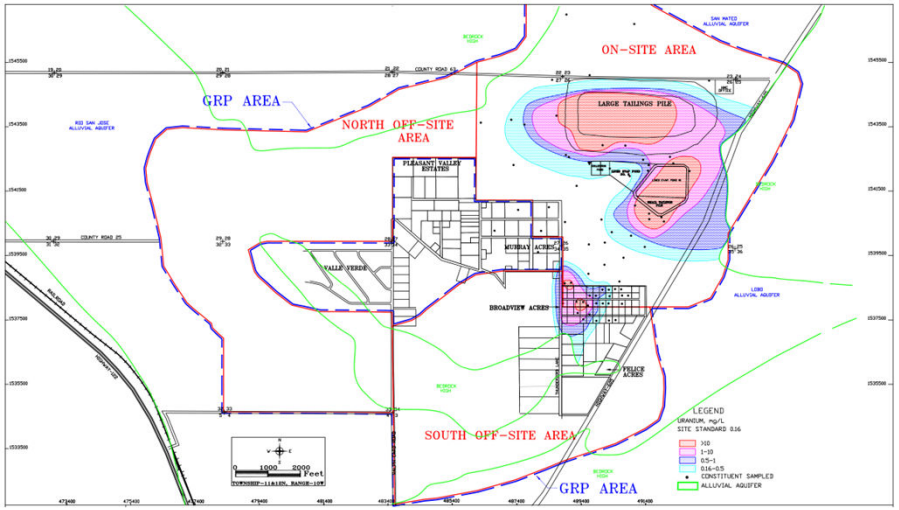
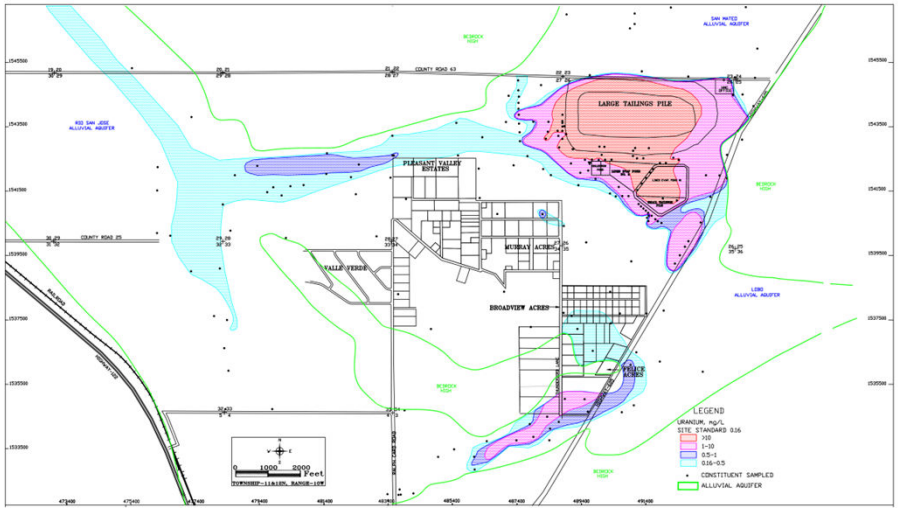
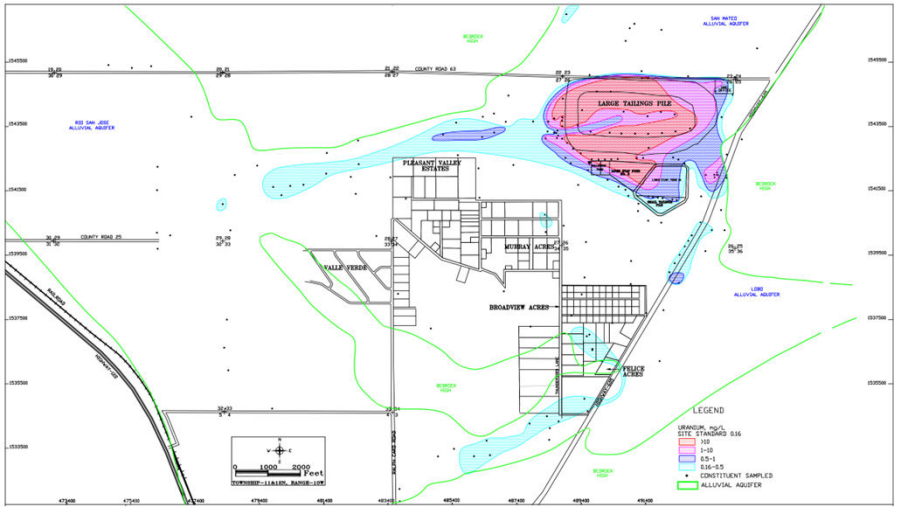
Figure 4.1-32
Large Tailings Pile Well Concentrations for Uranium, Molybdenum, and Selenium



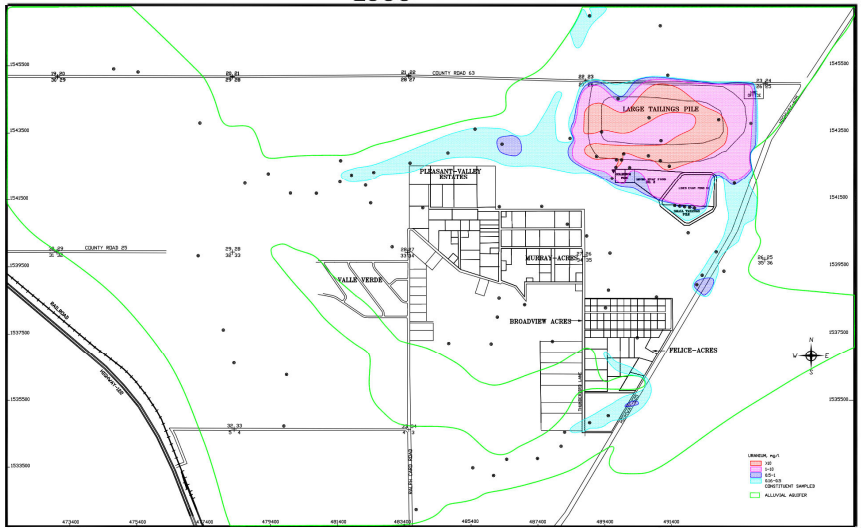
1976



1999



2009



2024

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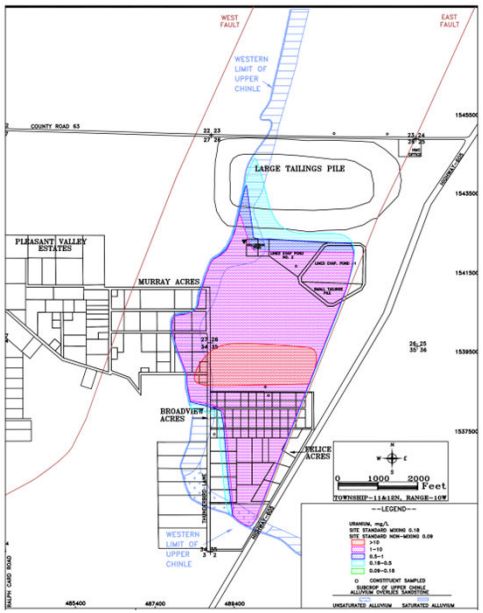
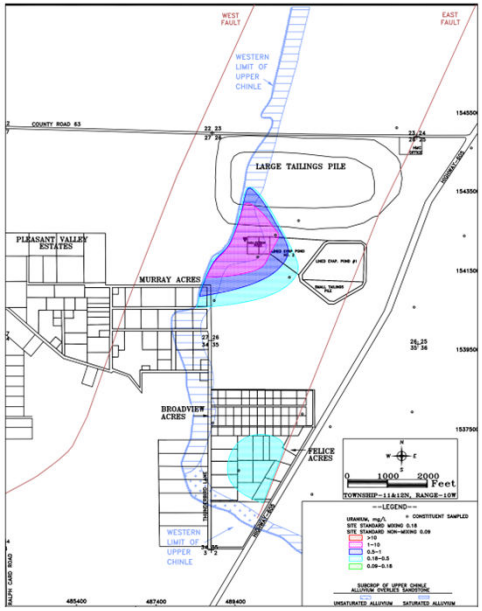
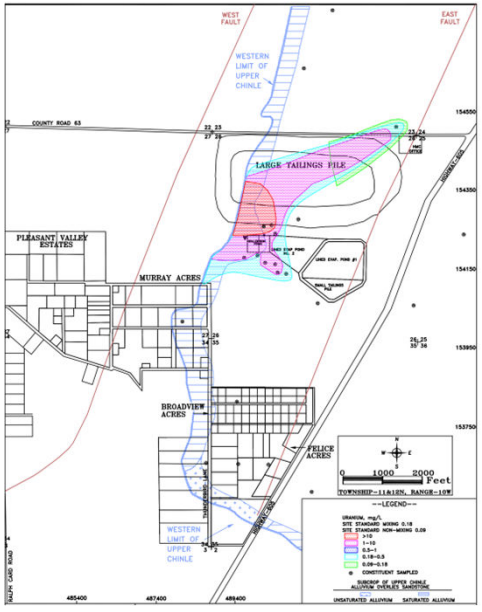
Figure 4.1-33
Extent of Uranium in Alluvial Groundwater
1976, 1999, 2009, 2024



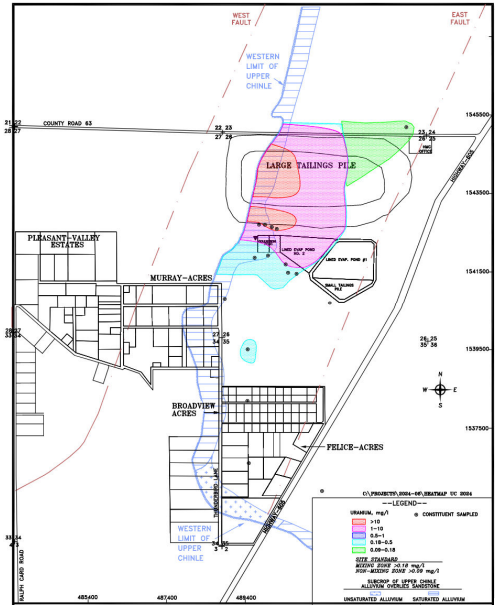
1982



1999



2009



2024

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Figure 4.1-34
Extent of Uranium in Upper Chinle Groundwater
1982, 1999, 2009, 2024

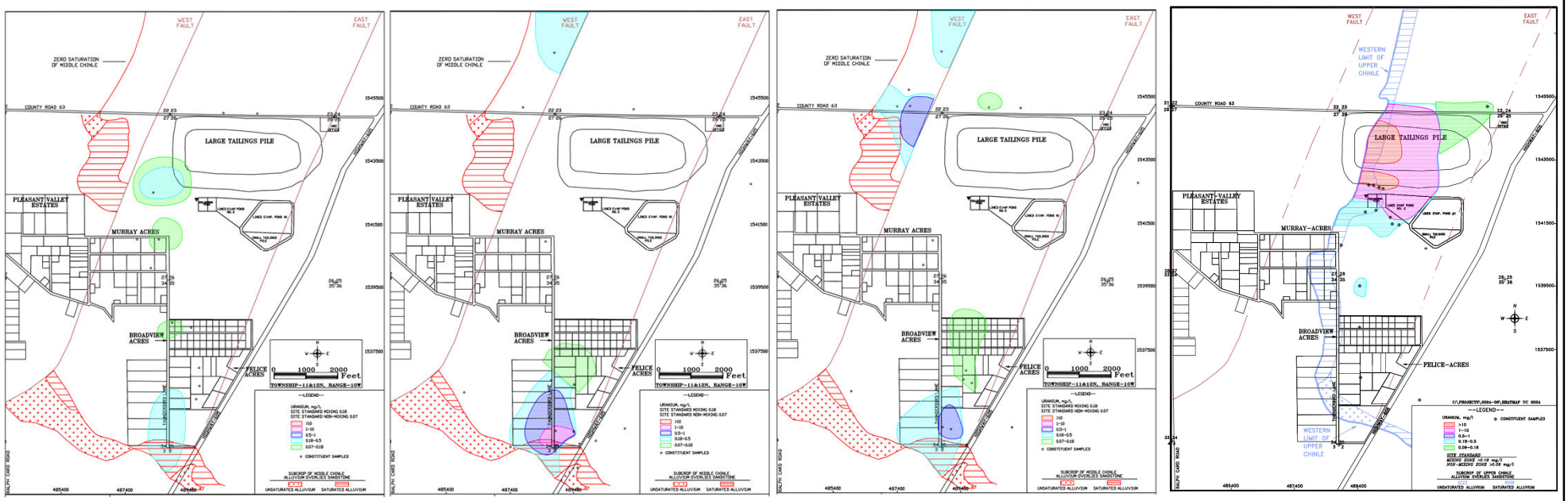

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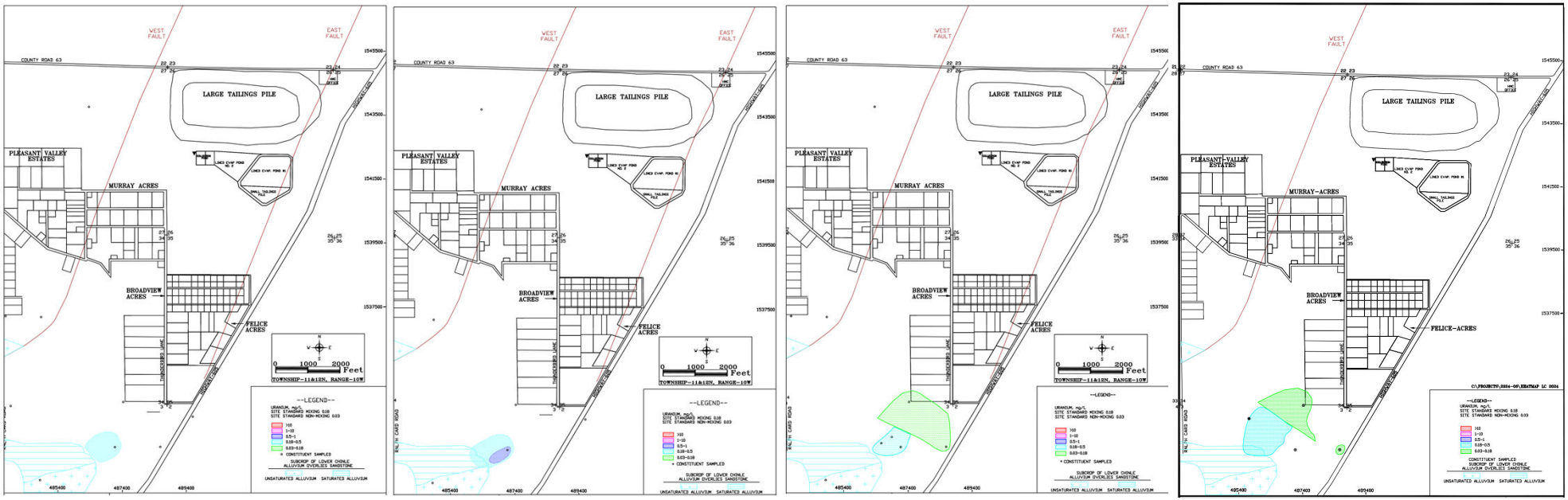
Figure 4.1-35
Extent of Uranium in Middle Chinle Groundwater
1982, 1999, 2009, 2024



1982 1999 2009 2024

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Figure 4.1-36
Extent of Uranium in Lower Chinle Groundwater
1982, 1999, 2009, 2024

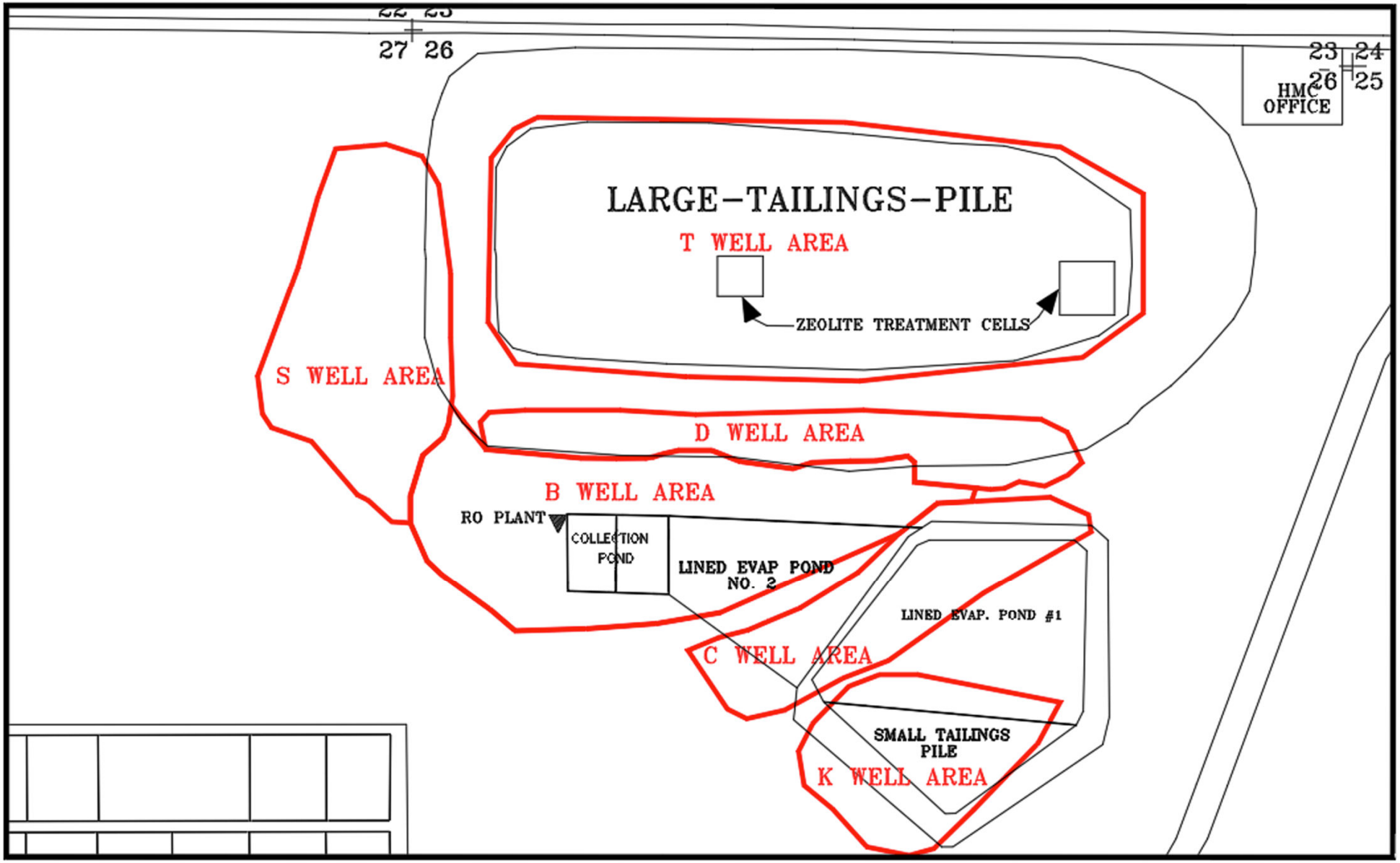

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Figure 4.1-37
Monitoring Well Grouping Areas

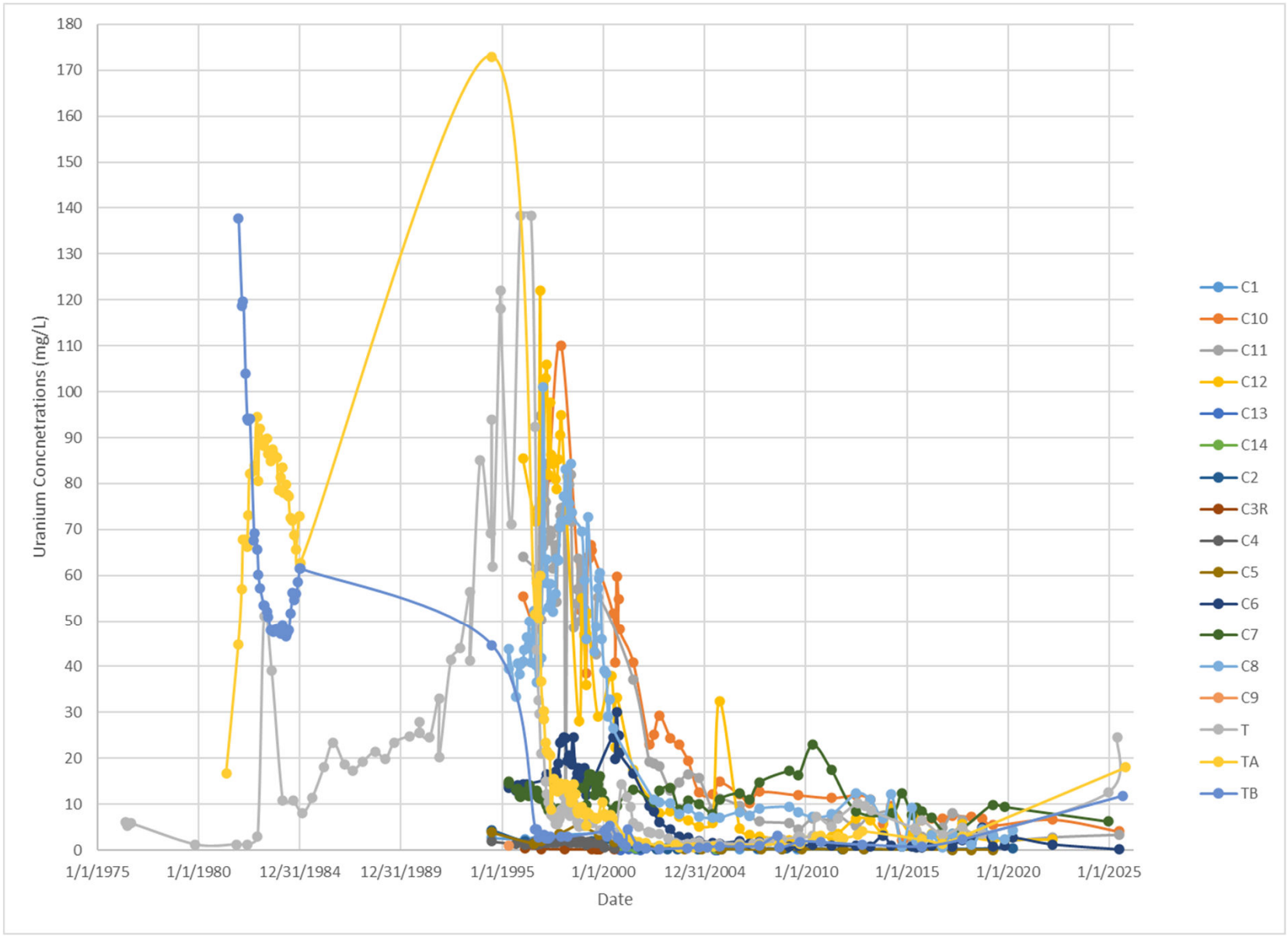

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Figure 4.1-38
C Well Uranium Concentrations

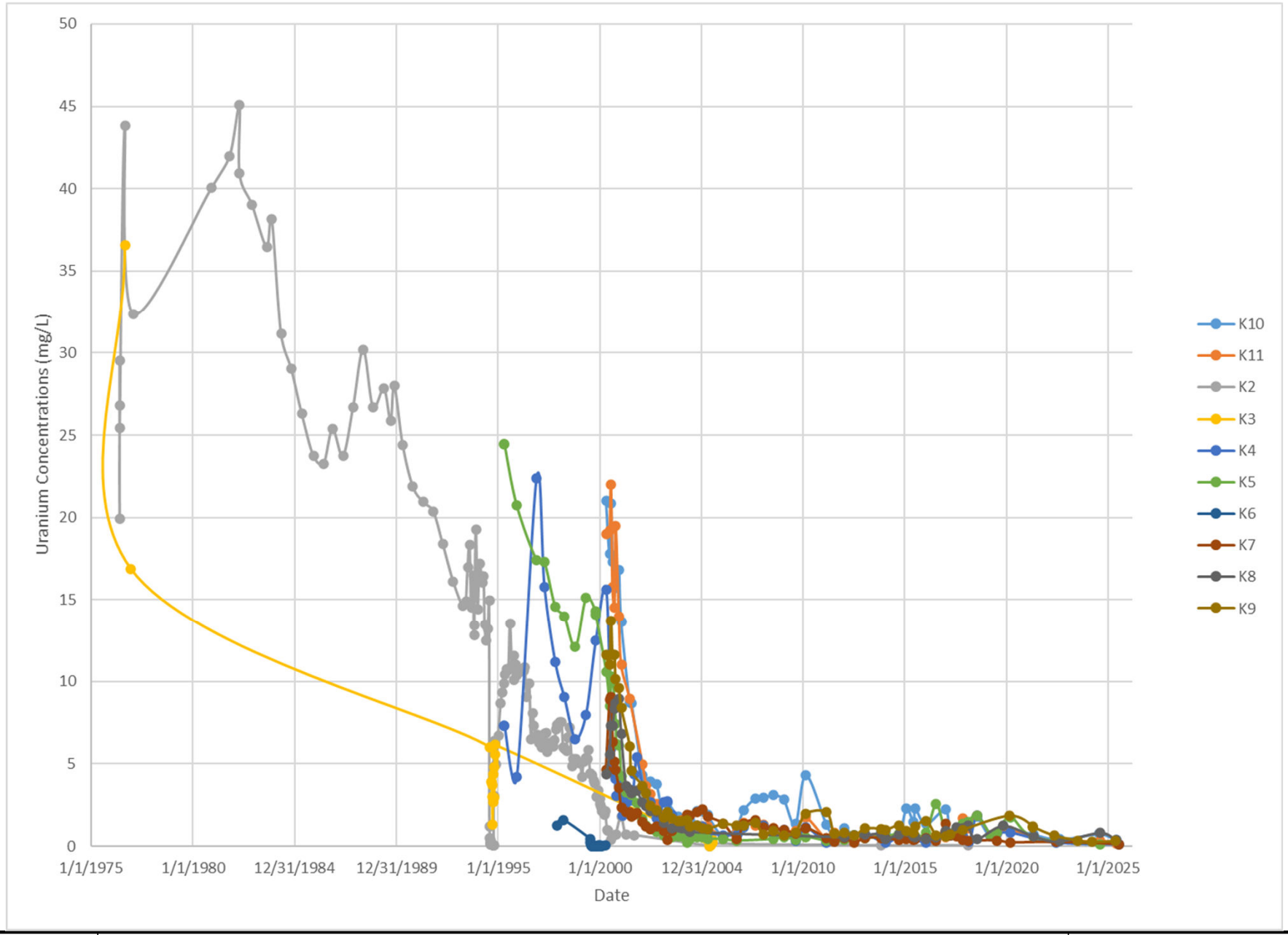

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Figure 4.1-39
K Well Uranium Concentrations

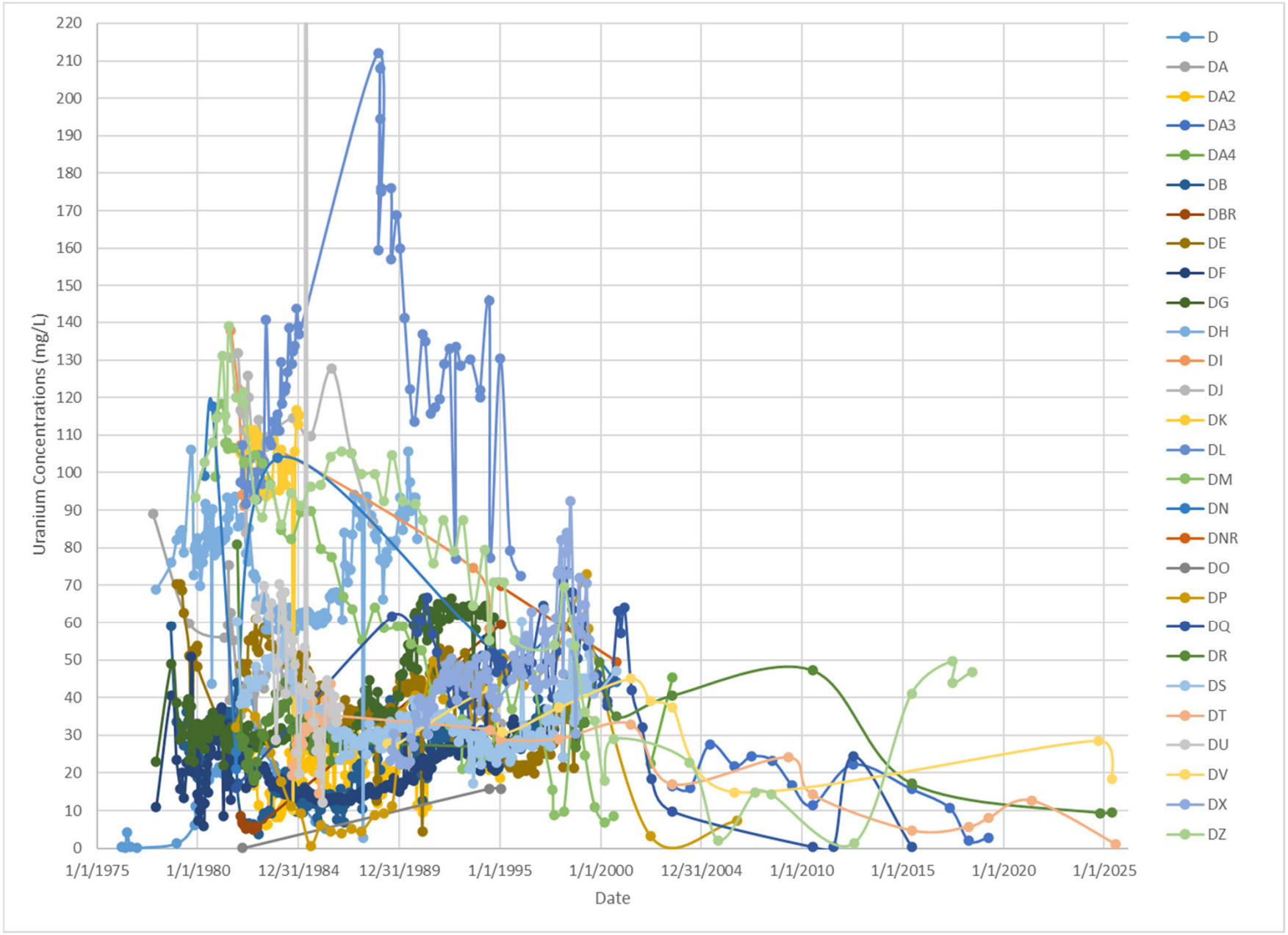

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Figure 4.1-40
D Well Uranium Concentrations

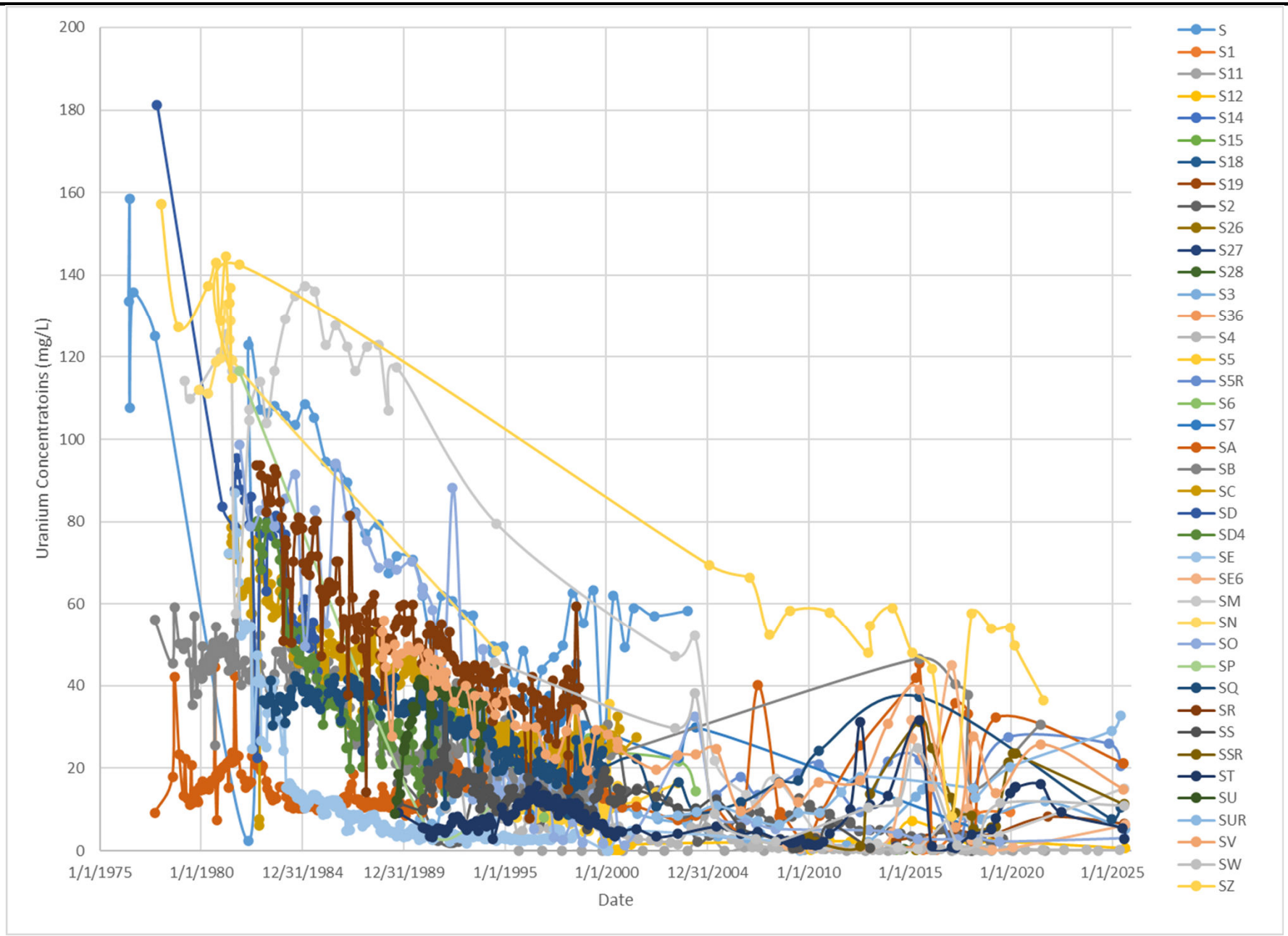

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Figure 4.1-41
S Well Uranium Concentrations

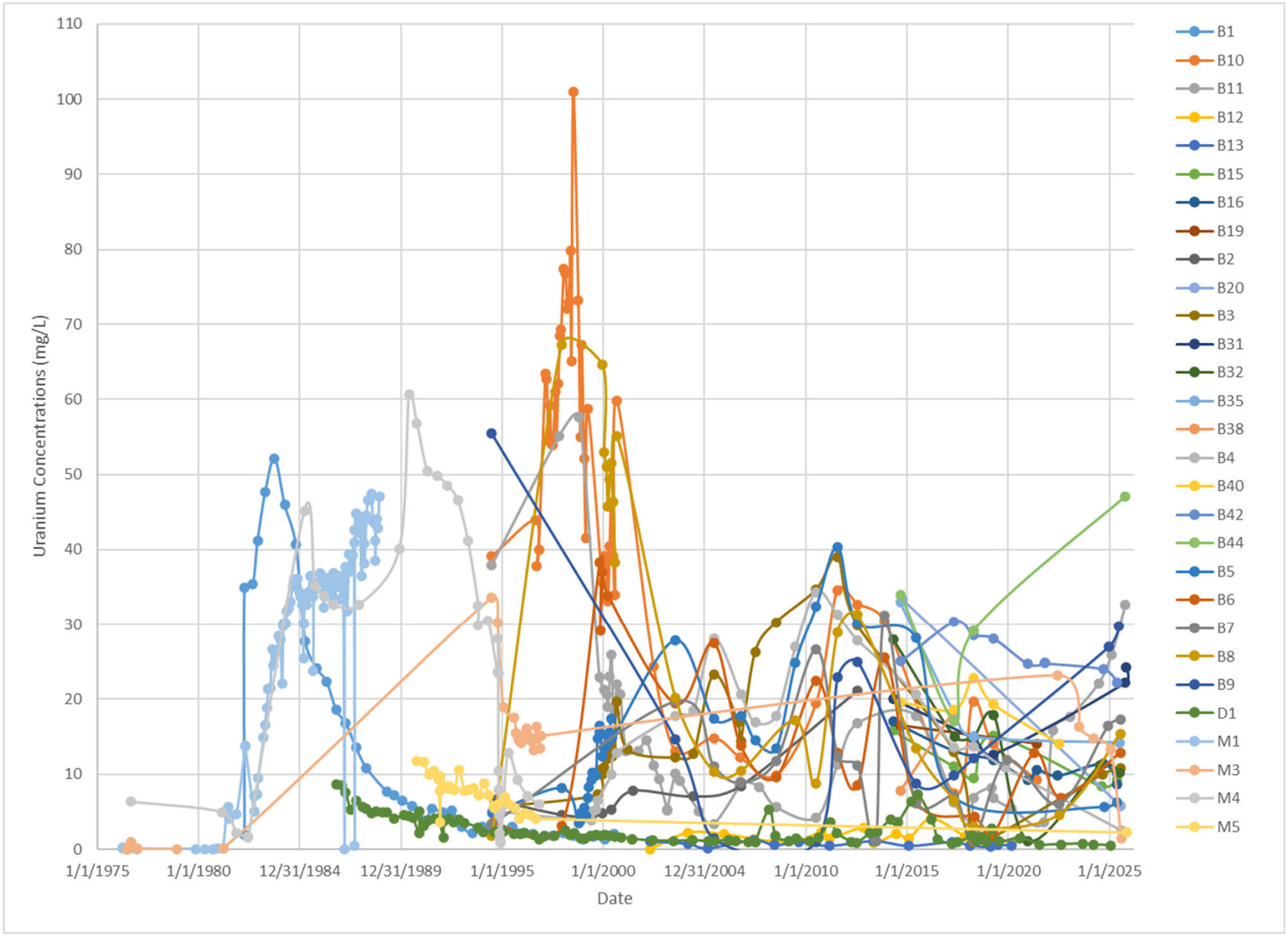

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Figure 4.1-42
B Well Uranium Concentrations

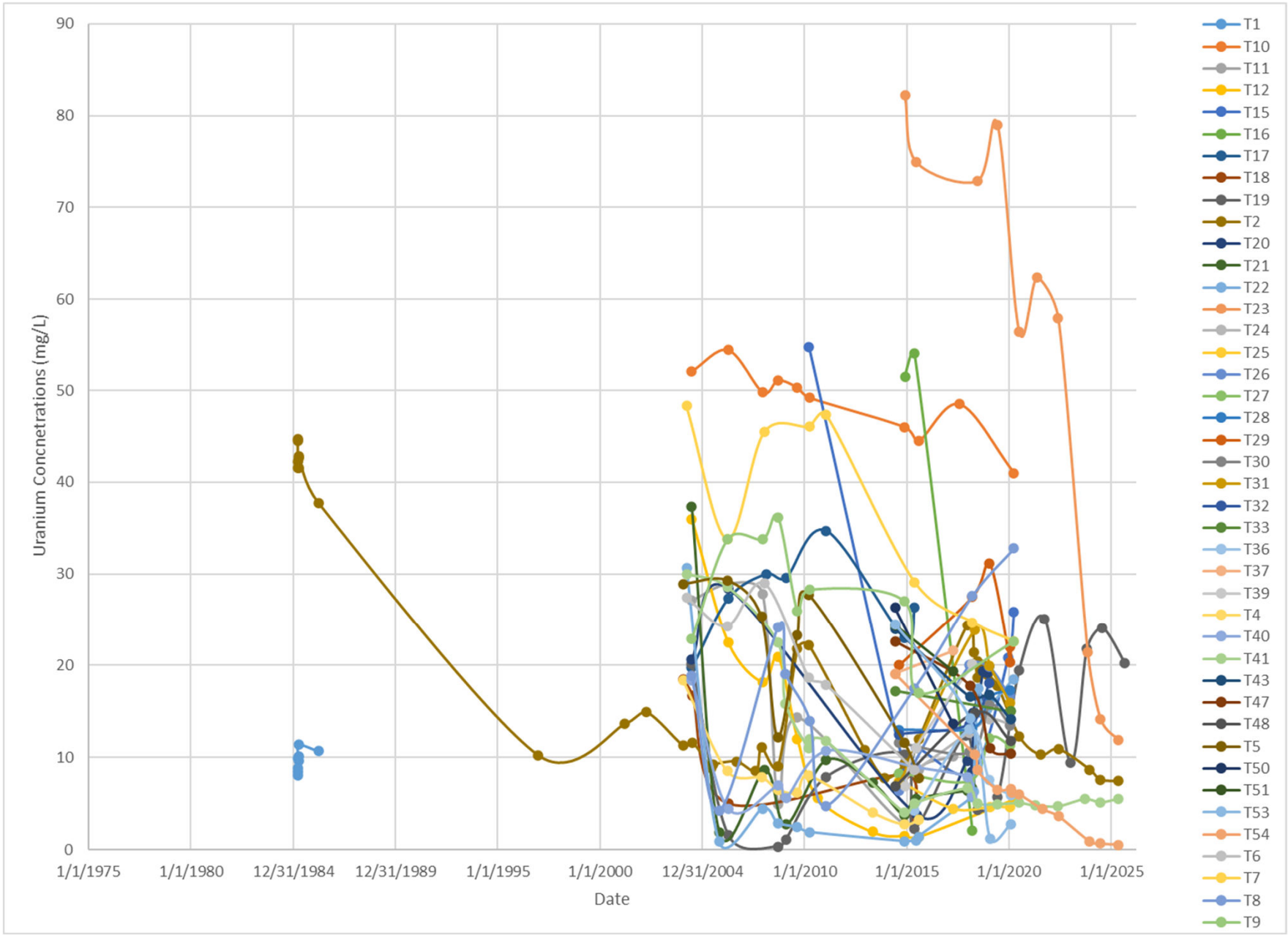

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Figure 4.1-43
T Well Uranium Concentrations

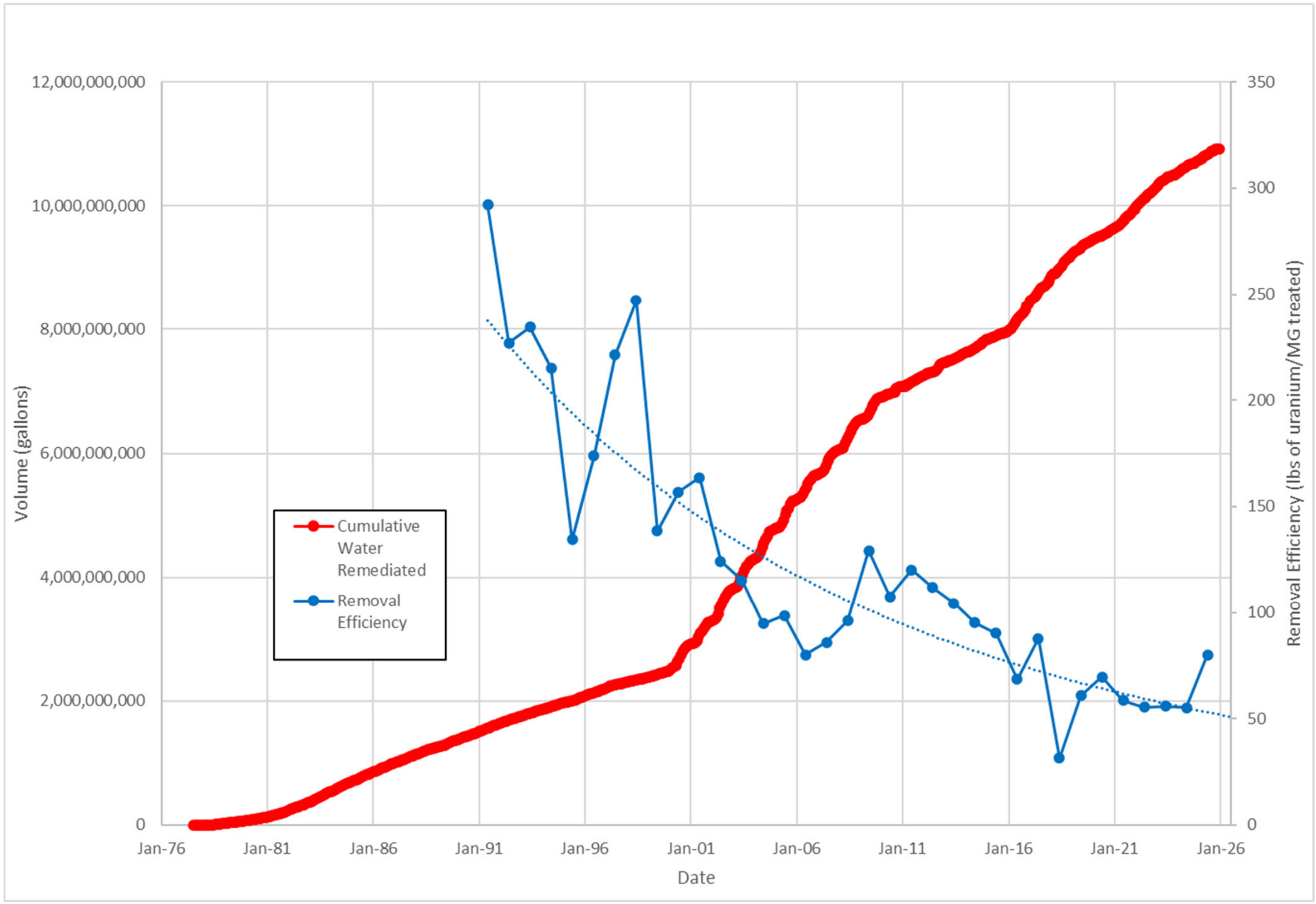

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Figure 4.1-44
Cumulative Remediated Volume & Removal Efficiency

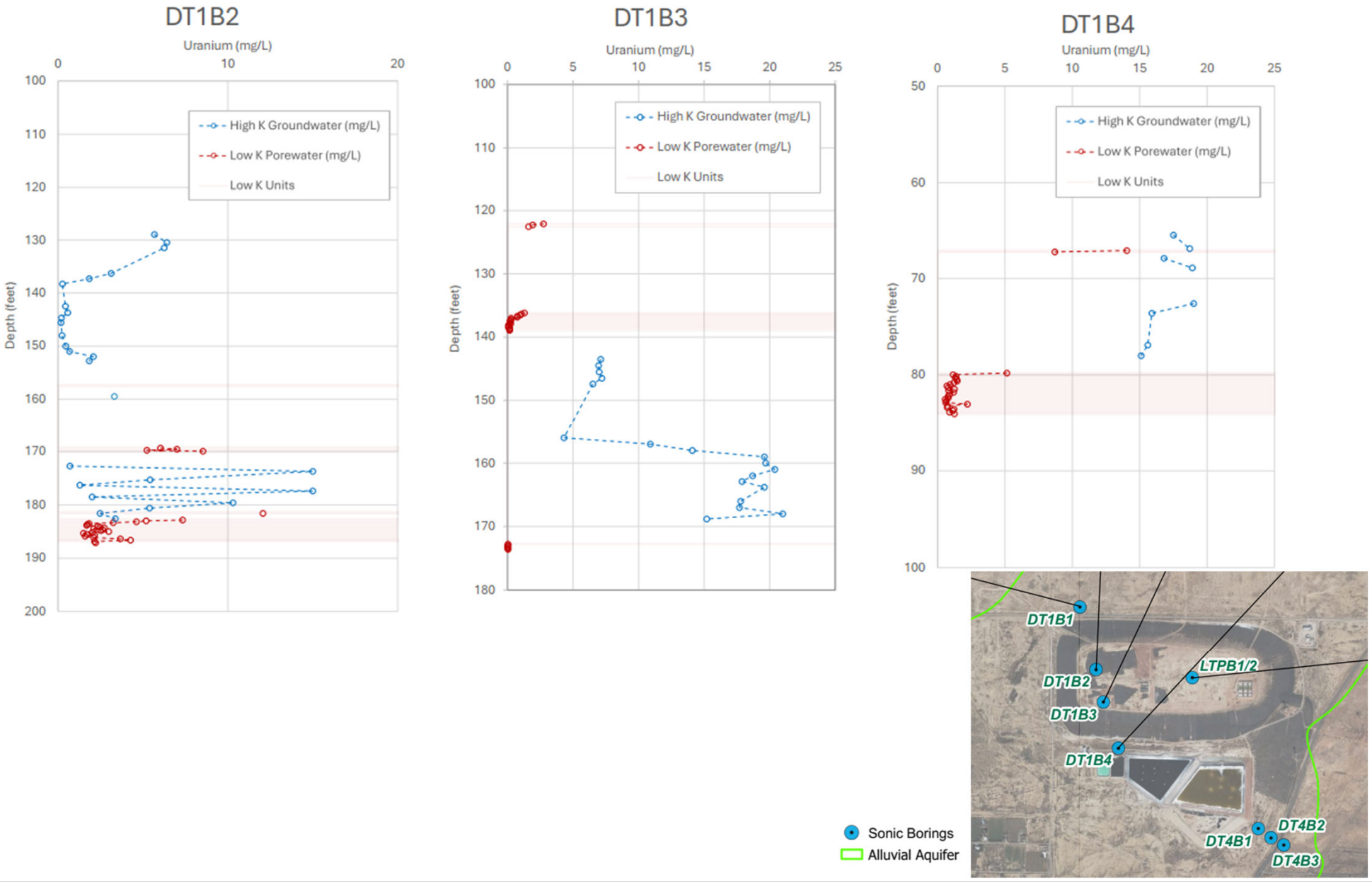

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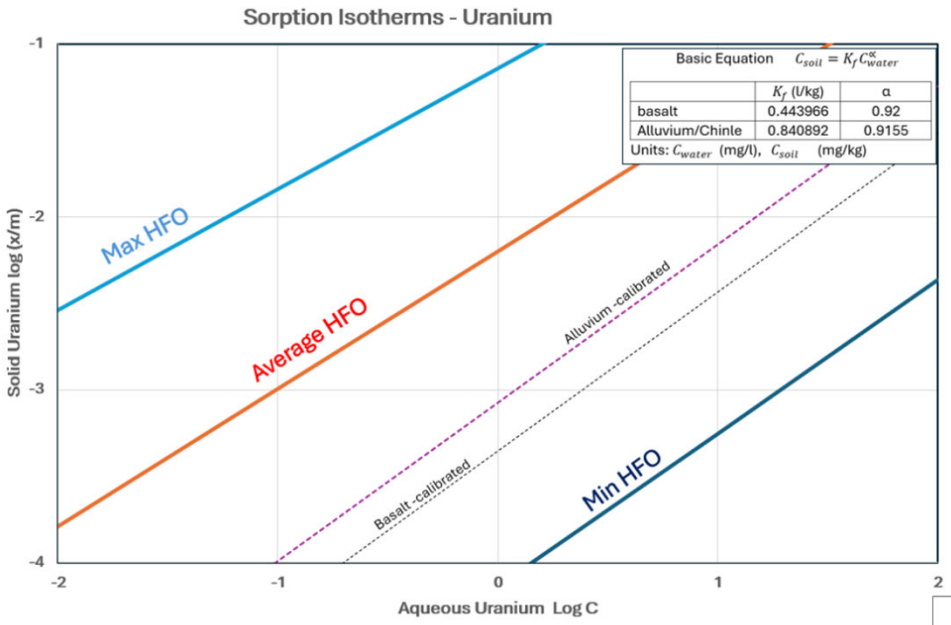
Figure 4.1-45
Uranium Concentrations in High K vs. Low K Units



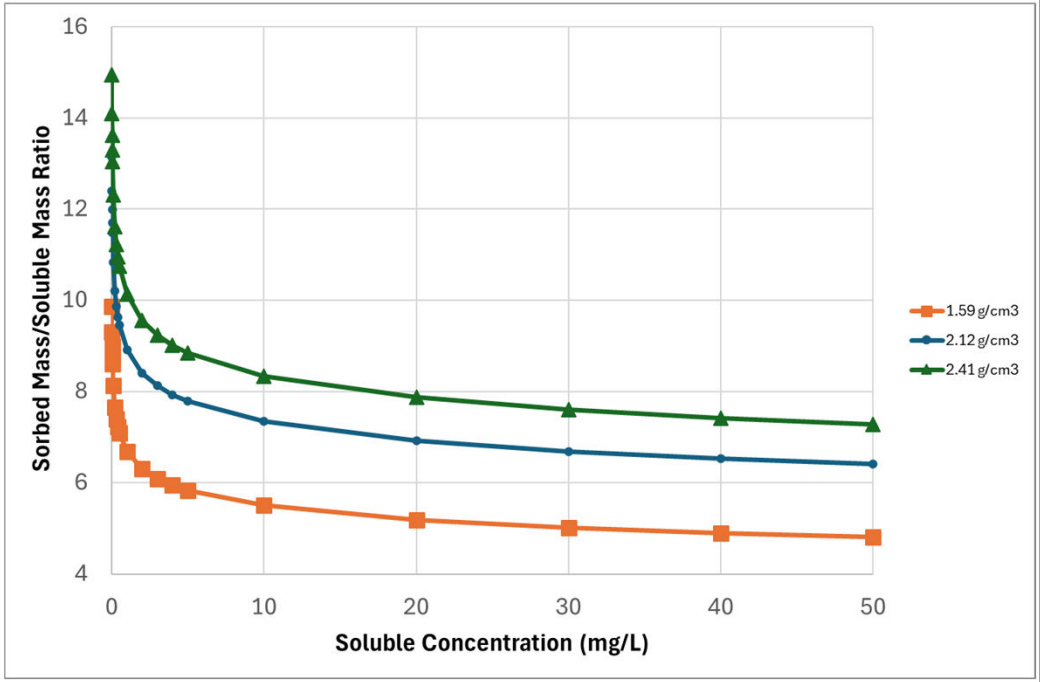


Figure 4.1-46
Uranium Sorption Behavior

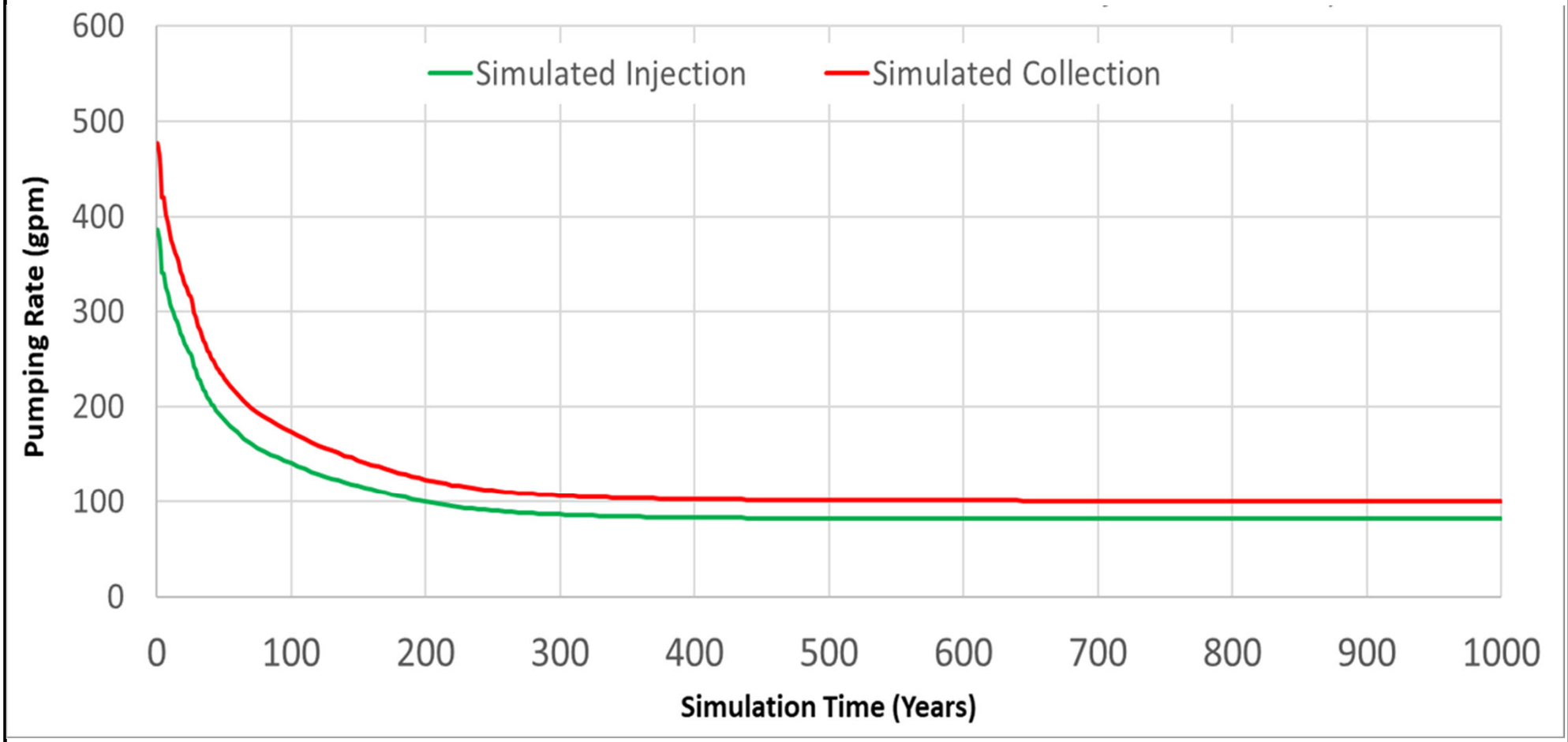


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Figure 4.2-1
Alternative 1 Predictive Model
Collection & Injection Summary

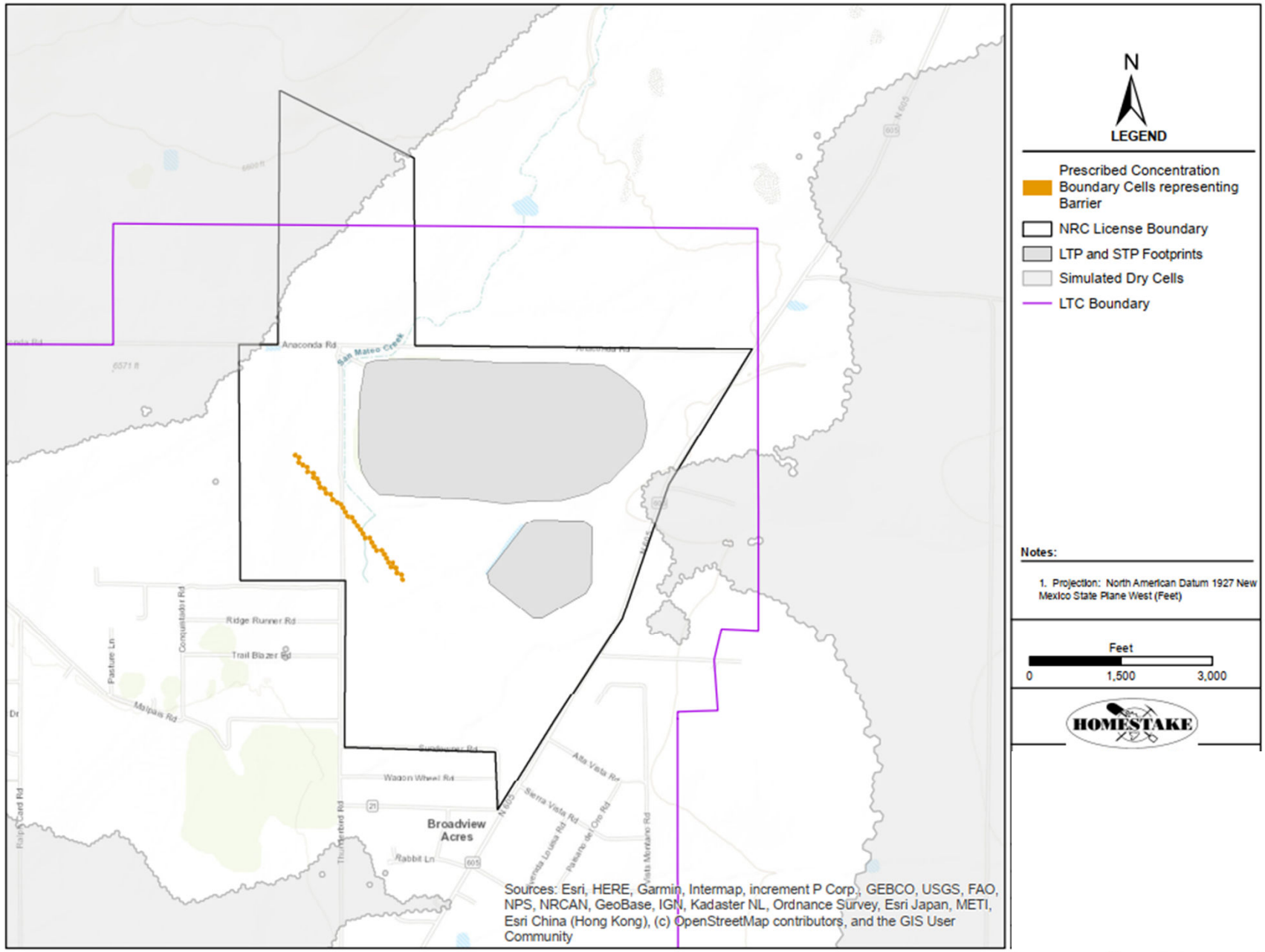

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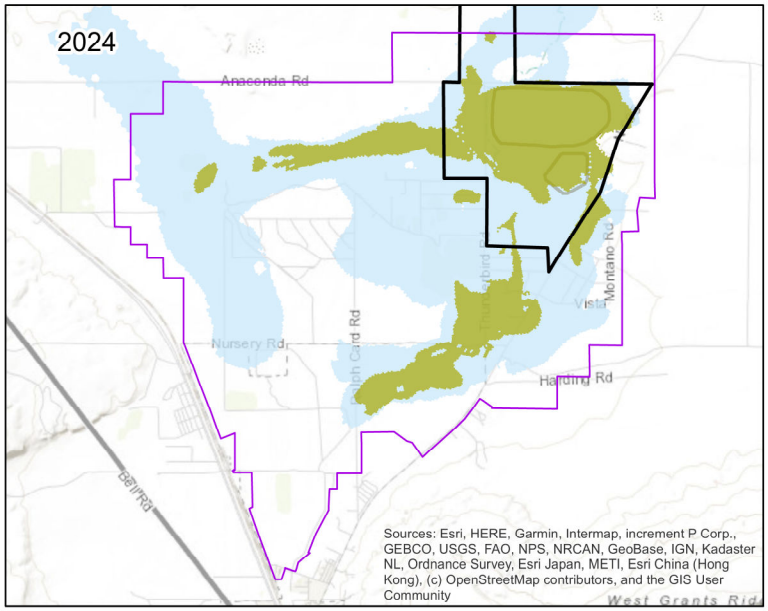
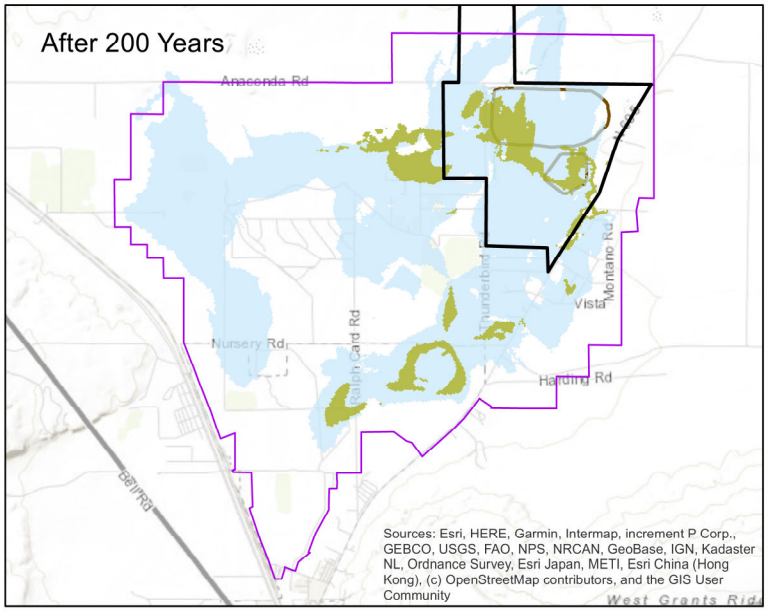
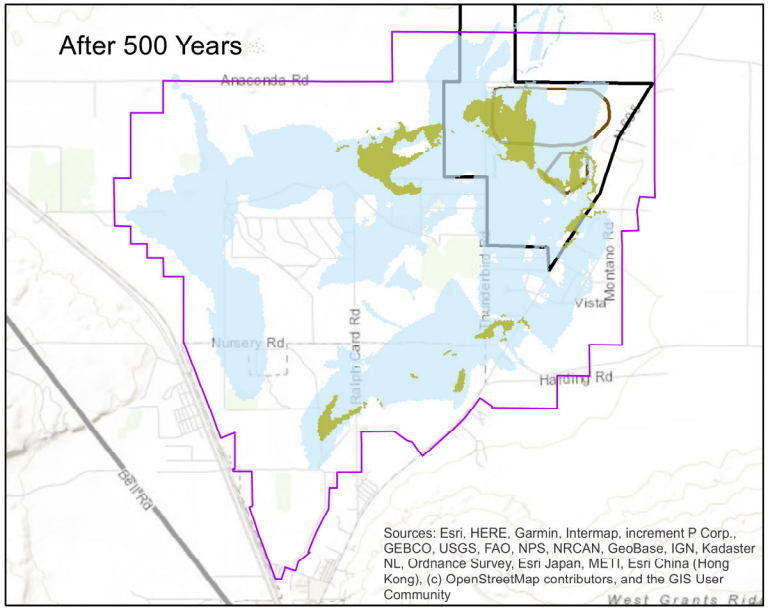
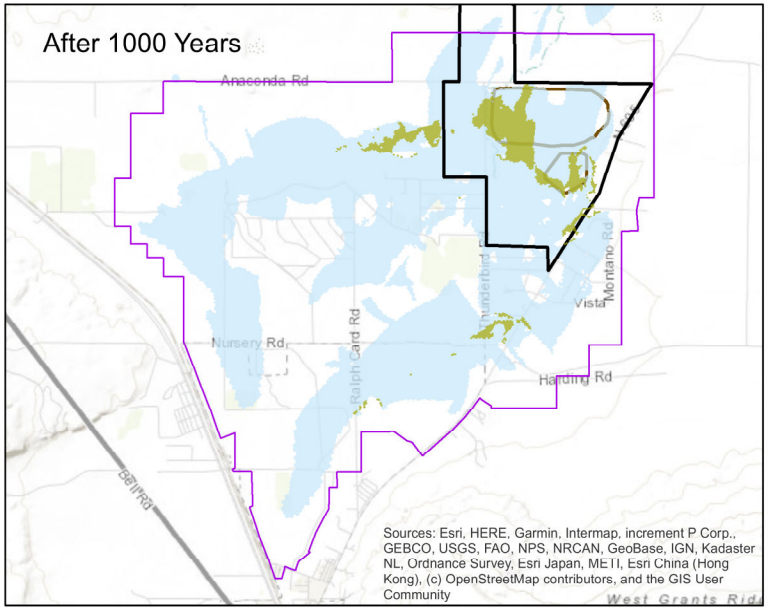
Figure 4.2-2
Alternative 2
Permeable Reactive Barrier









N

LEGEND

- LTC Boundary
- Modeled Uranium Extent above 0.16 mg/L
- Modeled Uranium Extent above 0.03 mg/L
- NRC License Boundary
- LTP and STP Footprints

Notes

1. Projection: North American Datum 1927 New Mexico State Plane West (Feet)

0 1,000 2,000 4,000 Feet

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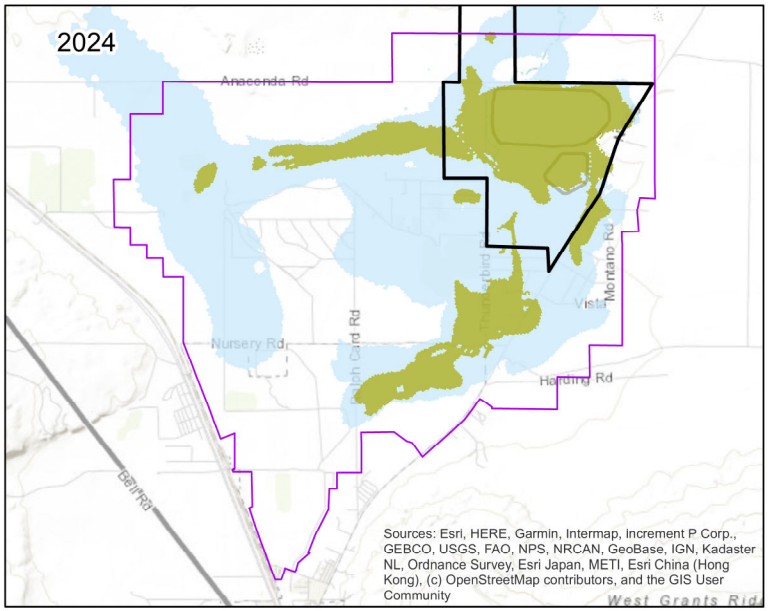
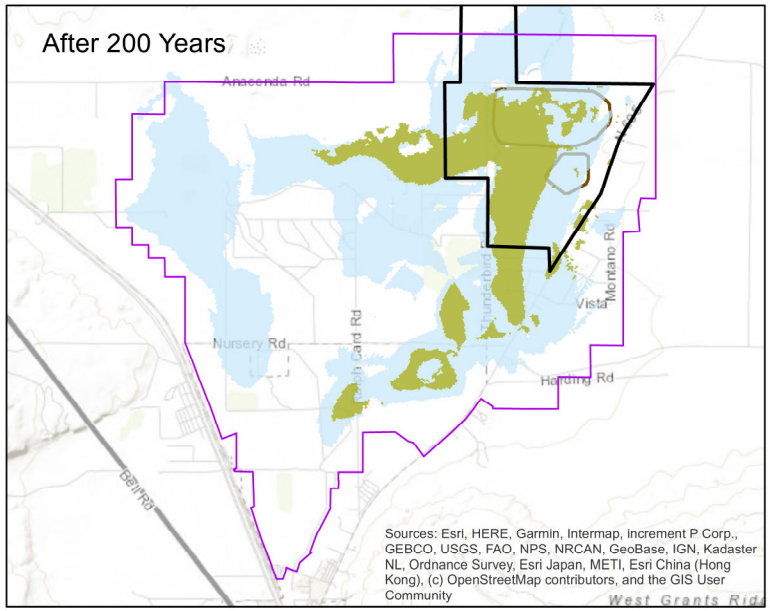
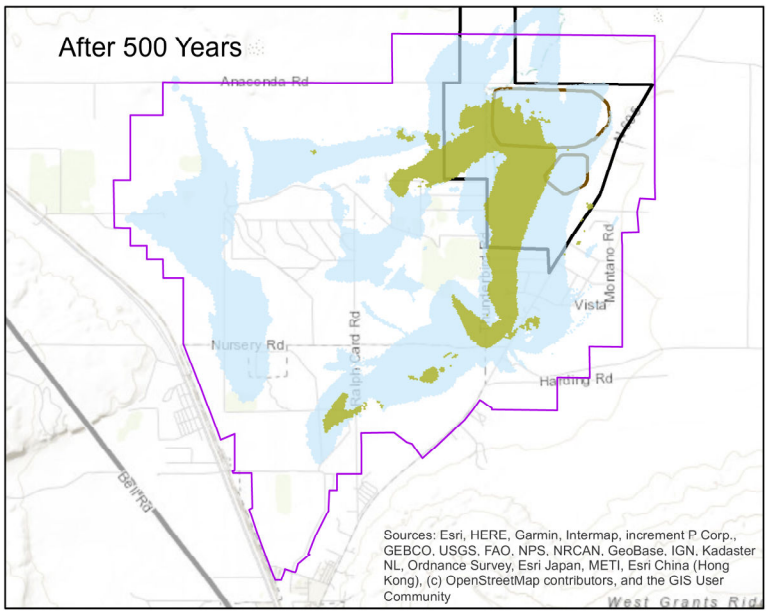
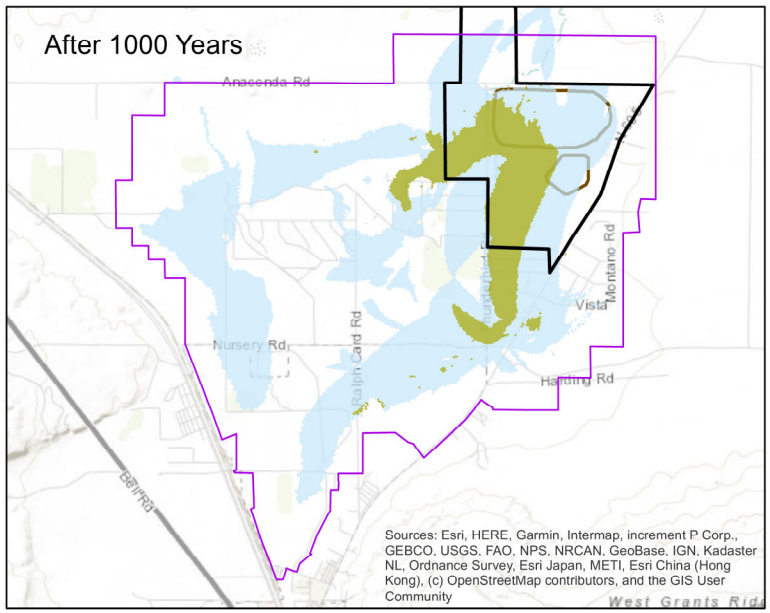
Figure 4.3-1
Alternative 1
Maximum Extent of Uranium in Groundwater









N

LEGEND

- LTC Boundary
- Modeled Uranium Extent above 0.16 mg/L
- Modeled Uranium Extent above 0.03 mg/L
- NRC License Boundary
- LTP and STP Footprints

Notes

1. Projection: North American Datum 1927 New Mexico State Plane West (Feet)

0 1,000 2,000 4,000 Feet

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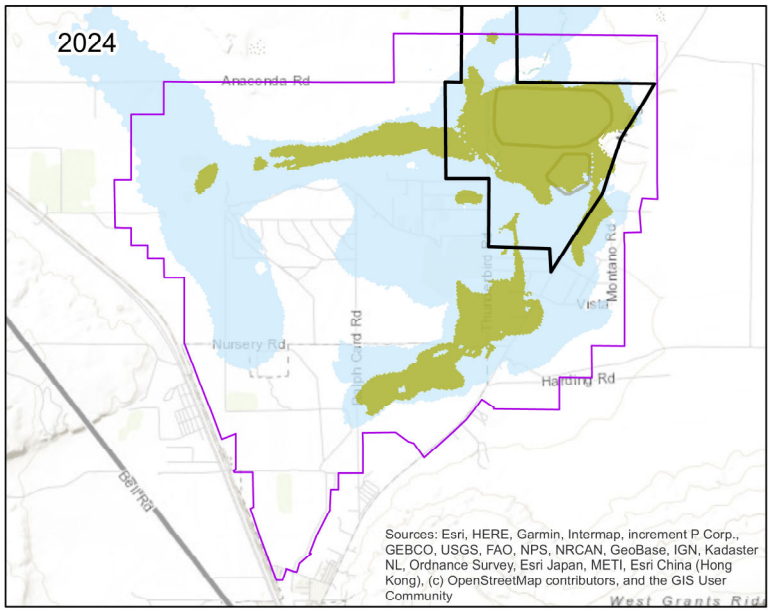
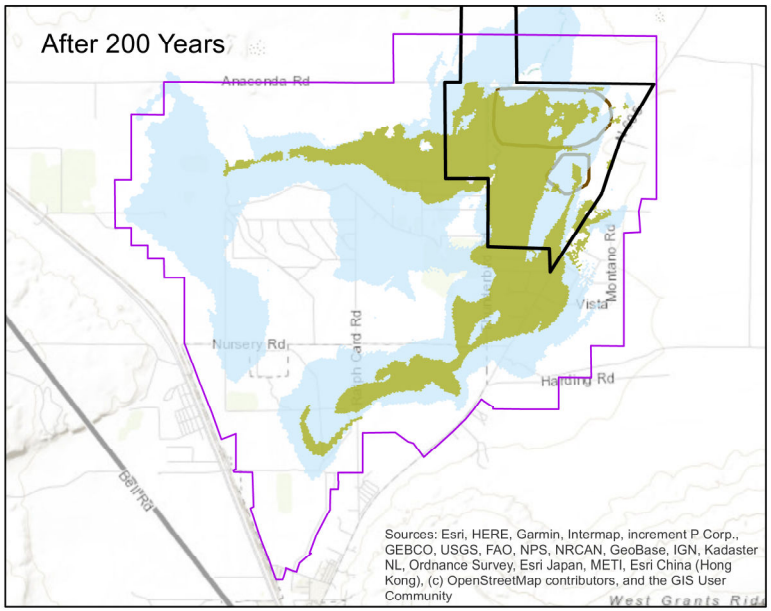
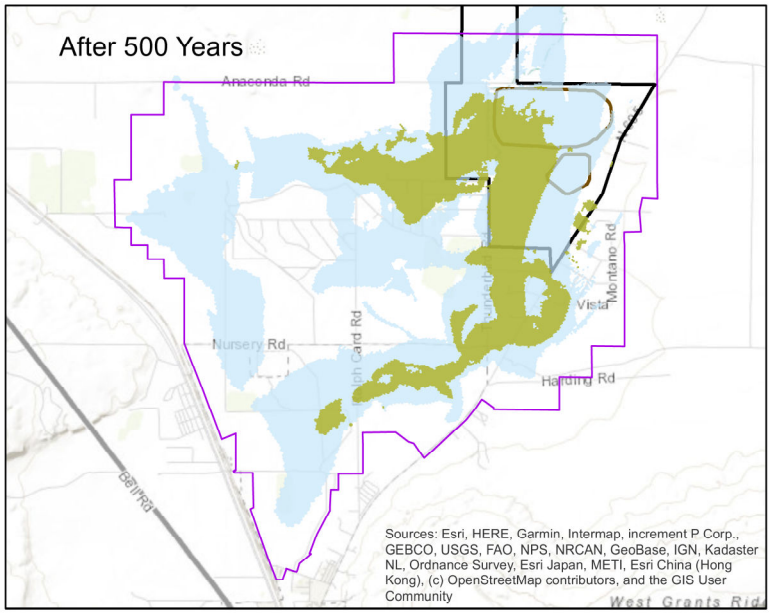
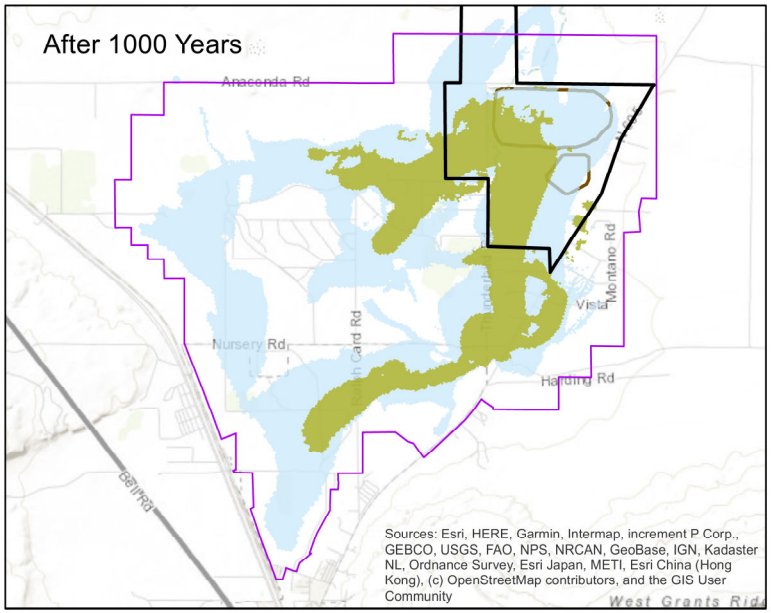
Figure 4.3-2
Alternative 2
Maximum Extent of Uranium in Groundwater









N

LEGEND

- Modeled Uranium Extent above 0.16 mg/L
- LTC Boundary
- Modeled Uranium Extent above 0.03 mg/L
- NRC License Boundary
- LTP and STP Footprints

Notes

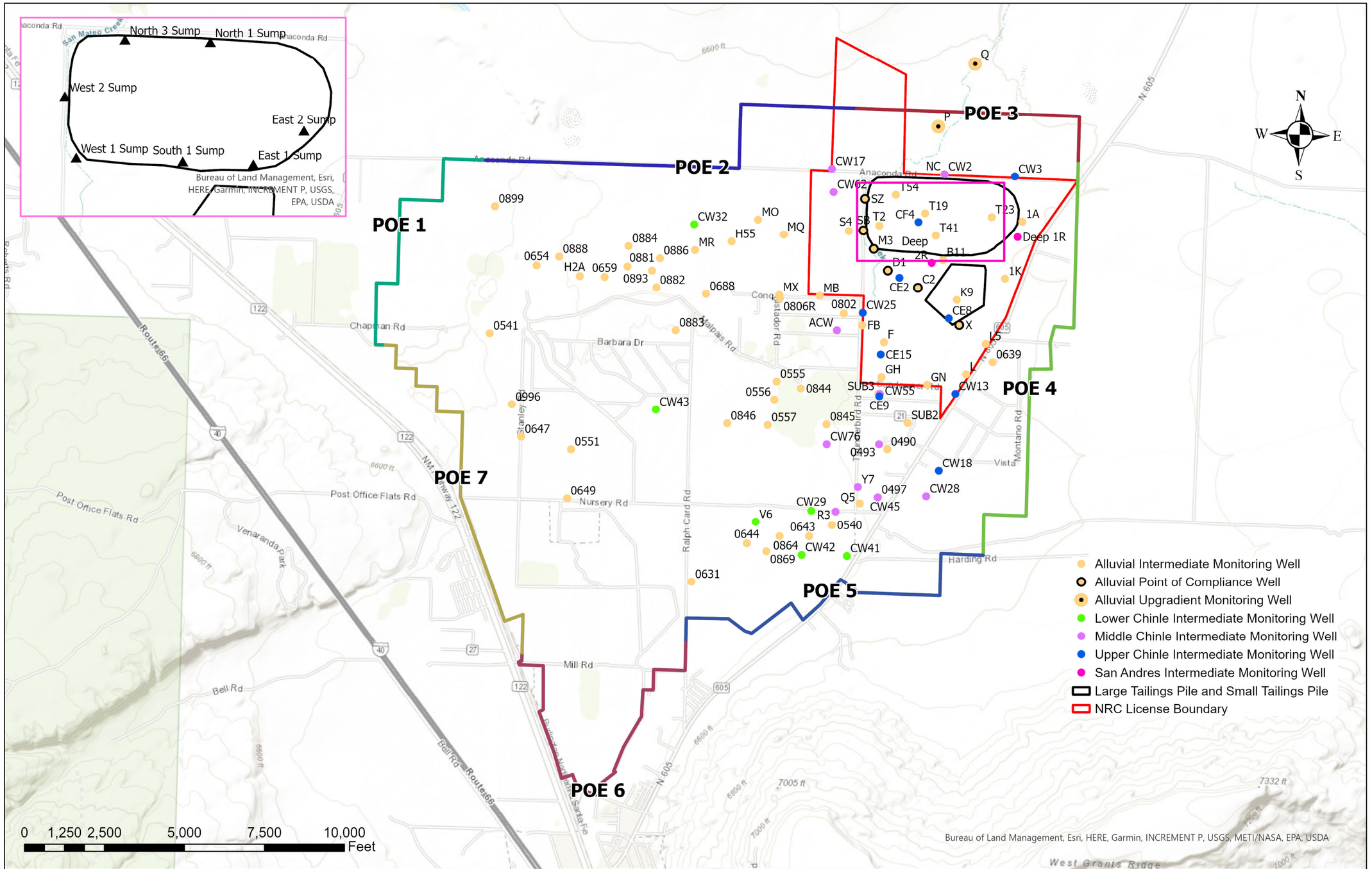
1. Projection: North American Datum 1927 New Mexico State Plane West (Feet)

0 1,000 2,000 4,000 Feet

HOMESTAKE

Grants Reclamation Project
Corrective Action Program

Figure 4.3-3
Alternative 3
Maximum Extent of Uranium in Groundwater



Grants Reclamation Project
Corrective Action Program

Figure 5.1-1
Proposed Groundwater Compliance Monitoring Locations

Appendix 1.1-A
NRC Form 313

NRC FORM 313 (11-25-2025) 10 CFR 30, 32, 33, 34, 35, 36, 37, 39, and 40

U.S. NUCLEAR REGULATORY COMMISSION

APPLICATION FOR MATERIALS LICENSE

APPROVED BY OMB: NO. 3150-0120 **EXPIRES: 07/31/2026**

Estimated burden per response to comply with this mandatory collection request: 4.3 hours. Submittal of the application is necessary to determine that the applicant is qualified and that adequate procedures exist to protect the public health and safety. Send comments regarding burden estimate to the FOIA, Library, and Information Collections Branch (T-6 A10M), U. S. Nuclear Regulatory Commission, Washington, DC 20555-0001, or by email to Infocollects.Resource@nrc.gov, and the OMB Reviewer at: OMB Office of Information and Regulatory Affairs, (3150-0120), Attn: Desk Officer for the Nuclear Regulatory Commission, 725 17th Street NW, Washington, DC 20503. The NRC may not conduct or sponsor, and a person is not required to respond to, a collection of information unless the document requesting or requiring the collection displays a currently valid OMB control number.

INSTRUCTIONS: SEE THE CURRENT VOLUMES OF THE NUREG-1556 TECHNICAL REPORT SERIES ("CONSOLIDATED GUIDANCE ABOUT MATERIALS LICENSES") FOR DETAILED INSTRUCTIONS FOR COMPLETING THIS FORM: http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1556/. SEND ONE COPY OF THE COMPLETED APPLICATION TO THE NRC OFFICE SPECIFIED BELOW OR ONLINE AT https://www.nrc.gov/security/byproduct/ismp/wbl.html.

APPLICATION FOR DISTRIBUTION OF EXEMPT PRODUCTS FILE APPLICATIONS WITH:

MATERIALS SAFETY AND LICENSING BRANCH
DIVISION OF MATERIALS SAFETY, SECURITY, STATE AND TRIBAL PROGRAMS
OFFICE OF NUCLEAR MATERIALS SAFETY AND SAFEGUARDS
U.S. NUCLEAR REGULATORY COMMISSION
11555 ROCKVILLE PIKE
ROCKVILLE, MD 20852-2738

*NOTE: The preferred method to submit NRC Form 313 is online at https://www.nrc.gov/security/byproduct/ismp/wbl.html or email at LBLicensingAssistant.Resource@nrc.gov.
Any other documents (e.g., financial assurance documents) should be sent via email.

ALL OTHER PERSONS FILE APPLICATIONS AS FOLLOWS:

IF YOU ARE LOCATED IN:

ILLINOIS, INDIANA, IOWA, MICHIGAN, MINNESOTA, MISSOURI, OHIO, OR WISCONSIN, SEND APPLICATIONS TO:

MATERIALS LICENSING BRANCH
DIVISION OF RADIOLOGICAL SAFETY AND SECURITY
U.S. NUCLEAR REGULATORY COMMISSION, REGION III
2056 WESTINGS AVENUE, SUITE 400
NAPERVILLE, IL 60563-2657

*NOTE: The preferred method to submit NRC Form 313 is online at https://www.nrc.gov/security/byproduct/ismp/wbl.html or email at R3-DRSSMAIL.Resource@nrc.gov.
Any other documents (e.g., financial assurance documents) should be sent via email.

IF YOU ARE LOCATED IN:

ALABAMA, CONNECTICUT, DELAWARE, DISTRICT OF COLUMBIA, FLORIDA, GEORGIA, KENTUCKY, MAINE, MARYLAND, MASSACHUSETTS, NEW HAMPSHIRE, NEW JERSEY, NEW YORK, NORTH CAROLINA, PENNSYLVANIA, PUERTO RICO, RHODE ISLAND, SOUTH CAROLINA, TENNESSEE, VERMONT, VIRGINIA, VIRGIN ISLANDS, OR WEST VIRGINIA,

SEND APPLICATIONS TO:

LICENSING ASSISTANCE TEAM
DIVISION OF RADIOLOGICAL SAFETY AND SECURITY
U.S. NUCLEAR REGULATORY COMMISSION, REGION I
475 ALLENDALE ROAD, SUITE 102
KING OF PRUSSIA, PA 19406-1415

*NOTE: The preferred method to submit NRC Form 313 is online at https://www.nrc.gov/security/byproduct/ismp/wbl.html or email at R1DRSSMail.Resource@nrc.gov.
Any other documents (e.g., financial assurance documents) should be sent via email.

IF YOU ARE LOCATED IN:

ALASKA, ARIZONA, ARKANSAS, CALIFORNIA, COLORADO, HAWAII, IDAHO, KANSAS, LOUISIANA, MISSISSIPPI, MONTANA, NEBRASKA, NEVADA, NEW MEXICO, NORTH DAKOTA, OKLAHOMA, OREGON, PACIFIC TRUST TERRITORIES, SOUTH DAKOTA, TEXAS, UTAH, WASHINGTON, OR WYOMING,

SEND APPLICATIONS TO:

MATERIALS LICENSING BRANCH
DIVISION OF RADIOLOGICAL SAFETY AND SECURITY
U.S. NUCLEAR REGULATORY COMMISSION, REGION IV
1600 E. LAMAR BOULEVARD
ARLINGTON, TX 76011-4511

*NOTE: The preferred method to submit NRC Form 313 is online at https://www.nrc.gov/security/byproduct/ismp/wbl.html or email at R4licensing@nrc.gov.
Any other documents (e.g., financial assurance documents) should be sent via email.

PERSONS LOCATED IN AGREEMENT STATES SEND APPLICATIONS TO THE U.S. NUCLEAR REGULATORY COMMISSION ONLY IF THEY WISH TO POSSESS AND USE LICENSED MATERIAL IN STATES SUBJECT TO U.S. NUCLEAR REGULATORY COMMISSION JURISDICTIONS.

1. THIS IS AN APPLICATION FOR *(Check appropriate item)*

- ☐ A. NEW LICENSE
- ☑ B. AMENDMENT TO LICENSE NUMBER SUA-1471
- ☐ C. RENEWAL OF LICENSE NUMBER

2. NAME AND MAILING ADDRESS OF APPLICANT *(Include zip code)*

Homestake Mining Company of California
P.O. Box 98
Grants, NM 82070

3. LIST ADDRESS AND/OR TEMPORARY JOB SITE (TJS) ADDRESS, WHERE LICENSED MATERIALS WILL BE USED OR POSSESSED

Homestake Mining Company of Califronia
560 Anaconda Road
Route 650
Milan, NM 87021

4. NAME OF PERSON TO BE CONTACTED ABOUT THIS APPLICATION

Eric Burch

BUSINESS TELEPHONE NUMBER	BUSINESS CELLULAR TELEPHONE NUMBER
(505) 278 4456 ext. 34	775 934 1766

BUSINESS EMAIL ADDRESS
eburch@barrick.com

SUBMIT ITEMS 5 THROUGH 11 ON 8-1/2 X 11" PAPER. THE TYPE AND SCOPE OF INFORMATION TO BE PROVIDED IS DESCRIBED IN THE APPLICABLE **LICENSING GUIDANCE**.

5. RADIOACTIVE MATERIAL a. Element and mass number; b. chemical and/or physical form; and c. maximum amount which will be possessed at any one time.	6. PURPOSE(S) FOR WHICH LICENSED MATERIAL WILL BE USED. 7. INDIVIDUAL(S) RESPONSIBLE FOR RADIATION SAFETY PROGRAM AND THEIR TRAINING AND EXPERIENCE.
8. TRAINING FOR INDIVIDUALS WORKING IN OR FREQUENTING RESTRICTED AREAS.	9. FACILITIES AND EQUIPMENT.
10. RADIATION SAFETY PROGRAM.	11. WASTE MANAGEMENT.

12. LICENSE FEES (Fees required only for new applications, at time of application submission, with few exceptions*) *(See 10 CFR 170 and Section 170.31)*
***Amendments/Renewals that increase the scope of the existing license to a new or higher fee category will require a fee.**

FEE CATEGORY | AMOUNT TO BE PAID VIA www.pay.gov | $

PER THE DEBT COLLECTION IMPROVEMENT ACT OF 1996 (PUBLIC LAW 104-134), YOU ARE REQUIRED TO PROVIDE YOUR TAXPAYER IDENTIFICATION NUMBER. PROVIDE THIS INFORMATION BY COMPLETING NRC FORM 531: https://www.nrc.gov/reading-rm/doc-collections/forms/nrc531info.html. FAX THE COMPLETED NRC FORM 531 TO (301) 415-6725.

13. CERTIFICATION. *(Must be completed by applicant) THE APPLICANT UNDERSTANDS THAT ALL STATEMENTS AND REPRESENTATIONS MADE IN THIS APPLICATION ARE BINDING UPON THE APPLICANT.*

THE APPLICANT AND ANY OFFICIAL EXECUTING THIS CERTIFICATION ON BEHALF OF THE APPLICANT, NAMED IN ITEM 2, CERTIFY THAT THIS APPLICATION IS PREPARED IN CONFORMITY WITH TITLE 10, CODE OF FEDERAL REGULATIONS, PARTS 30, 32, 33, 34, 35, 36, 37, 39, AND 40, AND THAT ALL INFORMATION CONTAINED HEREIN IS TRUE AND CORRECT TO THE BEST OF THEIR KNOWLEDGE AND BELIEF.
WARNING: 18 U.S.C. SECTION 1001 ACT OF JUNE 25, 1948, 62 STAT. 749 MAKES IT A CRIMINAL OFFENSE TO MAKE A WILLFULLY FALSE STATEMENT OR REPRESENTATION TO ANY DEPARTMENT OR AGENCY OF THE UNITED STATES AS TO ANY MATTER WITHIN ITS JURISDICTION.

CERTIFYING OFFICER -- TYPED/PRINTED NAME AND TITLE	SIGNATURE	DATE
Eric Burch Closure Manager	Eric Burch Signer ID: XGGZKJ6E14...	03/25/2026